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SPATIOTEMPORAL EVOLUTION AND SUSTAINABLE LANDSCAPE PLANNING OF PERI-URBAN AREAS IN POLYCENTRIC CITIES

THE THESIS OF THE PHD DISSERTATION

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1.BACKGROUND OF THE WORK AND ITS AIMS

1.1 Background

Global urbanization has led to the accelerated expansion of urban development in many regions. A key feature of urbanization was the global shift from a predominantly rural population to a predominantly urban population. A considerable portion of urban population and territorial growth occurs at the urban periphery (Friedmann, 2011, Leaf, 2016, Tan et al., 2024, Webster, 2002). As a result, an increasing number of spaces worldwide blur the boundaries between urban and rural areas (Chelcea and Moss, 2022, Leaf, 2016, Petrovici and Poenaru, 2025, Wandl et al., 2014a). This process is referred to as peri-urbanization.

In most literature, peri-urban areas (PUAs) are defined through multiple characteristics. Geographically, they are located at the intersection of urban and rural areas, often where key infrastructure such as roads and economic centers are present (Davis et al., 1994). Demographically, PUAs typically host a mix of urban residents, migrants from other rural areas, and local rural populations, resulting in a blend of lifestyles and livelihoods. In terms of land use, PUAs are generally characterized as a hybrid of urban and rural land uses. Functionally, they are increasingly recognized as multifunctional and mixed-use spaces (Butt, 2024, Holmes, 2008, Hugo, 2017). Ford (1997) described these areas as urban-rural continua, where these regions shift from urban to rural, with urban characteristics becoming less prominent and rural characteristics becoming more dominant. The ongoing and uneven process of urbanization in PUAs has led to a struggle between urban and rural forces, resulting in the distinct characteristics of these areas—hybridity and dynamism.

The interaction between urban and rural landscapes within PUAs has shaped unique peri-urban landscapes (PULs), highlighting the coupled and coordinated relationship between human activities and natural habitats within limited space. At the same time, PULs are highly susceptible to the dual pressures of urban expansion and natural disasters, posing significant challenges (Aguilar et al., 2022,

Chettry, 2022, Salem and Tsurusaki, 2024). According to *Sustainable Development Goal 11: Sustainable Cities and Communities*, proposed by the United Nations in 2015, PULs, as an increasingly prevalent landscape type in cities, should undoubtedly incorporate sustainability as a fundamental objective in planning (Hopkins, 2012).

1.2 Research objectives

The overall objective of this study is to quantify the spatial extent of PUAs in polycentric cities, analyze their spatiotemporal evolution, and propose guidelines for sustainable PUL planning. Within this overarching objective, a series of sub-objectives are included:

(1) Summarize the research progress and gaps in PUAs through a literature review;

(2) Compare the accuracy and applicability of three quantitative methods (Threshold method, Breakpoint Clustering, and Multilayer Perceptron model) in identifying PUAs within the study region;

(3) Conduct a quantitative analysis of the spatiotemporal evolution of PUAs from 2000 to 2020, focusing on changes in spatial transitions, expansion patterns, land use, and location types;

(4) Examine the differences among PUAs, urban areas, and rural areas along the urban-rural gradient in terms of construction, economy, naturalness, and population;

(5) Analyze the morphology of PUAs and PULs using Morphological Spatial Pattern Analysis (MSPA);

(6) Determine the structural characteristics of PUAs and PULs in terms of composition and configuration based on Landscape Metrics;

(7) Explore the multifaceted driving factors behind the evolution of PUAs;

(8) Propose specific PUL planning guidelines based on the context of the study area.

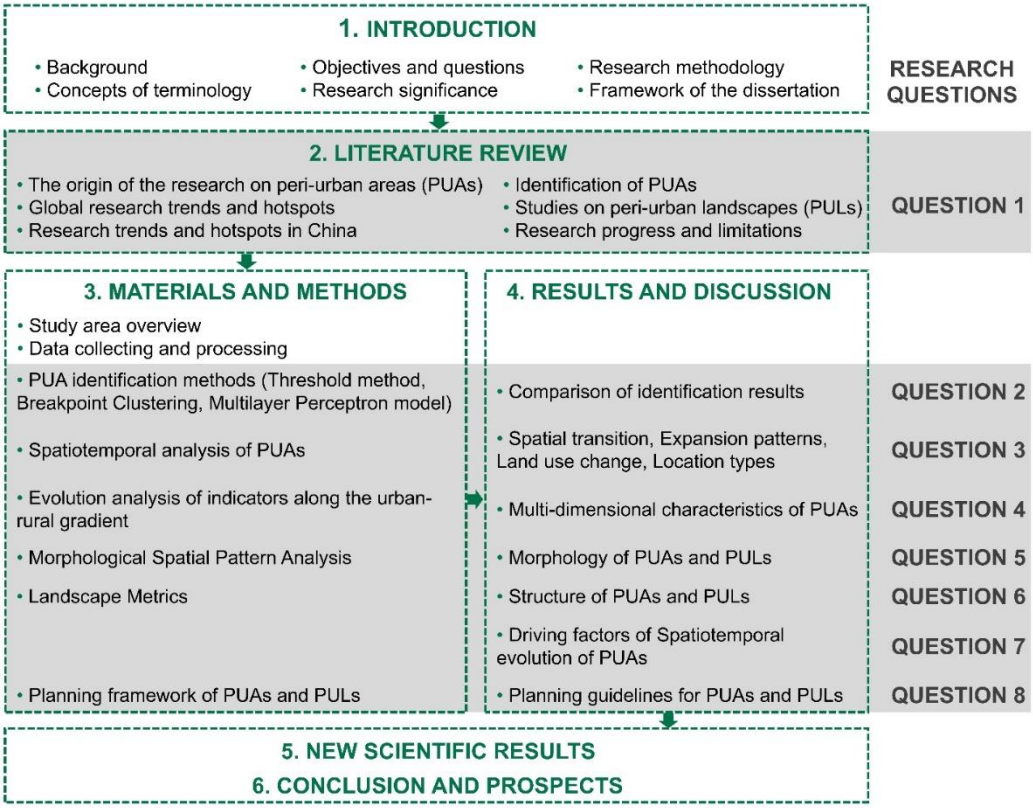

Figure 1: Framework of the dissertation.

2.MATERIALS AND METHODS

2.1 Study area

Zhengzhou (112°42'–114°13' E, 34°15'–34°59' N) is located in central China and serves as the capital of Henan Province. It covers an area of approximately 7,565 km². By the end of 2020, the permanent population of Zhengzhou City was approximately 12.6 million, with urban residents constituting 78.4%. Zhengzhou includes a central urban area, five county-level cities, and one county. In the master plan of Zhengzhou, the central urban area is planned as the primary urban center, and other urban areas are planned as sub-urban centers. Therefore, there is a polycentric structure in Zhengzhou (***Figure 2***).

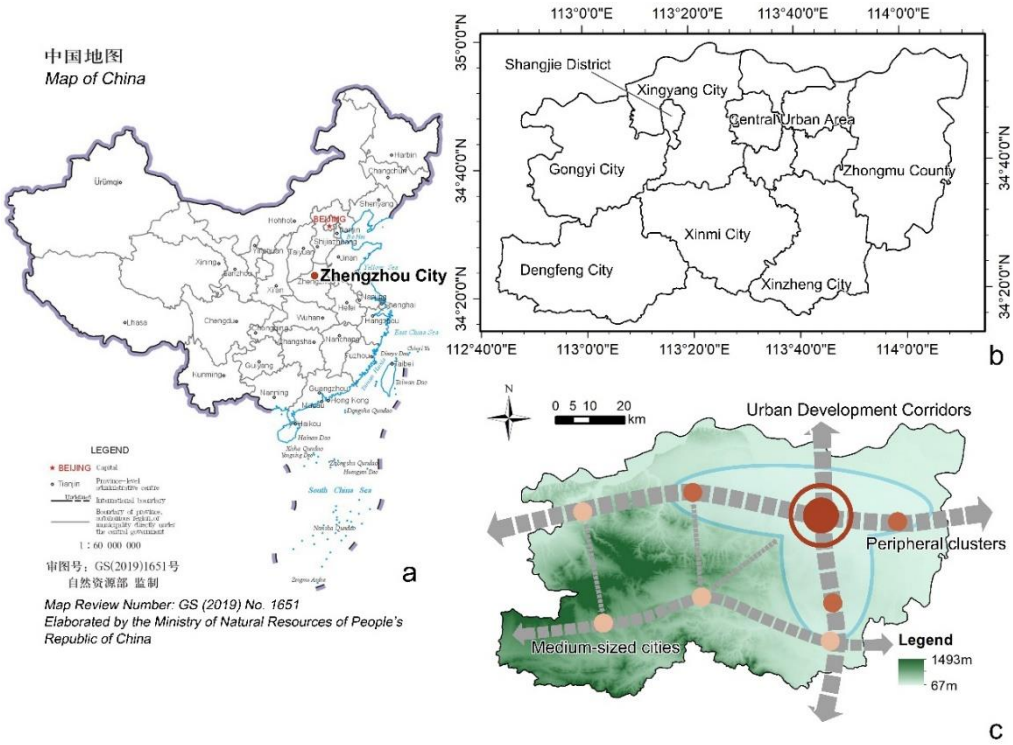

Figure 2: Location and administrative boundaries of the study area: a. Location of Zhengzhou in China[1]; b. Administrative divisions of Zhengzhou[2]; c. Topographic Map of Zhengzhou and Spatial Planning Structure in *The Master Plan for Zhengzhou Metropolitan Area (2012-2030)*.

[1] http://bzdt.ch.mnr.gov.cn/
[2] https://www.zhengzhou.gov.cn/view/index.jhtml

2.2 Data collection and processing

Based on the characteristics of PUAs, four indicators were selected to identify PUAs. These indicators include Imperviousness Density (ID), Nighttime Light Intensity (NLI), Proportion of (semi-) natural land (PNL), and Per Capita Land Area (PCLA). The data on which these indicators are calculated include: *Global 30m Resolution Impervious Surface Dataset* (Zhang et al., 2022), *Global NPP-VIIRS-like Nighttime Light Dataset* (Chen et al., 2021), *China's multi-period land use and land cover remote sensing monitoring dataset*(Xu et al., 2018), the census data from the Zhengzhou Bureau of Statistics (2021) and the *WorldPop population dataset* (WorldPop et al., 2018). Given the mixed attributes of PUAs, I hypothesized that these indicators exhibit values that fall between those of urban and rural areas.

2.3 Methods

In order to determine an appropriate method for identifying PUAs, I compared three quantitative methods. The first method is the Threshold method, which identifies the indicator threshold of PUAs through statistical principles. The second method is Breakpoint Clustering. It is based on the hypothesis that there are distinct breakpoints between urban, peri-urban, and rural areas when viewed from any complete urban-rural gradient. The last method is the Multilayer Perceptron model, which is based on the principles of machine learning. After obtaining the identification results from the three methods, I calculated the kappa coefficients to assess their accuracy.

After obtaining the spatial extents of PUAs for the years 2000, 2010, and 2020, a series of spatiotemporal analyses were conducted from four perspectives: spatial transition, spatial expansion, land use changes, and location types. Among these analyses, the location type analysis is a static analysis based on the identification results of three years, while the others are dynamic analyses based on the two time periods of 2000-2010 and 2010-2020.

To visually illustrate the variation of indicator values along the urban-rural gradient, I delineated cross-sectional profiles extending from the Central Urban Area of Zhengzhou to its various sub-centers as the urban-rural gradient zones. Finally, indicator data were sampled at 1 km intervals along these gradient zones, and profile line charts were plotted. One-way analysis of variance (ANOVA) and Tukey HSD post-hoc test were used to test the significance of differences in the

indicators on these gradient zones among different spatial types. Additionally, three location types of PUAs along the gradient zones were identified, and their indicator values were subjected to statistical analysis to determine differences between them.

Morphological Spatial Pattern Analysis (MSPA) and Landscape Metrics were respectively employed to quantify the morphological and structural characteristics of PUAs and PULs. The Landscape metrics that I selected include Percentage of Landscape (PLAND), Patch Density (PD), Mean Patch Area (AREA_MN), Shannon's Diversity Index (SHDI), Mean Perimeter-Area Ratio (PARA_MN), Total Edge Contrast Index (TECI), Mean Proximity Index (PROX_MN, and Contagion (CONTAG).

In the last section, I synthesized PUL planning experiences from various case studies through a literature review and analyzes the current challenges faced by PUAs in Zhengzhou. Based on these experiences and challenges, regional-level and local-level planning guidelines were proposed for the PULs in the study area.

3. RESULTS AND DISCUSSION

(1) Identification and evolution of PUAs

The results obtained from the three identification methods show that the Multilayer Perceptron model has the highest accuracy rate and a wide range of applications. Therefore, I used the model to identify PUAs in Zhengzhou for multiple years (***Figure 3***). Both urban areas and PUAs exhibit an expanding spatial extent over time. Correspondingly, the area of rural regions has gradually decreased. From 2000 to 2020, PUAs have primarily converted into urban areas. At the same time, the increase in PUAs was mainly driven by the conversion of rural areas.

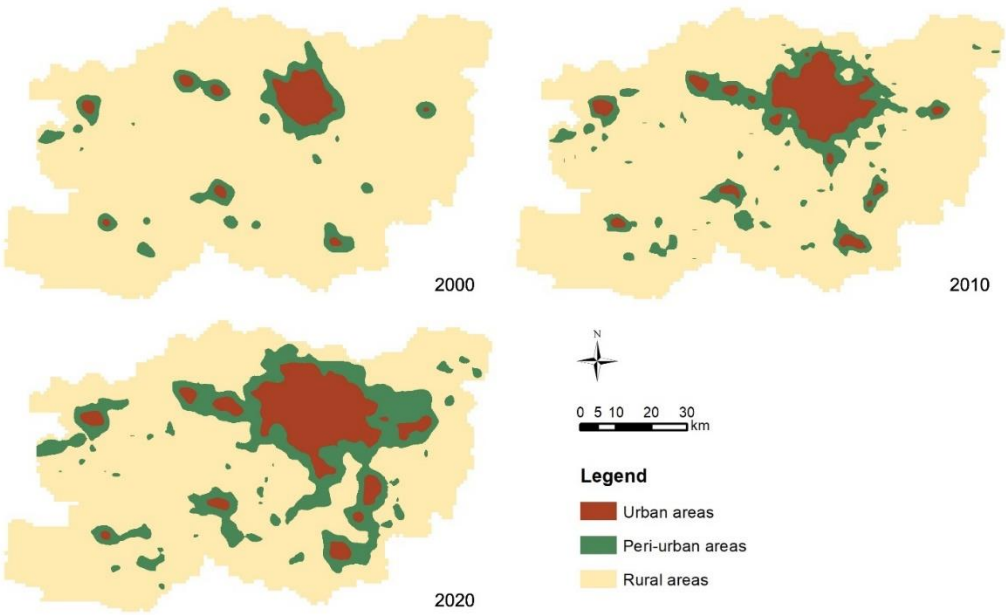

Figure 3: Interpolated identification results obtained using the Multilayer Perceptron model.

After classifying the expansion types of the newly grown PUAs, I found that edge expansion has consistently been the dominant expansion type during the research period. The Normalized Difference Expansion Index of the PUAs in Zhengzhou shows that all administrative regions are expanding outward.

Among all land use types in PUAs, agricultural land and built-up land accounted for the largest proportions. The Land Cross Transition Matrix reveals a large-scale

conversion of agricultural land into built-up land, reflecting the encroachment of urban expansion on rural areas. Additionally, parts of green land and water bodies were absorbed by urban expansion, while a small portion of these landscapes was converted into agricultural land.

Based on the established criteria (***Figure 4***), PUAs were geographically classified. In all three years, Transitional PUAs occupied the largest proportion of the total area, making them the most typical type of PUAs. The formation of these PUAs is primarily driven by the radiative influence of urban areas. Isolated PUAs also experienced an initial increase followed by a decrease in number, while their area continued to grow. The number and area of Interurban PUAs changed relatively steadily, with an increase observed only during 2000-2010.

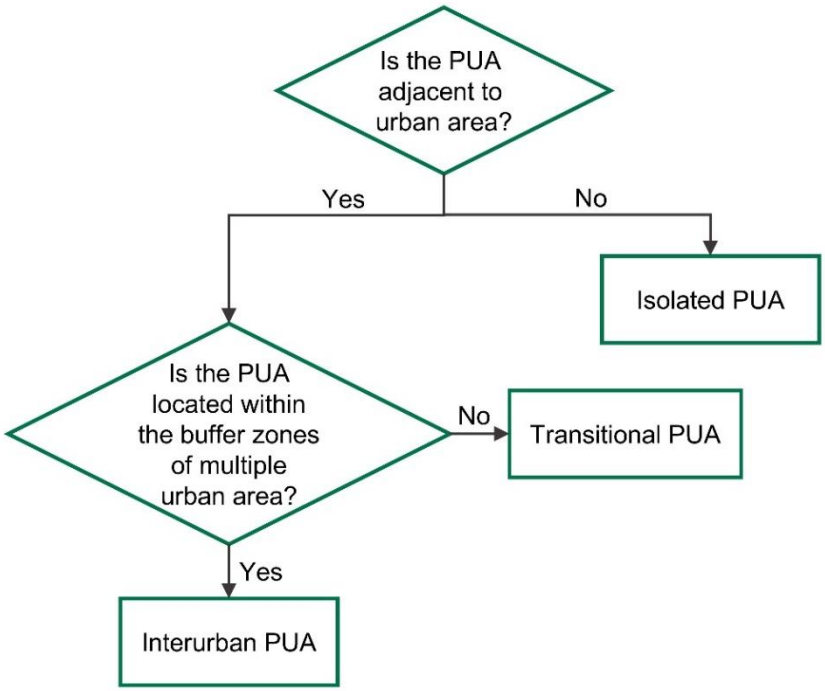

Figure 4: Classification process of the three location types of PUAs.

(2) Multidimensional characteristics of PUAs

Figure 5 shows the spatiotemporal evolutions of six urban-rural gradient zones. Through a comparative analysis of multi-dimensional indicators across urban-rural gradient zones, it was found that the previously hypothesized position of PUAs' indicator values, falling between those of urban and rural areas, holds true. This finding quantitatively supports the hybridity of PUAs. Additionally, the changes observed in PUAs over time clearly reflect their dynamic attributes.

Although the dynamic trends of PUAs differ across various indicators, such as the ID and PCLA values of PUAs approaching those of urban areas over time, the NLI of PUAs grows in sync with that of urban areas, while the PNL of PUAs declines and consistently shows a blurred boundary with the PNL of rural areas.

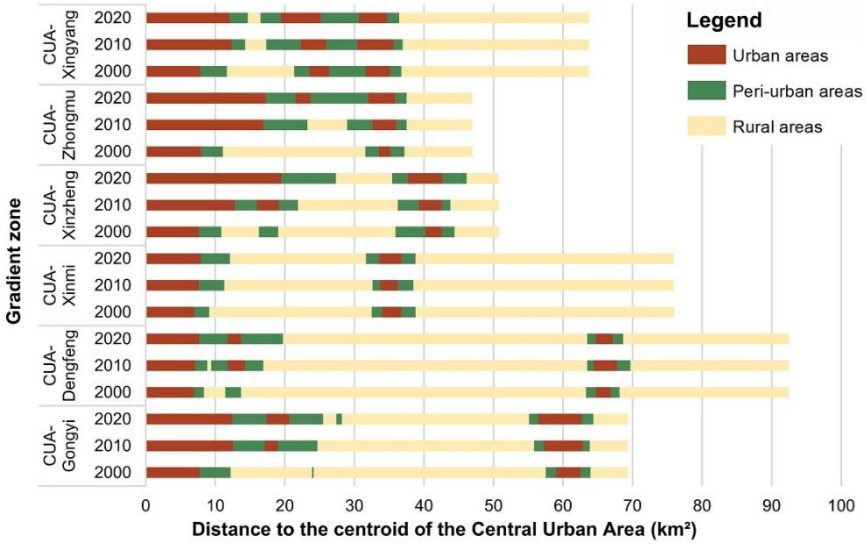

Figure 5: Spatial type evolution across the urban-rural gradient zones.

(3) Morphology and structure of PUAs and PULs

Through MSPA, it was found that in both artificial and agricultural landscapes, the *Core* is the main morphological type. In water landscapes, the proportion of linear forms gradually increases. Linear forms include the *Bridge*, *Branch*, and *Loop*. In the green landscape, the proportions of these morphological types are gradually becoming balanced. I also analyzed the morphology of urban landscapes and compared them with PULs. I found that in urban landscapes, the proportion of the Core is larger, but the linear form is much less than that of PULs. In addition, I summarized three forms in PUAs: ring, belt, and patch.

Based on the results of Landscape Metrics, I summarized the characteristics of these location types of PUAs: The SHDI of interurban PUAs continues to increase, and they have a larger patch area and lower patch density. Isolated PUAs have an obvious trend of fragmentation, and their landscape heterogeneity and proximity are the lowest. Transitional PUAs have the highest landscape diversity. Then I compared these metrics of urban and PULs. I found that they have similarities, such as increased landscape heterogeneity, which can be observed from TECI. Meanwhile, I also found that there are some structural differences. For example, from the changes in SHDI, it can be seen that the diversity of PULs has increased

while the diversity of urban landscapes has decreased. In addition, they have different changing trends in terms of fragmentation trend, patch shape, and proximity.

(4) Driving factors of spatiotemporal evolution of PUAs

The first factor is Urban-rural driving forces. On the one hand, the radiation of multiple urban centers promotes the emergence of Transitional and Interurban PUAs; on the other hand, Rural industrialization promotes the emergence of Isolated PUAs. The second driving factor is location and topography. In Zhengzhou, I found that those administrative regions close to the Central Urban Area and with flat terrain have a faster growth in PUAs. The last factor is city planning. In *the Master Plan for Zhengzhou Metropolitan Area*, Zhengzhou is divided into three functional zones to undertake different functions. These functional differences have also affected the growth rate of PUAs.

(5) Planning guidelines for PUAs and PULs

First of all, I summarized the peri-urbanization challenges currently faced by Zhengzhou in terms of planning governance and spatial pattern. Then, through a literature review, I summarized the spatial planning and regulatory tools used in global PUA research cases and presented ten case studies, including Romania, Great Cairo, Chattogram Metropolitan Area, Greater Helsinki Region, Stockholm, Krakow, Mexico, Rome, Turin, and Budapest. In these cases, I have listed their existing challenges, policy tools, tool effectiveness, and suggestions for the future as references.

In the end, I proposed corresponding planning guidelines from both the regional and local levels. At the regional level, I put forward four suggestions based on the previous analysis results. At the local level, the selected PUAs exhibit more detailed regional characteristics, and detailed planning goals and policy implementation tools were proposed based on these characteristics.

4.CONCLUSION AND PROSPECTS

The global emergence of peri-urbanization has driven both theoretical and practical research in recent years. Building on these studies, I use Zhengzhou as a case study to demonstrate an analytical framework for examining the spatiotemporal evolution of PUAs within a polycentric urban context, as well as to propose sustainable planning guidance for PULs.

The study of PUA identification and evolution not only aids in the rational planning and management of PUAs but also provides theoretical support for controlling urban sprawl, enhancing urban-rural integration, and promoting sustainable development. While PUAs are currently planned in China's urban planning primarily in the form of administrative regions such as townships, emphasizing the importance of PUAs in urban planning will elevate their status among policymakers and planners. In the future, the introduction of specialized planning could break administrative boundaries and facilitate unified planning and management.

However, some limitations should be noted. Firstly, due to the large study area in this research, I used 1 km^2 square grids for sampling when spatializing the indicator data. This process reduced the precision of some data. Additionally, there was a lack of multi-scale comparative analysis when choosing the grid size. Secondly, the selection of indicators has a significant impact on the identification results. Although I selected indicators from different dimensions and used different data to calculate them to avoid multicollinearity, it was still difficult to comprehensively characterize the characteristics that distinguish PUAs from other regions.

While I presented methods for PUA identification, many quantitative identification methods have not been explored. Additionally, the identification methods were applied using data from only a single year, lacking a temporal comparison across multiple years. This may weaken the persuasive power of the results. Future studies could consider using multi-year data to compare the accuracy and applicability of PUA identification methods and explore more methods based on the specific characteristics of the study area.

Furthermore, when formulating the sustainable planning guidelines for PULs in Zhengzhou, the cases I referred to were limited, and the proposed guidelines were relatively general, lacking discussions on the governance structure of the study

area and their integration with policy tools. Throughout the entire research, I only discussed the case of PUAs in a polycentric city and lacked comparisons with other urban form cases. Future research could selectively compare various cases with different urban forms, which will help gain a more detailed understanding of how the formation of PUAs is influenced by urban forms.

5.NEW SCIENTIFIC RESULTS

Thesis 1: Progress and limitations of peri-urban area (PUA) research at the global and Chinese levels.

Through a review of the literature, I found that research on PUAs is widespread globally. However, despite shared popular themes, there are regional differences that result in context-specific interpretations of the concept and characteristics of PUAs, lacking a unified standard. Consequently, current studies face limitations in the delineation, quantitative analysis, and landscape planning of these areas.

A bibliometric analysis of global PUA research literature reveals that the highest volume of research output comes from Asia, North America, and Europe. In terms of research chronology, North America, Australia, and Europe were the earliest regions to initiate studies on PUAs. The most prominent research topics worldwide include ecological and environmental research, policy and conflict research, spatial morphology research, and land use research.

In China, research on PUAs began in 1989. These researches were first initiated in major cities, as well as in the economically developed eastern coastal regions, which have also produced the most extensive research outcomes. Chinese PUA research has primarily focused on land use research, land governance research, ecological and environmental research, and spatial morphology research.

Previous research has introduced numerous qualitative and quantitative identification approaches, which vary depending on regional and socio-spatial scales. Consequently, there is a notable lack of literature offering direct comparisons among these approaches. Moreover, studies that use identification results to conduct spatiotemporal analyses are also relatively limited.

A review of the literature on peri-urban landscapes (PULs) reveals a set of common characteristics, particularly their dynamic, disordered, and fragmented nature. Regional variations are also evident; for instance, in China, PULs often feature agricultural landscapes as the basic landscape and factory landscapes as the dominant landscape. However, there is a notable lack of case studies focusing on the future sustainable planning and practical implementation of PULs, limiting the availability of references for applied research and policy-making.

Thesis 2: Differences in accuracy and applicability of three quantitative PUA identification methods.

Based on the literature review, I selected three quantitative methods for identifying PUAs: the Threshold method, Breakpoint Clustering, and the Multilayer Perceptron model. Using a unified study area and set of indicators, I conducted a direct comparison of their identification performance and discussed the applicability of each method.

In selecting the identification methods for comparison, I first chose the Threshold method, which has been widely applied across multiple case studies with consistently effective results. Then, I creatively combined two commonly used approaches, the breakpoint detection and the clustering method, into a hybrid method termed Breakpoint Clustering, aiming to address the limitations of each individual technique. Finally, I introduced the currently popular machine learning techniques by selecting the Multilayer Perceptron model for the identification of PUAs. The main comparative findings include:

a) Based on the criteria of accessibility and wide applicability, I constructed a multi-source indicator system, which includes Imperviousness Density (ID), Nighttime Light Intensity (NLI), Proportion of (semi-) natural land (PNL), and Per Capita Land Area (PCLA). The values of these indicators can represent different regional characteristics, and thus have performed very well in the identification of PUAs.
b) Using the data from 2020, these three methods yielded similar PUA identification results in Zhengzhou. Among them, the Threshold method showed lower accuracy, while both the Breakpoint Clustering and Multilayer Perceptron model demonstrated higher consistency and accuracy in their identification results.
c) In terms of operation and application, the Threshold method is widely used due to its simplicity, making it suitable for macro-scale applications such as overall planning and policy formulation. The Breakpoint Clustering and the Multilayer Perceptron model involve more complex procedures, but they are better at accurately capturing the complex boundaries of PUAs. Therefore, they can be used not only to define the boundaries of PUAs at the macro level but also to play a role in more detailed design and management processes.

Thesis 3: Spatiotemporal evolution of PUAs in multiple dimensions.

After identifying the PUAs of Zhengzhou in 2000, 2010, and 2020 using the Multilayer Perceptron model, I summarized the spatiotemporal trends of PUAs from the perspectives of spatial transition, expansion patterns, land use changes, and locational types.

Spatial transition: Both urban and PUAs in the study region exhibit a growth trend in the area. The expansion of urban areas primarily results from the conversion of PUAs, while the growth of PUAs mainly depends on the transformation of rural areas. Notably, the rate of conversion of rural areas to PUAs accelerated during the period from 2010 to 2020.

Expansion patterns: The spatial extent of PUAs has gradually expanded over time, with edge expansion being the dominant pattern. This has led to an overall expansion-driven rather than compact development trend across all administrative regions of Zhengzhou.

Land use change: Agricultural land and built-up land are the dominant land types within PUAs. Through the Land Cross Transfer Matrix calculations, I found that the spatiotemporal evolution of PUAs is marked by significant agricultural land encroachment by built-up land.

Location types: Along with the expansion of PUAs, three types of PUAs have emerged in Zhengzhou: Interurban PUAs are located between urban areas, exhibiting relatively stable changes and serving as a bridge connecting different urban centers; Transitional PUAs are situated between urban and rural areas, accounting for the largest proportion of PUAs and most accurately reflecting urban expansion; Isolated PUAs are surrounded by rural areas, characterized by smaller average sizes and more scattered spatial distribution. Isolated PUAs primarily result from bottom-up rural industrialization.

Thesis 4: Quantification of the hybrid and dynamic attributes of PUAs.

By plotting line graphs of the indicators along the urban-rural gradient zones and conducting statistical analysis, I validated the hypothesis that PUAs exhibit indicator values, specifically in ID, NLI, PNL, and PCLA, that fall between those of urban and rural areas. This finding quantitatively demonstrates the hybridity of PUAs, which integrate both urban and rural characteristics in terms of construction, economy, naturalness, and population. It also reveals their dynamic nature over time.

The indicator values along the gradient zones confirm a transitional pattern from urban to peri-urban to rural areas: both ID and NLI exhibit a decreasing trend, while PNL and PCLA show an increasing trend. Among these indicators, ID displays pronounced differences among these areas. In contrast, NLI and PNL reveal blurred boundaries between rural and PUAs, indicating less distinct transitions. PCLA values vary across different gradient zones; for instance, the CUA-Xinzheng and CUA-Zhongmu gradients exhibit notably lower PCLA values compared to other zones, suggesting relatively higher overall population densities in these two gradients.

In addition, the direction of dynamic changes in PUAs varies across different indicators. For example, both ID and PCLA of PUAs tend to approach the values of urban areas over time, urban and PUAs show synchronized growth in NLI, while the PNL of PUAs continues to decline, remaining blurred at the boundary between the PNL of rural areas.

Within PUAs, there are certain differences between different location types of PUAs in terms of ID and NLI. The difference in ID between Transitional PUAs and Interurban PUAs is significant. As for NLI, the difference between Interurban PUAs and Isolated PUAs is even more pronounced. In terms of PNL and PCLA, there are no significant differences in indicator values of all location types of PUAs.

Thesis 5: The morphological evolution of PUAs and PULs and their comparison with urban landscapes

In Zhengzhou, I identified ring-shaped, belt-shaped, and patch-shaped PUAs. Based on the Morphological Spatial Pattern Analysis (MSPA), I found both similarities and differences in the morphological evolution of PUAs across the three location types. For PULs, not only do the morphological evolutions among different categories within them vary, but their distinctions from urban landscapes are also quite evident. The morphology of PULs influences regional functions, while the functional demands of PUAs directly impact their spatial morphology.

In PUAs, the ring-shaped morphology is the most typical, often occurring on the outskirts of urban areas, mostly classified as Transitional PUAs. Isolated PUAs are primarily patch-shaped, small in area, and scattered. Belt-shaped PUAs emerged later and are primarily found between adjacent urban areas.

Within PUAs, the area of each morphological type in all categories shows an increasing trend. The *Core* remains the largest morphological type, although its proportion has decreased. In contrast, the proportion of *Bridges* and *Branches* has gradually increased. In comparison, the growth rates of each morphological type in Isolated PUAs are slower and more stable, with Core slightly outperforming the other two types in terms of proportion. In Transitional PUAs, the proportion of Core is the smallest, but the proportion of Bridge consistently remains slightly higher than the other two types of PUAs. In Interurban PUAs, the growth of *Core*, *Bridge*, and *Branch* types was particularly evident between 2000 and 2010.

In PULs, agricultural PULs show a trend of transitioning from *Core* to linear and even fragmented forms. In artificial PULs, the area proportions of each morphological type remain relatively stable, with a notable increase in the proportion of *Bridges*. In green PULs, the area proportions of each morphological type are gradually becoming more evenly distributed. In water PULs, there is also a relatively balanced distribution of the proportions of each morphological type, with a general dominance of linear forms.

A comparison between the morphologies of PULs and urban landscapes reveals that the morphology of PULs is more balanced and diverse than that of urban landscapes, with linear *Bridges* and *Branches* occupying a larger proportion.

Thesis 6: Structural quantification of PUAs and PULs and their distinction from urban landscapes.

I selected Landscape Metrics related to both composition and configuration to quantify the spatial structure of PUAs and PULs. The results revealed structural differences among various locational categories within PUAs, as well as a distinct pattern in PULs characterized by fragmentation of natural and semi-natural landscapes and aggregation of artificial landscapes.

From the composition metrics, I selected Percentage of Landscape (PLAND), Patch Density (PD), Mean Patch Area (AREA_MN), and Shannon's Diversity Index (SHDI), while from the configuration metrics, I used Mean Perimeter-Area Ratio (PARA_MN), Total Edge Contrast Index (TECI), Mean Proximity Index (PROX_MN), and Contagion (CONTAG). The analysis based on these metrics revealed that:

In PUAs, Interurban PUAs are characterized by large patch areas and low patch density, with a clear increasing trend in patch diversity and significant temporal changes in patch shapes. Isolated PUAs primarily consist of small patches with high patch density and low landscape heterogeneity. Transitional PUAs exhibit the highest landscape diversity, with strong connectivity among similar patches, mainly due to the clustering of artificial landscapes.

In composition metrics, agricultural and artificial PULs exhibit more prominent composition characteristics, specifically reflected in higher PLAND, PD, and AREA_MN. At the landscape level, the dominant PUL type shifted from agricultural to artificial PULs, accompanied by a fragmentation process that first accelerated and then slowed down over time. Meanwhile, the SHDI gradually increased. In contrast, urban landscapes exhibited lower diversity, with a notable intensification of fragmentation during the 2010-2020 period.

In configuration metrics, the patch shapes of PULs tend to become more complex, and the landscape exhibits increasing heterogeneity. Meanwhile, artificial PULs contribute to enhanced spatial connectivity; however, the overall aggregation of PULs shows a declining trend due to human activity disturbances. Similarly, the heterogeneity of urban landscapes also increased; however, the shape of patches in urban landscapes tended to be more regular compared to those in PULs, and the overall landscape exhibited a higher degree of spatial aggregation.

Thesis 7: The spatiotemporal evolution of PUAs is mainly driven by urban-rural driving forces, location and topography, and city planning.

Based on the preceding analysis, I found that the spatiotemporal evolution of PUAs exhibits regional disparities. In the case of Zhengzhou, the northeastern region shows both a larger extent and a faster growth rate of PUAs compared to the southwestern region. To explain these spatial differences, I identified three main driving factors.

Urban-rural driving forces: The radiative influence of urban areas has facilitated the formation of Transitional PUAs. In polycentric cities, the radiation of multiple urban centers has further promoted the emergence of Interurban PUAs and also enhanced the connectivity between PUAs, leading to the formation of continuous networks. Rural industrialization has led to the creation of Isolated PUAs, which, over time, have transitioned into Transitional PUAs and even Interurban PUAs.

Location and topography: The administrative regions located close to the CUA with flat terrain experience faster growth in PUAs. In contrast, administrative regions that are farther from the CUA and situated in more mountainous terrains face certain limitations in the development of PUAs.

City planning: The administrative regions within the study area are assigned different functional roles in urban planning, which influence their peri-urban development. For example, the CUA, as the primary functional zone, has significantly higher construction intensity and density compared to other administrative regions. This has accelerated the expansion of PUAs in the CUA.

The spatial evolution of PUAs is influenced by the aforementioned multiple factors. Conversely, it can quickly reflect the dynamic development of the city. Focusing on these areas can provide timely feedback to governments and planners, enabling them to better control the direction of urban planning, improve land use efficiency, and promote sustainable development.

Thesis 8: Context-specific planning guidelines for PUAs and PULs at the regional and local levels.

Drawing on planning experiences from other cases, I applied these insights to the challenges currently faced by Zhengzhou's PULs. At the regional level, I proposed planning guidelines centered on spatial planning and regulatory tools. At the local scale, I selected three towns as case studies to develop detailed planning recommendations and policy implementation tools.

I examined the current peri-urbanization challenges faced by Zhengzhou, which include a lack of comprehensive planning and management, the dual effects of a polycentric urban structure, and increasing homogenization in spatial form and structure. Subsequently, I identified four main types of spatial planning and regulatory tools based on ten case studies: (a) urban growth management policies; (b) spatial planning and zoning; (c) nature and landscape conservation planning; and (d) other individual plans.

Building on the assessment of current conditions in the study area and global planning experiences, I propose the use of spatial planning and regulatory tools at the regional scale to address existing problems within the PUAs. These proposals include:

a) Conducting spatial and land monitoring to predict future development.
b) Coordinating compact settlements and low-density development in spatial patterns.
c) Maintain the morphological diversity of PULs.
d) Enhancing the connectivity of natural and semi-natural landscapes.

At the local scale, I selected three representative towns and addressed specific issues that emerged during the evolution of PUAs in these areas, such as the abandonment of arable land and the lack of infrastructure management. For each case, I proposed detailed planning objectives, guidelines, and policy implementation tools. This analytical framework provides a theoretical foundation for the optimization practices of PUAs.

PUBLICATIONS

1. Shi, Z., Liu, M., Tian, G., & Kovács, K. F. (2024). Web of science-based literature review of peri-urban areas: a comparison between Europe and China. European Journal of Remote Sensing, 57(1), 2414475. https://doi.org/10.1080/22797254.2024.2414475
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