

Article

Spatio-Temporal Evolution and Driving Mechanism of Coupling Coordination of Pseudo Human Settlements in Central China's Urban Agglomerations

Shenzhen Tian ^{1,2,3,4}, Yadan Wang ^{1,4,*}, Xueming Li ^{1,2,3,4}, Wenmei Wu ^{1,4}, Jun Yang ^{1,2,3,4} , Xueping Cong ^{1,2,3,4} and Hui Wang ^{1,2,3,4}

¹ School of Geography, Liaoning Normal University, Dalian 116029, China; tsz999@lnnu.edu.cn (S.T.); lxm999@lnnu.edu.cn (X.L.); wwm3133752652@163.com (W.W.); yangjun@lnnu.edu.cn (J.Y.); congxpueping97@lnnu.edu.cn (X.C.); wanghuiouki@126.com (H.W.)

² University Collaborative Innovation Center of Marine Economy High-Quality Development of Liaoning Province, Dalian 116029, China

³ Research Base of Urban Agglomeration in Central-South Liaoning of China Urban Agglomeration Research Base Alliance, Liaoning Normal University, Dalian 116029, China

⁴ Human Settlements Research Center of Liaoning Normal University, Dalian 116029, China

* Correspondence: wangyd0129@163.com

Abstract: The construction of pseudo human settlements in the context of “digital-real integration” in the information age is crucial for the high-quality development of human settlements in the new era. This study aimed to investigate the spatio-temporal evolution of the pseudo human settlements and its mechanism to provide new ideas for scientific breakthroughs in cross-disciplinary fields, such as human settlements, and to provide a strong basis for promoting the overall improvement of the quality of the human settlements in the central China's urban agglomerations in the new era. Employing the theoretical framework of “three states” in human settlements, this study utilizes big data, including tourism, shopping, work, and socialization, to investigate the dynamic patterns and driving mechanisms of pseudo human settlements within Central China's urban agglomerations from 2011 to 2021, employing methodologies such as the coupling coordination model, standard deviation ellipse, kernel density, and gray correlation degree. The results show the following: (1) the overall pseudo human settlements in central China's urban agglomerations exhibit a pattern of “high coupling and low coordination”. (2) The overall coupling degree exhibits a fluctuating upward trend and has been at a high coupling-state level. (3) The degree of coupling coordination has obvious spatial differentiation characteristics, such as the core circle, “tower”, and “two main and one secondary” core structure. (4) The overall level of pseudo human settlements is influenced by the combination of time, space, and the multidimensionality of systems and indicators. This study conducted research on pseudo human settlements to enrich the theory of the human–land interaction relationship in geography and reflect the decision-making needs in the strategy of network power.

Keywords: pseudo human settlements; central China's urban agglomerations; high coupling–low coordination; tower character; two mains, one pair; multipolar drive



Citation: Tian, S.; Wang, Y.; Li, X.; Wu, W.; Yang, J.; Cong, X.; Wang, H. Spatio-Temporal Evolution and Driving Mechanism of Coupling Coordination of Pseudo Human Settlements in Central China's Urban Agglomerations. *Land* **2024**, *13*, 858. <https://doi.org/10.3390/land13060858>

Academic Editor: Dagmar Haase

Received: 23 April 2024

Revised: 8 June 2024

Accepted: 12 June 2024

Published: 15 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Since the twenty-first century, the internet [1], big data [2], cloud computing [3], artificial intelligence [4], blockchain, 5G, and other technologies that have accelerated innovation have been increasingly integrated into various areas of the world's socio-economic development, and projects like the European digitalization strategy, the strategic of digital Germany, the construction of spatial and temporal big data, and the community of destiny in cyberspace have been gradually developed. In recent years, big data have been increasingly emphasized in the Chinese government's work report starting from 2014

to the national strategy in 2015 and the “14th Five-Year Plan” for constructing the big data standards system in 2020. The integration of big data into social life is gradually promoted. In the context of an increasingly data-driven and networked society [5], the creation of good, livable, and sustainable pseudo human settlements (PHS) is one of the tasks to promote high-quality development [6] and socialist modernization. Since the implementation of the strategy of the rise of Central China, all aspects of the central region have been developed and improved, but due to the uniqueness of the resource endowment, social settlements, etc., the construction of its PHS is relatively weak, and the previous research model is not fully applicable. Therefore, it is necessary to enrich the research system of PHS and promote the continuous development of PHS in the central China’s urban agglomeration to respond to the strategy of the rise of Central China and meet the trend of digital development.

PHS is an important part of human settlements (HS). HS is the place where human beings live together, the surface space that is closely related to the survival activities of human beings [7], meaning that the HS refers to the sum of the natural and manmade environments on which human beings depend for their survival and development, and focuses on the science of exploring the interrelationships between human beings and the environment. The term “pseudo settlements” was first proposed by Lippmann to refer to the settlements suggested to people through selective processing of information by mass communication media modeled on the real world [8]. The PHS exists in human and real living environments and is a virtualized information environment based on humans’ own judgments, wills, and preferences, and it is constructed by filtering, processing, and editing real environments using media such as text, images, audio, and video [9]. Examples include the international platforms Facebook and Twitter, as well as the Chinese platforms Sina News, WeChat, and Meituan. As society continuously evolves, generating an increasing volume of information, the likelihood of direct access to this vast and intricate information by individuals is minimal. Therefore, the use of pseudo settlements is often necessary to comprehend real settlements. Research on PHS has arisen and evolved in response to real-world needs and disciplinary developments, and existing research has been categorized into the following areas: (1) research content—to explore the spatial and temporal distribution characteristics of the quality of PHS [10], to analyze its influencing factors or mechanisms, and to explore the relationship between PHS and a certain element and so on; (2) research scale—from small to large, including towns and cities [11], provinces, urban agglomerations [12], three major subregions [13], the national scale [14], etc.; (3) data materials—statistical yearbook, Baidu index, big data, etc.; and (4) research methods—entropy method, ArcGIS spatial analysis, coupling coordination degree model, geographical detector [15], kernel density [16], etc.

The degree of coupling coordination refers to the process by which systems coordinate and interact with each other. Among them, the coupling degree measures the synergy between elements within the system, and the coordination degree gauges the consistency between the heterogeneous parts of the elements in the system’s evolution. Together, they reflect the harmony within the system, emphasize the benign coordination of multiple elements within the system, and are comprehensive [17,18]. The methods and techniques of coupling coordination in practical applications are mainly concentrated in various fields, such as mathematics [19], physics [20], machine learning [21], artificial intelligence [22], and so on. With the continuous development and promotion of digital technology, its importance has become increasingly prominent, and the field of application has broadened. There are three main parts of the application of coupling coordination in the field of geography: (1) coupling coordination between geographic elements and elements in other fields, such as development and ecological protection [23], economy, and environment [24]; (2) coupling development between multiple geographic elements, such as “tourism–ecology–urbanization”, “production–life–ecology” [25], and so on; and (3) coupling within individual geographic elements, such as biocultural diversity [26] and environmental sustainability assessment [27]. Existing studies reveal the increasing maturity of the coupling coordination degree model’s development, and its application

in geography has yielded substantial results, contributing to the advancement of related research to some extent.

The report of the 20th National Congress of the Communist Party of China (CPC) proposes establishing a coordinated development pattern among large, medium, and small cities centered on urban agglomerations. This aims to enhance the quality of urban planning and construction and foster livable [28], resilient, and smart cities [29]. The central China's urban agglomerations, situated in the hinterland of China's national territory, spans from east to west and extends from north to south. It serves as a vital comprehensive transportation hub, boasting convenient transportation and holding strategic importance in national security and development due to its extensive food production base, ample labor force, and abundant energy and raw material reserves [30]. Since the implementation of the strategy of the rise of Central China, the infrastructure in the central region has been significantly improved, the economic system has become increasingly complete, and the social undertakings have developed comprehensively, which has a great influence on the economic development of the country and the construction of the HS [31]. After numerous years of development in the central region, although certain achievements have been made, there are still some problems that have not yet been solved. For instance, in the development of the internet, the delineation of content scope, participation of thematic boards, standardization of the publicity system, and other aspects of high-quality content construction are not flawless. In terms of the development of digital infrastructure and digital industry, there has been a large gap between the 5G construction, the expansion and speeding up of the fiber optic network, and the introduction and development level of the digital industry and the eastern part of the country. Regarding the cognitive aspects of networked and digitized development, network security and informatization construction have not been adequately understood or given sufficient attention. In this context, examining the evaluation system of the PHS in the central China's urban agglomerations and investigating its driving mechanism can enhance the quality of the PHS and improve people's well-being.

In summary, on the one hand, research related to PHS has been fruitful, but the following shortcomings still exist: (1) The research on PHS started relatively late, and the related research content needs to be expanded and improved. (2) PHS internal influencing factors and its driving mechanism are yet to be further studied. (3) The characteristics of the study areas are mostly similar, lacking diversity and uniqueness. On the other hand, Central China has a distinct uniqueness and typicality, as well as the necessity to carry out research on the PHS.

In order to improve the quality of the PHS in Central China's urban agglomerations, explore the spatio-temporal development characteristics and driving mechanism of PHS, and improve the research system of PHS, the PHS in the context of "digital-realistic fusion" in the information age is of great significance to the development of social production and life. It collects data through the Baidu index, designates the central China's urban agglomerations as the research area, and establishes the "Y" evaluation system for PHS. Data underwent processing via the entropy weight method. The coupling coordination degree model explored the degree of coupling coordination between evaluation systems. The kernel density estimation method visualized the distribution characteristics of sample data in each region. A gray correlation was used to analyze the correlation between each system, each indicator, and coupling coordination. The suitability of PHS for the central urban agglomeration and the three internal urban agglomerations, as well as the impact mechanisms of various evaluation systems and indicators on their overall performance, was also analyzed. To enhance the research content of human-land interaction in geography, we need to further promote the development of PHS, establish a scientific foundation for the micro-level integration of digital and physical aspects in PHS, and chart a development path for the synergistic optimization of "pseudo + reality" in Central China's urban agglomerations.

2. Theoretical Framework

2.1. Theoretical Extensions

In recent years, with the rapid development and application of high and new technology, the data-oriented, informationized, and virtualized features of social life have become increasingly significant, and the HS can be continuously enriched and developed. Referring to the existing studies [32,33], the HS is categorized into three parts: reality, pseudo, and imagery HS (Figure 1). Among them, the study of reality human settlements (RHS) primarily focusses on the settlements where human beings live together, analyzes the characteristics of the spatial and temporal distribution of the quality of the HS in a certain region, researches the influencing factors or mechanisms of the quality of the HS [34], and explores the mechanism of the interaction between the HS and a certain element [35]. With the increasing development of networking, digitalization, and the construction of HS, PHS continues to require continuity. It plays a dual role in the rapid formation and development and has formed a basic framework for studying the five systems of information, socialization, entertainment, living, and tools. Urban imagery is a generalized image of the external settlements by the individual mind, which is a joint product of direct sensation and memory of experience. Image human settlements (IHS) constitute the third state of HS, following the RHS and PHS. The specific urban imagery mainly includes five elements: roads, boundaries, areas, nodes, and markers [36]. Studying the PHS will promote its sustainable operation, contribute to the continuous development of IHS, enhance the comprehensive quality of HS, and facilitate a more scientific and systematic examination of the three states of HS.

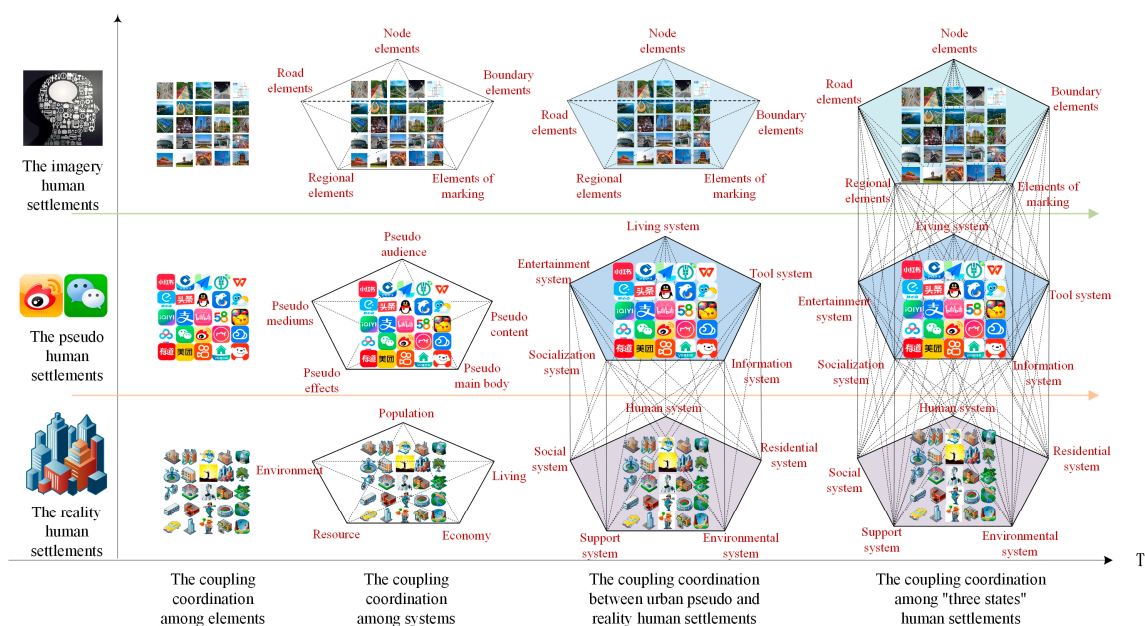


Figure 1. Coupling between states within the HS.

2.2. Structural Components

The coupling of the three states of the PHS involves multi-factor, multi-system, multi-faceted, and multidimensional interactions, representing a “spoked” development transitioning from simplicity to complexity and from a single pole to multiple poles. Multi-factor coupling involves the interrelationship of elements in one-to-one, one-to-many, or many-to-many situations. Multi-system coupling is a mutually reinforcing or constraining relationship between systems formed by the combination of elements of similar “nature” at a certain stage of development of each element. Multidimensional coupling is the existence of a complex relationship of influence between the different levels represented by each system. Multidimensionality means it includes the continuous action and development of elements and systems within a single level, and the three-dimensional intersection between

different elements and systems at multiple levels, directly or indirectly, and in a single line or multiple lines.

2.3. State of Development

The coupling development of the three states of HS is a “circular” development in the horizontal, vertical, and longitudinal directions. (1) Horizontal: Over time, at all levels, there is a progression from a single element to multi-factors and from a single system to multi-systems. The element influences the system, and the system impacts the development of the element. (2) Vertical: With the continuous development of each region, small cities and relatively underdeveloped regions contribute development resources to large cities and relatively advanced regions. In turn, large cities and relatively advanced regions offer development opportunities and experience to small cities and relatively underdeveloped regions. (3) Vertical direction: As horizontal and vertical development progress positively, the coupling development level of the three states of the HS exhibits an increasing trend. This progression moves from dysfunction to harmonization, from single-pole domination to multi-pole coexistence, and eventually manifests the characteristics of merging into one.

The PHS has achieved fruitful results in the context of the era of big data, “Internet+”, and virtualization, and under the guidance of national policies on High-Quality Development, Beautiful HS, information security, and other related policies. Based on the previous research [37–39], this study developed a Y-shaped evaluation system for PHS. It primarily centered on assessing the quality of PHS as the main stem. Subsequently, it formulated two branches, examining the interplay among internal factors in its development process and the extent of their contributions to enhance the research content of PHS, facilitate its systematic development, and offer theoretical support for its construction.

3. Overview of the Study Area and Data Sources

3.1. Overview of the Study Area

With reference to China’s national strategy for the rise of Central China and related documents and literature, the central China’s urban agglomerations was selected as the study area, comprising the Central Shanxi urban agglomeration (CSUA), Central Plains urban agglomeration (CPUA), and the middle reaches of the Yangtze River (UAMRYR). It involves eight provinces and includes 66 cities. The area covered is extensive and densely populated, with diverse resources and complex socio-economic development (Figure 2).

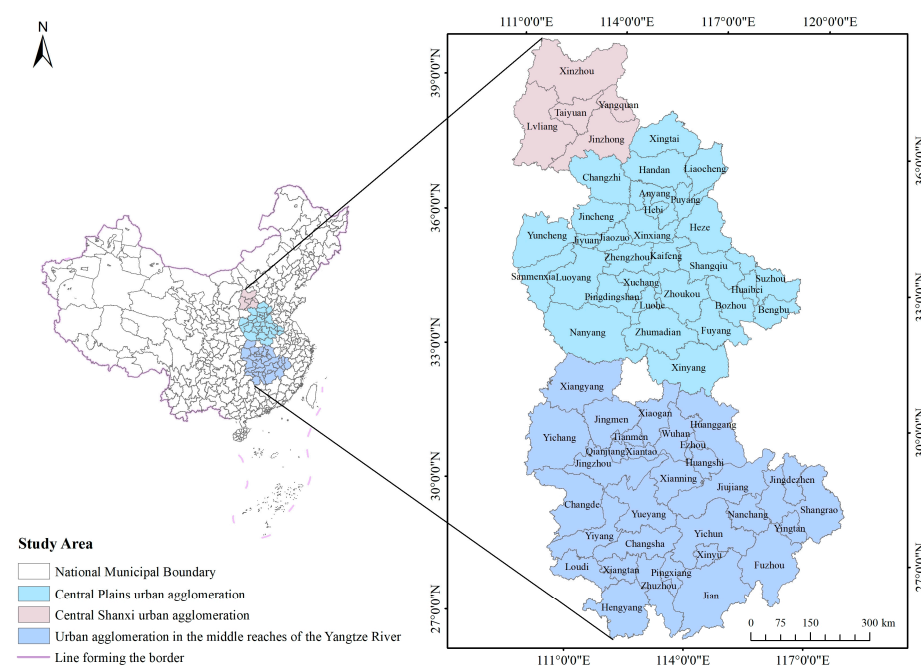


Figure 2. Study area central China’s urban agglomerations.

3.2. Model Construction and Data Sources

3.2.1. Evaluation Index System Construction and Index Assignment

In recent years, socio-economic development has been increasingly characterized by networking and virtualization. China's 14th Five-Year Plan emphasizes the advancement of digital life, smart cities [40], digital villages [41], and related dimensions. Based on this, this paper is oriented to enhance the connotation and quality of the PHS, under the perspective of geography, based on the RHS, following the principles of scientificity, representativeness and operability, drawing on the research results related to the HS [42,43], with reference to the characteristics of the disciplines of geography, informatics, journalism and communication, and computer science, and searching for information through Baidu and other platforms to select five systems that are closely related to the lives of people—life, entertainment, information, socialization, and tools—to analyze and evaluate the quality of the PHS. In view of the wide range of each system, the corresponding systems were interpreted on the basis of reference to the results of previous scientific research [11] and according to the representative and typical classification of the top search rankings in cell phones and computer systems. A total of 64 indicators, including Taobao, Baidu map, Tencent video, WeChat, Weibo, etc., are included to construct the PHS coupling and coordination index system (Figure 3).

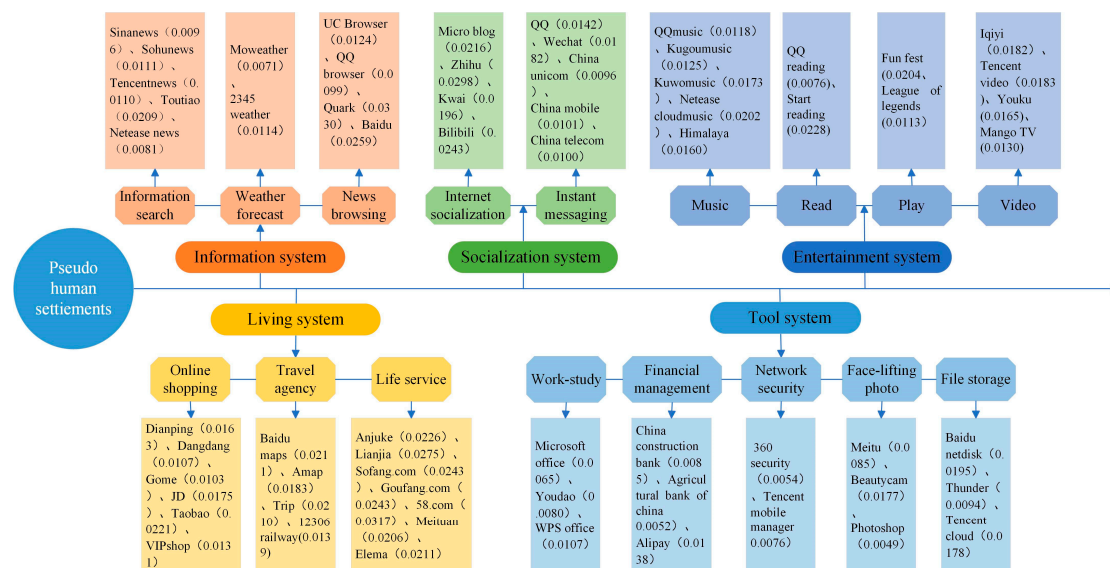


Figure 3. Coupling coordination index system of pseudo human settlements.

3.2.2. Data Sources

The study extracted Baidu index data for 64 indicators from 66 cities in the central China's urban agglomerations. Taking into account data accessibility and continuity, the study opted to extract data spanning from 2011 to 2021. The selected keywords included "Dianping", "Taobao", "Baidu", "WeChat", etc. The search time series was set from January 1st to December 31st each year. Overall daily averages of indicators for each city in every year were collected, resulting in a total accumulation of 16,959,360 data points over 4015 days.

4. Research Methods

4.1. Entropy Weight Method

To mitigate the impact of subjective factors and objective limitations during data processing, the entropy weight method was employed to measure the data. The weight value was objectively assigned to each indicator based on its entropy value [44].

(1) Standardized treatment:

$$Z_j = \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}} \quad (1)$$

(2) Calculation of indicator variability and information entropy:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}}, e_j = -k \sum_{i=1}^n P_{ij} \ln P_{ij}, K = 1/\ln m \quad (2)$$

(3) Calculate the information entropy redundancy and the weight of each indicator:

$$g_i = 1 - e_i, W_j = \frac{g_i}{\sum_{j=1}^m g_i} \quad (3)$$

(4) Calculation of the Comprehensive Evaluation Index:

$$S_i = \sum_{j=1}^m W_j X_{ij} \quad (4)$$

where Z_{ij} and X_{ij} represent the standardized and original values of the j th indicator in year i th, respectively; $\min X_{ij}$ and $\max X_{ij}$ denote the minimum and maximum values of the j th indicator, respectively; P_{ij} signifies the weighting of the indicator value in year i th during the calculation of the j th indicator; and $e_j \in [0, 1]$.

4.2. Coupling Coordination Degree Model

We explored the relationship between urban agglomeration and its internal roles, drawing on existing research results [45], combined with the characteristics of PHS evaluation indexes, to construct the coupling coordination evaluation model and to classify the coupling coordination degree level (shown in Table 1).

$$C = 5 \left\{ \left[f_{(X_1)} * f_{(X_2)} * f_{(X_3)} * f_{(X_4)} * f_{(X_5)} \right] / \left[f_{(X_1)} + f_{(X_2)} + f_{(X_3)} + f_{(X_4)} + f_{(X_5)} \right]^5 \right\}^{1/5} \quad (5)$$

where C represents the degree of coupling and its value range $[0, 1]$; and $f_{(X_1)}$, $f_{(X_2)}$, $f_{(X_3)}$, $f_{(X_4)}$, and $f_{(X_5)}$ denote the evaluation index of life, entertainment, information, social, and tool systems. These are obtained by multiplying the value of each system's evaluation index by the respective weight:

$$D = \sqrt{CT}, T = \alpha f_{(X_1)} + \beta f_{(X_2)} + \gamma f_{(X_3)} + \delta f_{(X_4)} + \varepsilon f_{(X_5)} \quad (6)$$

where D represents the coupling coordination degree with a value range of $[0, 1]$; T is the comprehensive development level of five systems; and α , β , γ , δ , and ε are coefficients to be determined with the condition $\alpha + \beta + \gamma + \delta + \varepsilon = 1$, taking into account that the five criterion layers have the same important roles in coupling systems, so set $\alpha = \beta = \gamma = \delta = \varepsilon = 0.2$.

Table 1. Criteria for coupling and coordination levels.

Coupling Degree	C	Coordination Degree	D	Coupling Degree	C	Coordination Degree	D
High-level coupling stage	$0.8 < C \leq 1$	Excellent coordination	$0.9 < D \leq 1.0$	Antagonistic stage	$0.3 < C \leq 0.5$	Near disorder	$0.4 < D \leq 0.5$
		Good coordination	$0.8 < D \leq 0.9$			Mild disorder	$0.3 < D \leq 0.4$
Break-in stage	$0.5 < C \leq 0.8$	Intermediate coordination	$0.7 < D \leq 0.8$	Low-level coupling stage	$0 < C \leq 0.3$	Moderate disorder	$0.2 < D \leq 0.3$
		primary coordination	$0.6 < D \leq 0.7$			Severe disorder	$0.1 < D \leq 0.2$
		Barely coordination	$0.5 < D \leq 0.6$			Extreme disorder	$0.0 < D \leq 0.1$

4.3. Kernel Density

Kernel density estimation is a nonparametric estimation method that can visualize distribution dynamics and evolutionary patterns and is widely used in the study of spatial distribution [46].

$$f(x) = \frac{1}{Nh} \sum_{i=1}^N K\left(\frac{x_i - x}{h}\right), K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \quad (7)$$

where N represents the number of urban agglomerations in Central China; x and x_i are the observed mean and observed value of coupling coordination degree of urban agglomerations in Central China, respectively, ($i = 1, 2, 3 \dots$); $K(x)$ is the kernel function; and h is the estimation accuracy and smoothness of the broadband decision kernel density.

4.4. Standard Deviation Ellipse

The standard deviation ellipse method can analyze the directional characteristics of spatial distribution. The center of gravity migration trajectory model can be developed based on the weighted expression of geographic elements to depict its spatiotemporal evolutionary law. It is grounded in the geographic location of the research object and quantitatively elucidates the centrality, directionality, morphology, and other spatial characteristics of the elements from both global and spatial perspectives [47].

Center of gravity:

$$\bar{X} = \frac{\sum_{i=1}^n w_i x_i}{\sum_{i=1}^n w_i}, Y = \frac{\sum_{i=1}^n w_i y_i}{\sum_{i=1}^n w_i} \quad (8)$$

Azimuth:

$$\tan \theta = \frac{\left(\sum_{i=1}^n w_i^2 \tilde{x}_i^2 - \sum_{i=1}^n w_i^2 \tilde{y}_i^2 \right) + \sqrt{\left(\sum_{i=1}^n w_i^2 \tilde{x}_i^2 - \sum_{i=1}^n w_i^2 \tilde{y}_i^2 \right)^2 + 4 \sum_{i=1}^n w_i^2 \tilde{x}_i \tilde{y}_i}}{\sum_{i=1}^n 2 w_i^2 \tilde{x}_i \tilde{y}_i} \quad (9)$$

The x - and y -axis standard deviation:

$$\sigma_x = \sqrt{\frac{2 \sum_{i=1}^n \left(w_i \tilde{x}_i \cos \theta - w_i \tilde{y}_i \sin \theta \right)^2}{\sum_{i=1}^n w_i^2}}, \sigma_y = \sqrt{\frac{2 \sum_{i=1}^n \left(w_i \tilde{x}_i \sin \theta - w_i \tilde{y}_i \cos \theta \right)^2}{\sum_{i=1}^n w_i^2}} \quad (10)$$

Ellipse area:

$$S = \pi \sigma_x \sigma_y \quad (11)$$

where n represents the number of municipalities within the central China's urban agglomerations; (x_i, y_i) represent the latitude and longitude geographic coordinates of each municipality; w_i represents the value of the PHS element corresponding to each municipality; θ is the azimuthal angle of the ellipse; σ_x and σ_y represent the standard deviation of the ellipse's x -axis and y -axis, respectively; and S represents the area of the standard deviation ellipse.

4.5. Gray Correlation

The fundamental concept of the gray correlation analysis is to assess the proximity of connections based on the similarity in the geometric shapes of sequence curves. The stronger the resemblance between curves, the higher the correlation among the respective sequences; conversely, the weaker the resemblance, the lower the correlation [48]. In this study, the gray correlation was employed to scrutinize the impact of individual system layers on the outcomes of urban agglomeration coupling and coordination, as well as the influence of each indicator on the results of coupling and coordination within each city. The detailed analytical process is outlined below:

Step 1: Select the mother series $Y = (Y_1, Y_2, Y_3 \dots Y_m)$; compare the series $X_i = (X_{i1}, X_{i2}, X_{i3} \dots X_{im})$, where $X_i = 1, 2, 3, \dots, n$.

Step 2: Select the mean value method to dimensionless each index variable in combination with the specific situation.

Step 3: Find the difference series.

$$\Delta i(k) = |Y(k) - X_i(k)| \quad (12)$$

Step 4: Calculate the correlation coefficient.

$$\xi_i(k) = \frac{\min_i \min_k \Delta i(k) + \rho \max_i \max_k \Delta i(k)}{\Delta i(k) + \rho \max_i \max_k \Delta i(k)} \quad (13)$$

where $\min_i \min_k \Delta i(k)$ represents the minimum difference between the two levels, and $\max_i \max_k \Delta i(k)$ denotes the maximum difference between the two levels. Moreover, ρ signifies the resolution coefficient, typically set at 0.5, and in this paper, it is calculated according to the general value.

Step 5: Seek correlation.

$$R_i = \frac{\sum_{k=1}^n \xi_i(k)}{n} \quad (14)$$

Step 6: Analysis of results.

Here, the larger the R_i value, the greater the impact that the sub-data columns have on the parent data columns; and the smaller the value, the smaller the impact. A specific analysis was realized with the help of the SPSS 26 software correlation analysis module.

5. Results

5.1. Analysis of Quality Evaluation Results

The overall fluctuating upward trend of the total scores of the three urban agglomerations in Central China was observed. Among them, 2012, 2015, and 2019 are critical fluctuation points. There was a rapid increase from 2012 to 2015, followed by a small decrease from 2015 to 2019 and from 2020 to 2021. The minimum point was 0.2770 in 2011, and the maximum point was 0.9946 in 2015 (Figure 4).

The three urban agglomerations in the central region exhibit an initial upward trend followed by a fluctuating decline. During 2011–2015, all three showed a clear upward trend, followed by a small fluctuating decline from 2015 to 2021. The smallest difference occurred in 2019, and the largest difference was observed in 2015. Regarding urban agglomerations: the CSUA is slightly higher than the CPUA and the UAMRYR in 2015–2019 and slightly lower than the CPUA and the UAMRYR in 2019–2021. The reason for this change is that the country's vigorous development of new energy sources and the pursuit of a low-pollution, sustainable development model have vigorously impacted the economic pattern of Shanxi, where coal and other energy sources are important development drivers, resulting in the phenomena of economic downturns and population exodus, which in turn affect the development of the pseudo subjects and objects. Since 2015, the CPUA has consistently been higher than the CSUA and UAMRYR. This is related to the growing socio-economic development of the CPUA, the optimization of smart city construction, and strong policy support. Until 2019, UAMRYR held its lowest position, surpassing CSUA and slightly trailing behind the CPUA thereafter. This phenomenon is closely linked to the development status of the upper and lower reaches of the Yangtze River. UAMRYR is connected to the lower reaches of the Yangtze River, and although it receives some development support, it has fewer resources than the lower reaches of the Yangtze River in terms of economic development, the importation of talents, and the construction of smart cities, leading to the phenomenon of insufficient impetus for the development of UAMRYR.

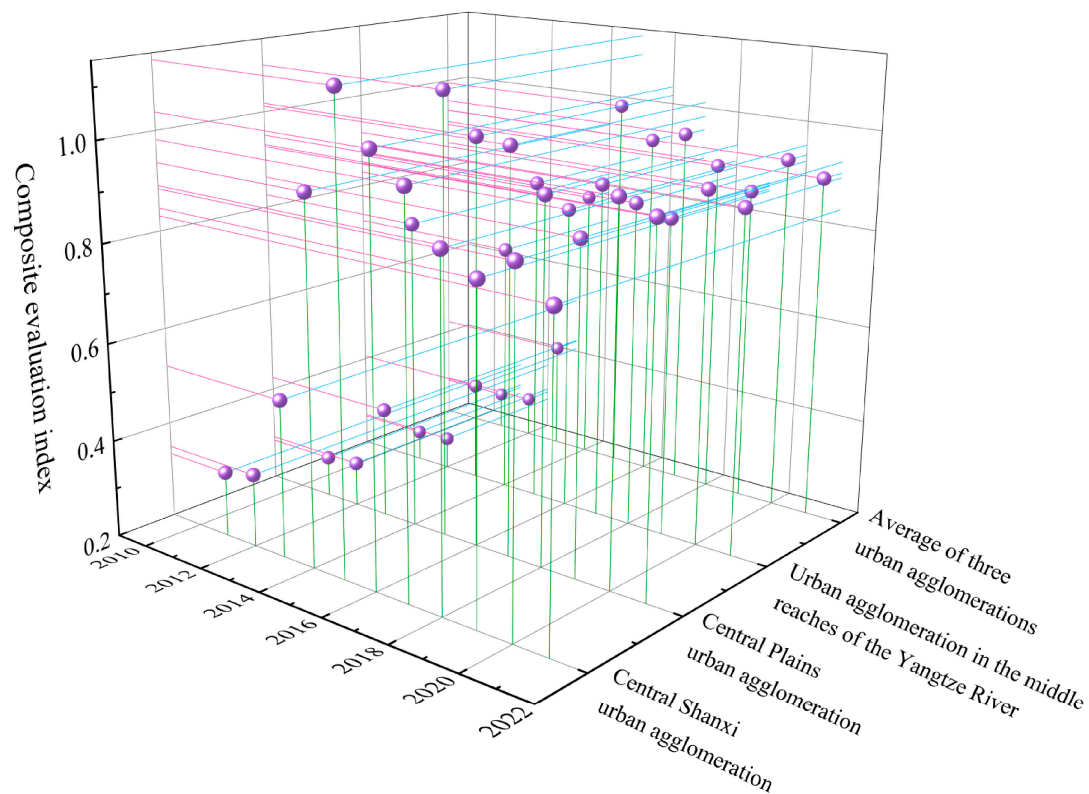


Figure 4. Central China's urban agglomerations composite evaluation index.

5.2. Analysis of Coupling Coordination Relationships

5.2.1. Coupling Degree Analysis

According to the coupling coordination degree model, we calculated the coupling degree among the five evaluation systems—living, recreation, information, socialization, and tool—of the PHS in the central three urban agglomerations. The data were visualized using Origin 2022, as illustrated in Figure 5.

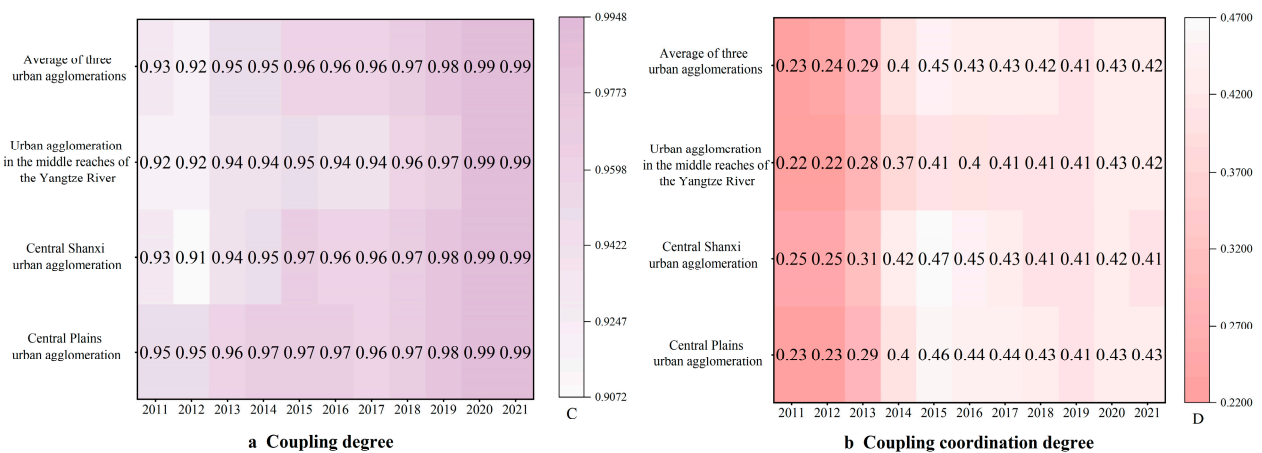


Figure 5. Central China's urban agglomerations coupling and coupling coordination degree.

Analysis of time dynamics: The three urban agglomerations exhibit a high level of coupling, displaying a fluctuating upward trend. The average coupling degree for the period 2011–2021 ranges from 0.9348 to 0.9929, with lower values in 2012 and 2017 and higher values in 2015 and 2020. This shows that urban agglomerations are affected by the social environment, economic development, and other complex factors in the process of

development, which leads to the emergence of a certain degree of mutual constraints and mutual influence alternating phenomena between the five major evaluation systems. The phases of 2013–2015, 2017–2020, and 2020–2021 show an upward trend, with the largest increase observed in 2017–2020. This indicates increased positivity between the interactions of PHS systems and better socio-economic development during these three time periods. Overall, throughout the study period, a high level of coupling is observed among the five evaluation systems—living, entertainment, information, socialization, and tool—of the PHS in the three central urban agglomerations. This high level of coupling indicates a substantial beneficial impact among these systems, fostering the coordinated development of the inter-region.

Analysis of spatial variability: The differences in coupling degree among the three urban agglomerations indicate a diminishing trend. The coupling degree difference among the three urban agglomerations from 2011 to 2021 ranges from 0.0305 to 0.0042, suggesting a gradual decrease in the disparity in the development status of their PHS. Among them, the coupling degree of the CPUA has been higher than that of the CSUA and UAMRYR, and the fluctuation range of its development and change has been smaller than that of the CSUA and UAMRYR. This is due to the steady state of economic development in the CPUA and continued policy support.

The coupling degree between the urban agglomeration of CSUA and UAMRYR was very close in 2011 and 2012 and closer in 2020, and the urban agglomeration of CSUA was higher than UAMRYR from 2012 to 2021. The coupling degree level of UAMRYR has been at the lowest position. It increased rapidly during 2012–2013 and 2017–2020, and the difference with the CPUA was the smallest in 2020.

5.2.2. Coupling Coordination Degree Analysis

Based on the establishment of the index system and the coupling coordination degree model, the data illustrating the coupling coordination degree for each city are visualized using ArcGIS 10.8, resulting in the acquisition of Figure 6.

Analysis of time dynamics: The coupling coordination degree of the three urban agglomerations exhibited a generally increasing trend throughout the study period. (1) The average coordination value of the three urban agglomerations demonstrated a trend of rapid increase, followed by a gradual decline. Specifically, it rapidly rose from 0.2337 in 2011 to a peak of 0.4459 in 2015, followed by a gradual decrease. It shows that the social environment and economic development of the three urban agglomerations in 2011–2015 were relatively stable, and the systems coordinated with each other significantly. (2) The average coordination value of the three urban agglomerations has exhibited a state of disorder, characterized by moderate disorder in 2011–2013, mild disorder in 2014, and near-disorder in 2015–2021. It shows that tourism travel facilities, public information management, and company cooperation and development between regions within the Central China's urban agglomerations need to be further strengthened. (3) The developmental changes in the coupling coordination degree of the three urban agglomerations are inconsistent. The CSUA experienced an upward trajectory until 2015, reaching its peak value of 0.4687 in that year. Subsequently, it surpassed the central plains and UAMRYR until 2017 but exhibited a declining trend compared to them after 2017. The CPUA was close to the average in 2011–2014 and slightly higher than the other two after 2016. UAMRYR lagged until 2018 but showed no significant difference from the other two thereafter. This is due to the differences in resource endowment, level of economic development, and history and humanities among regions that affect people's choices in work and study, socialization, and recreation, thus resulting in the phenomenon of inconsistent development among regions.

Analysis of spatial variability: The development among the three urban agglomerations is characterized by asynchrony, with the development of the CSUA preceding that of the CPUA and UAMRYR. It shows a transitional development from north to south. All urban agglomerations were in moderate disorder in 2011. The CSUA was the first to reach mild disorder in 2013; the CSUA and CPUA reached near disorder, and UAMRYR reached

mild disorder in 2016. All three urban agglomerations reached the verge of dissonance by 2021. There are obvious differences and transitions from the core to the peripheral areas within each urban agglomeration. During the study period, the development speed and quality of the core area of each urban agglomeration are better than those of the peripheral area. Prioritizing the development of the core area leads to the development quality of the adjacent areas, which in turn affects the development of the peripheral areas.

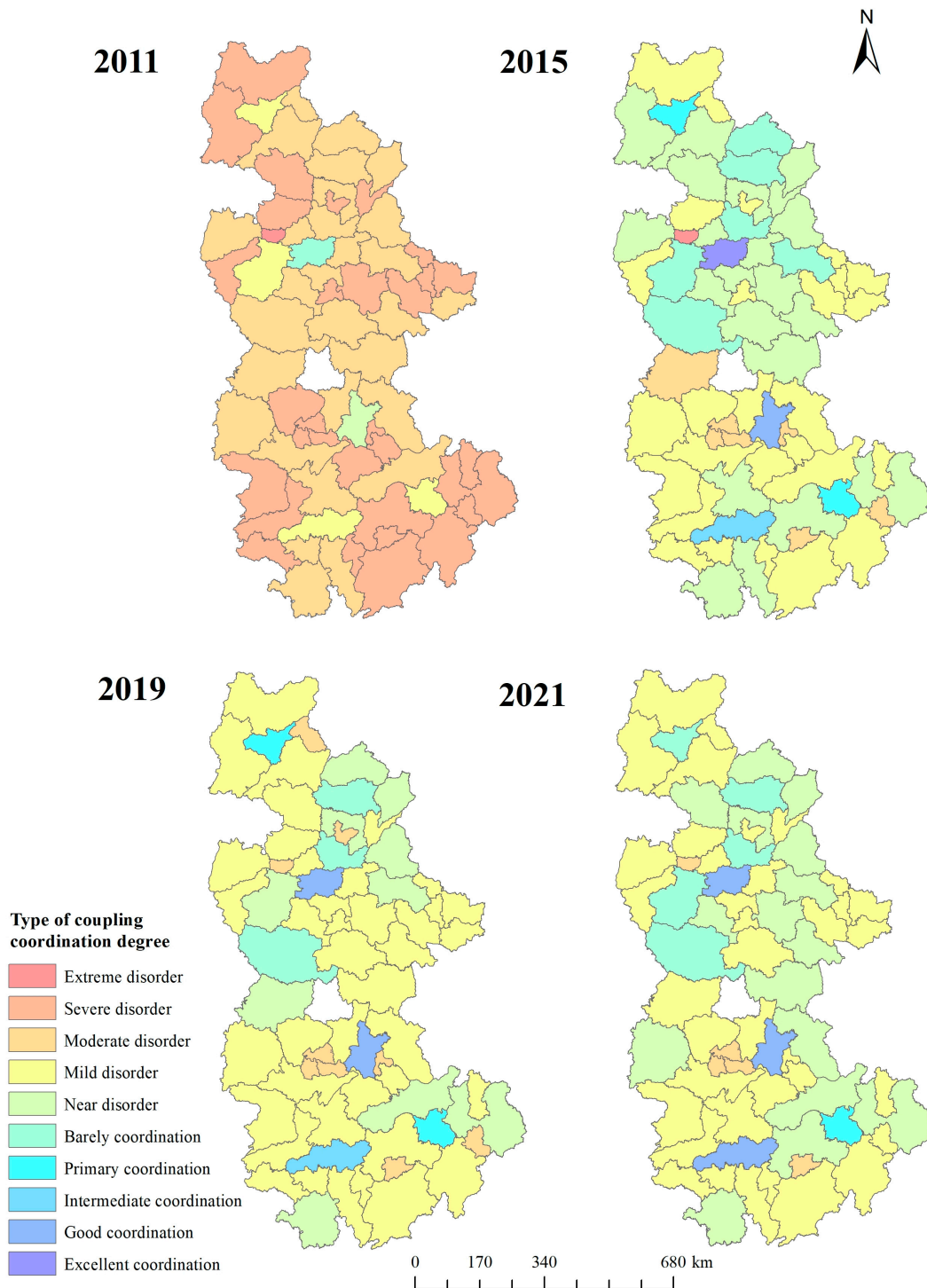


Figure 6. Central China’s urban agglomerations coupling coordination degree of cities.

The distribution of regional concentrations within each of the three urban agglomerations is distinctly delineated. ① The CPUA features a “tower” structure, with Zhengzhou

City representing the pinnacle, and Xinxiang, Nanyang, Handan, and others comprising the top layer. Zhoukou, Shangqiu, Xinyang, Anyang, and others form the middle layer, while Sanmenxia, Yuncheng, Suzhou, Zhumadian, and others constitute the grassroots level. From the pinnacle to the top, intermediate layer, and grassroots level, comprehensive strength diminishes, and various resource conditions deteriorate. The pinnacle plays a downward role in propelling the development of the layers, while the layers also play an upward role in providing resources to facilitate the further optimization of the pinnacle. ② The CSUA exhibits distinct core circle characteristics, comprising five cities with Taiyuan at the central hub and Xinzhou, Yangquan, Jinzhong, and Lvliang around the periphery. The growth at the circle's center radiates and propels the development of the surrounding area. However, due to resource disparities among regions, the development of the surrounding area exhibits asynchronous characteristics. ③ UAMRYR exhibits a core structure of “two main cities and one secondary city”. Wuhan and Changsha are the main cores, and Nanchang is the secondary core, forming a relatively stable triangle, UAMRYR. Owing to the vast size of the region and inter-regional differences, substantial variation exists within UAMRYR. Based on the 2021 data, a majority of the remaining cities exhibit moderate-to-mild disorder, except for Wuhan and Changsha, characterized by excellent coordination, and Nanchang, which has intermediate coordination.

5.3. Kernel Density Analysis

To vividly depict the dynamic evolution characteristics of the coupling coordination degree among the three central urban agglomerations, this study employed the kernel density estimation method to illustrate the distribution features of the sample data (Figure 7). It further examines crucial attributes of the kernel density curves, including the distribution position, distribution pattern of the main peaks, distribution ductility, and the number of wave peaks [49].

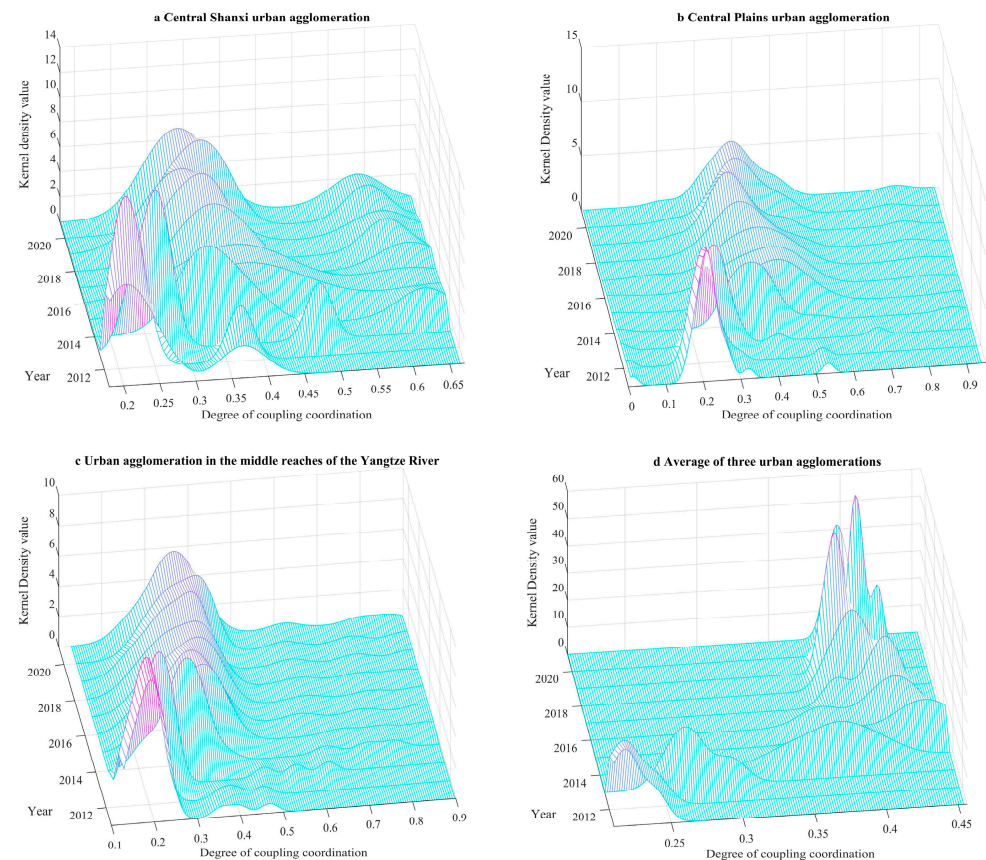


Figure 7. Dynamic evolution of coupling coordination degree of central China's urban agglomerations.

Distribution position: The distribution position approximately follows a left-to-right developmental trajectory. This direction implies that the coupling coordination degree of the three urban agglomerations in Central China is ascending, and the interactions within the PHS systems contribute positively. Nevertheless, a slight leftward shift transpires during the period 2018–2021, suggesting a subtle constraint on the interaction mechanism among systems in the central China's urban agglomerations region due to social settlements.

Distribution pattern of the main peaks: The width of the main peaks is narrowing, and the height is increasing in the distribution pattern. The kernel density curve at the overall level indicates a rising height and narrowing width, suggesting a decreasing trend in the discrete degree of coupling coordination among the three urban agglomerations. However, from the perspective of each urban agglomeration, the kernel density curves show a decreasing height and widening width for the three urban agglomerations, diametrically opposite to the average value. This indicates a significant difference in the degree of coupling coordination within the three urban agglomerations.

Distributional ductility: The trailing phenomenon in distributional extensibility is gradually becoming less distinct. The three central urban agglomerations and their mean kernel density curves all exhibit varying degrees of the trailing phenomenon, indicating the presence of cities within each region with significantly higher coupling coordination degrees than others in the same region. Overall, there is a trend from right trailing and right convergence at the general level, with the CSUA and the CPUA displaying right trailing, and UAMRYR showing left trailing. This suggests that the differences between the three urban agglomerations are gradually diminishing, but the variations within the urban agglomerations are increasing, and the likelihood of extreme values within them is growing.

Number of wave peaks: The peaks transition from numerous and low to few and high. Except for the CSUA, the study area exhibits the single-peak phenomenon, indicating a more balanced development within the CPUA and UAMRYR. The double-peak phenomenon in the CSUA was more pronounced in the early stage of the study. Toward the end, the height of the side fronts gradually decreased, tending to evolve into a single-peak phenomenon. This suggests a weakening of polarization characteristics within the region and a gradual reduction in regional differentiation.

5.4. Standard Deviation Elliptic Analysis

Based on the aforementioned analysis, the spatial standard deviation ellipse method was employed to elucidate the spatial distribution characteristics and evolutionary trends of the coupling coordination degree within the three urban agglomerations in Central China (Figure 8). Overall, the standard ellipse and center of gravity distribution of the three central urban agglomerations remained relatively stable between 2011 and 2021, though distinct variations exist when examined from a specific perspective.

In terms of the distribution of the center of gravity, the coupling coordination degree of the three urban agglomerations in the central part of the country, specifically related to the PHS, exhibits a general trend of moving first to the northeast and then to the southwest. The center of gravity shifted from Northwestern Xinyang to Southwestern Zhumadian during the period of 2011–2015, and it generally shifted southward during 2015–2019, exhibiting a trend toward the southwest in the period 2019–2021. This indicates that the optimization of the coupling coordination degree in the northeastern region progressed more rapidly before 2015, while the southern region experienced faster development after 2015. Analyzing the spatial distribution of the standard deviation ellipse, we see that the ellipse's area expanded by 12,461.487 km² from 2011 to 2019, suggesting that the growth rate within the ellipse is smaller compared to the growth rate outside the ellipse. In the period from 2011 to 2015, the long axis increased by 2.390 km, the short axis increased by 0.016 km, and the oblateness increased by 0.00176. This suggests that the expansion of the three urban agglomerations in Central China was more prominent along the long axis in the northwestern–southeastern direction than the spatial changes along the short axis.

during this period. From 2015 to 2019, the short axis increased by 7.7649 km, the long axis decreased by 3.1420 km, and the oblateness decreased by 0.0170. This indicates that the ellipse is becoming more rounded, and the internal regions are becoming more coordinated. From 2011 to 2019, the long axis remained in the northwest–southeast direction, the azimuth angle decreased by 0.278753 degrees, and the center of gravity shifted to the southeast. This suggests that the region to the right and above the long axis experienced a higher growth rate than other regions, indicating the development of PHS coupling coordination.

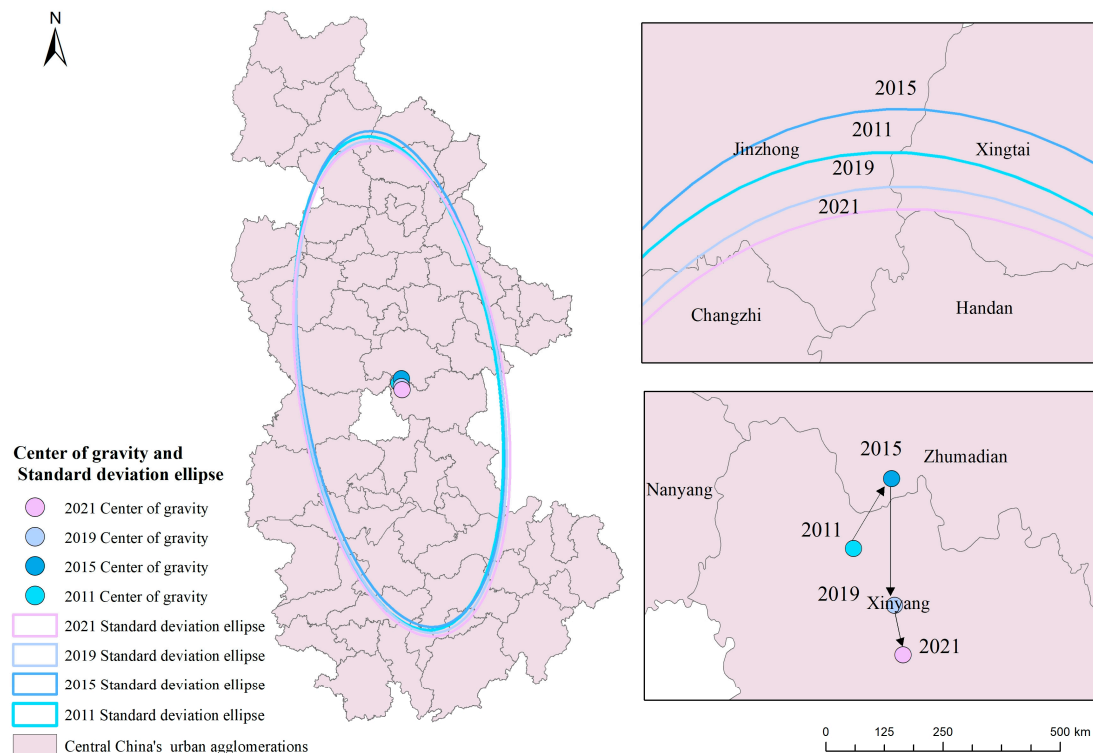


Figure 8. Center of gravity migration and standard deviation ellipse for urban agglomeration. This figure shows the positional distribution and moving trend of the regional center of gravity and standard deviation ellipse of the coupling coordination degree of urban agglomeration in Central China in 2011, 2015, 2019, and 2021.

5.5. Driving Mechanism Analysis

5.5.1. Impact of Major Influencing Factors on Coupling Coordination

Based on the factor analysis and the specific situation, the most representative indicators of each indicator layer were selected according to the weights of each indicator to carry out the correlation analysis [50,51], and the results are shown in Figure 9 (where 1–11 represent the years 2011–2021, respectively).

At the overall level, Baidu maps, Baidu, 2345 weather, WPS office, and Start reading were the main drivers during the study period, while Tencent video, Tencent mobile manager, Alipay, WeChat, and Taobao were secondary drivers, and Goufang.com, Toutiao, Beautycam, Baidu netdisk, Zhihu, and Netease cloudmusic were general drivers. In terms of ranking in the top five in each year, 2345 weather, Baidu, and Start reading appeared six times; Baidu maps and Alipay appeared five times; and Taobao, WeChat, Tencent video, and WPS office appeared four times. In terms of time evolution, the top core drivers from 2011 to 2021 are Taobao, WeChat, Goufang.com, Tencent video, WeChat, 2345 weather, Baidu maps, Baidu, and Toutiao. In terms of indicator dimensions, the fluctuation of the correlation of each indicator is large; for example, Taobao ranked 1 in 2011 but 17 in 2014, Alipay ranked 2 in 2017 but 14 in 2015, WeChat ranked 1 in 2013 but 15 in 2015, etc.

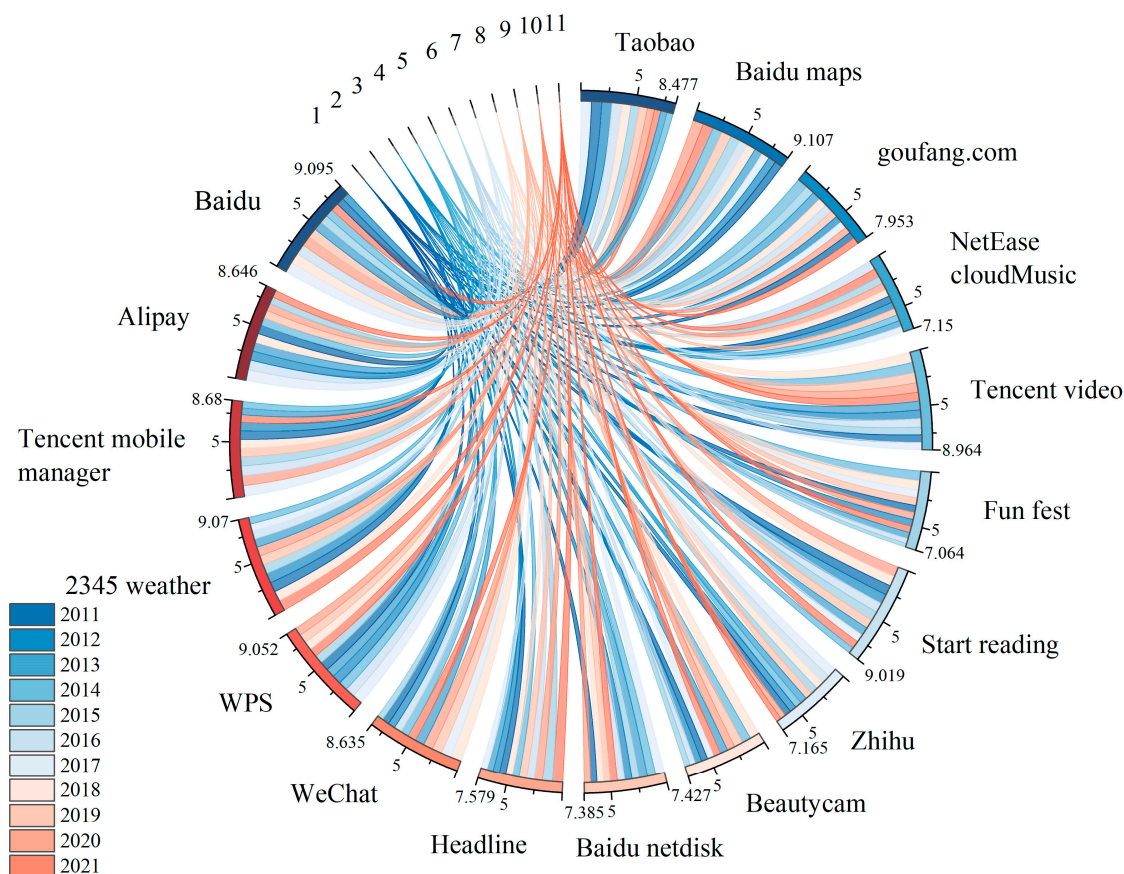


Figure 9. Chord chart of correlation shares of major factors.

5.5.2. Impact of Systems on Coupling Coordination

The correlation of the data was processed through the correlation analysis module of SPSS 26 software to obtain the correlation and ranking of the systems and indicators with the coupling coordination degree, and Figure 10 was plotted using Origin 2022. First of all, the overall ranking of the correlation between each system and coupling coordination is tool system > information system > living system > socialization system > entertainment system, which means that its dominant driving system is the tool system in the period of 2011–2021; and the magnitude of the correlation between each system and coupling coordination has a great deal of volatility. The relevance values of the tool system fluctuate relatively smoothly, with relevance rankings hovering mainly in the top three. The fluctuation trend of the relevance of the information system shows an “M” transformation, and its relevance ranking is polarized. The relevance ratio of the life system dropped from 25% to 14% between 2012 and 2017 and hovered around 23% in the remaining years. Socialization systems were in a better situation in terms of relevance share and ranking during 2014–2018 and were in a lower state of development in the remaining years. The relevance ranking of the entertainment system is the opposite of that of the tool system, which has fluctuated, mainly hovering in the bottom three.

Among these, the life, entertainment, and social systems peaked in 2013 and approached their zenith in 2018 and 2019. The Entertainment system was the least relevant in 2015 and ascended to the second position, closely approaching the first in 2018. The social system exhibited the highest correlation in 2016 and reached its lowest point in 2013, 2019, 2020, and 2021. Overall, the tool system exerted the most significant influence on the development and alteration of coupling coordination degree throughout the study period, acting as the dominant driving system. Simultaneously, the information system served as the secondary driving system, underscoring the significance of both the tool and information systems in the PHS.

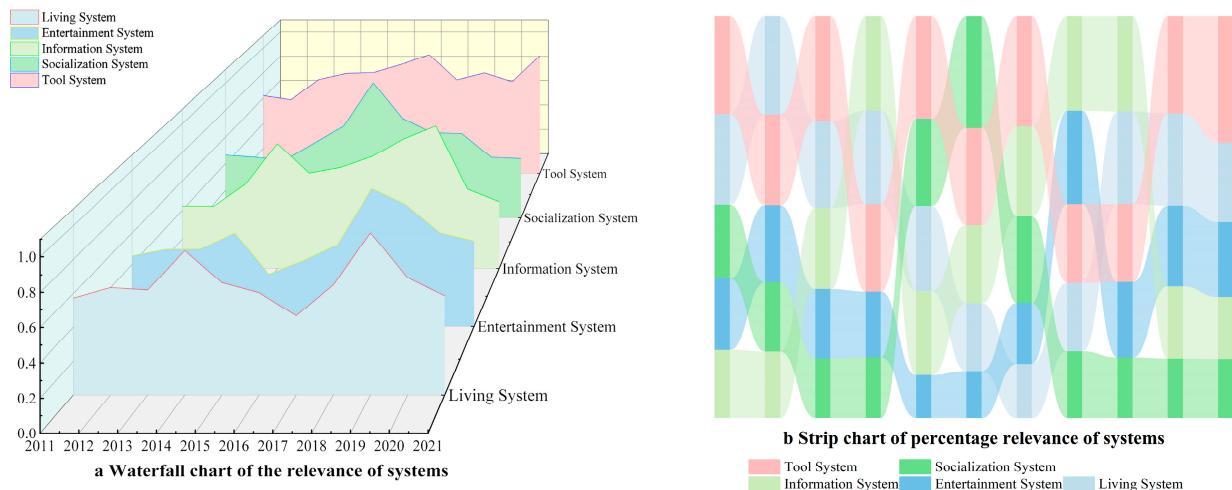


Figure 10. Correlation analysis of systems for coupling coordination degrees.

The driving mechanism of PHS suitability in the central China's urban agglomerations is a complex system. In the context of the high-quality development of information technology, the continuous improvement of the construction of HS, and the construction of beautiful HS proposed by the State, it is affected by the internal role of living and entertainment, information and socialization, and tools; and the external influence of national policies and the international environment. First of all, the tool system is the core driving system, work/study, financial management, file storage, internet socialization, and so on in contemporary people's daily lives account for a large part. With the achievements of science and technology innovation, the development and improvement of these software or web pages can greatly promote the enhancement of the PHS and improve the quality of life of people. Secondly, information systems and living systems play a major supporting role; news browsing, weather forecasting, online shopping, travel, etc., are essential parts of people's daily lives, and the relevant infrastructure in the PHS is constantly improved and rationally planned and controlled to play a stable and powerful supporting role. Social and recreational systems have a distinctly resilient push, enriching the PHS to some extent. Each system is an essential part of the PHS, and there is a continuous process of system optimization and promotion of comprehensive development; attention is paid to the interactions between systems while they are being developed in order to promote the continuous development of the PHS.

6. Discussion

6.1. Research on the Sustainable Development of PHS

There was an overall fluctuating upward trend in the quality of the PHS in the central China's urban agglomerations during the period 2011–2021, with significant regional differences. In recent years, the country has vigorously developed new energy and pursued a low-pollution and sustainable-development model, which has strongly impacted the economic pattern of Shanxi, in which coal and other energy sources are important development drivers, resulting in economic downturns and population outflows, causing the quality of PHS in the CSUA to rise and then fall during the period of 2011–2021, a result that is consistent with the study conducted by Li et al. [52]. The CPUA and UAMRYR are affected by the uncertainty of real factors, such as socio-economic development, policy guidance, and smart city construction, resulting in fluctuating changes, and this conclusion is the same as that in the study of Xue et al. [53]. on China's reality and pseudo HS. In summary, by continuously consolidating and optimizing the quality of the RHS, it is possible to reduce the fluctuations in the development of the PHS to a certain extent and promote the sustainable development of the PHS.

There were obvious spatial differences in the development of PHS in the central China's urban agglomerations during the period 2011–2021. Zhengzhou, Wuhan, Changsha, and Taiyuan have formed the development characteristics of “tower”, “two main cities and one sub-city”, and core circle, respectively. The cities of Zhengzhou, Wuhan, and Taiyuan are leaders in the region in terms of economic development, infrastructure, and technology. Zhou et al.'s [54] study on the ecological status of urban agglomeration shows that the urbanization of Zhengzhou and Luoyang is higher than that of other areas in the CPUA, and Chen et al.'s [55] study on the high-quality development of the central region points out that the central region shows a pattern of distribution in which “the provincial capitals are better than the non-provincial capitals”. Some of the results of the studies on PHS in central China's urban agglomerations are similar to those for ecological status and high-quality development, which verifies that the studies on PHS have a certain degree of reasonableness, and provides a reference for future studies in other regions of the world.

6.2. Limitations and Future Directions

This paper conducts PHS on Central China's urban agglomerations, empirically studies the time evolution and spatial pattern characteristics of its development, and explores the influence mechanism of each system and each indicator on the degree of coupling and coordination of urban agglomerations. Although the paper is still somewhat insufficient, certain results have been achieved:

(1) Due to the limitations of the target audience behind Baidu, there is a certain degree of missing data. Future research subjects should cover various groups in society as much as possible, such as increasing data research platforms, paying attention to the elderly population, and fully considering the impact of RHS on PHS, such as personal preferences and group characteristics.

(2) The PHS research system was established on the basis of reality, but the connection with reality is not high. Subsequent research can increase the connection with reality, improve the richness of data sources, and carry out research on the integration and development of pseudo and reality.

(3) At present, the research on PHS is still distributed only in some areas of Central and Eastern China, although some validation has been achieved but less involved in Western China and foreign areas; thus, future research should expand the research area, especially the study of some typical areas in the global context.

6.3. Policy Recommendations

Given the context of rapid economic development, continual technological updates and iterations, and increasing globalization and informatization, reinforcing digital construction and operational management serves as a crucial catalyst for fostering high-quality development and achieving Chinese-style modernization. The central region of China spans from east to west, connects the south to the north, and plays a pivotal role in bolstering China's coordinated regional development pattern. Consequently, enhancing the suitability of PHS in Central China and upgrading the infrastructure of diverse systems can robustly advance the implementation of the “Rise of Central China Strategy”, foster the construction of Digital China, and propel the comprehensive development of the region. Drawing on the aforementioned factors, the study outlines the following policy recommendations:

(1) In response to the significant regional differences and core development issues, we need to accelerate the construction of regional integration and implement a development model that combines large with small, and excellent with inferior. Narrowing the gap between the two poles; promoting communication and exchange between regions; fully leveraging the radiation and driving role of major cities, such as Taiyuan, Zhengzhou, Wuhan, and Changsha; and driving the development of surrounding areas are needed. The surrounding areas should leverage their strengths and make up for their weaknesses, vigorously develop advantageous industries, optimize and upgrade disadvantaged industries,

enhance their own strength, and promote comprehensive and coordinated development within the region.

(2) In response to the problem of unstable regional development and frequent fluctuations and changes, it is necessary to strengthen the construction of digital infrastructure, prosper the digital industry, and enhance the risk-resistance and self-recovery capacity of PHS. We will speed up the expansion and acceleration of fiber optic networks and the commercial deployment and scale application of 5G in the central China's urban agglomerations region, deeply implement the "East Counts, West Counts" project, and accelerate the transformation of infrastructure digitization and intelligence, so as to enhance the quality of PHS in the region and promote the stable and positive development of PHS.

(3) In response to the problem of non-consistency in the correlation results of systems and factors in the region, it is necessary to comprehensively promote the synergistic development of systems and create a multi-polarized driving mechanism. The existing development advantages of the tool system, information system, and life system should be fully utilized to improve the operation and management system of news browsing, work and study, and other related apps. In view of the uniqueness of the social system and entertainment system, we should learn from the management models of developed regions and combine them with the specific conditions of Central China's urban agglomerations, so as to provide proper guidance and rational planning and development.

7. Conclusions

Under the circumstance that the research system of PHS needs expansion and improvement, and the construction of PHS in the central China's urban agglomerations is relatively weak, to respond to the high-quality development of Central China [56] and cater to the digitalization of construction [57], this paper takes the three urban agglomerations in Central China as the research area, using 2011–2021 as the research period, and constructs a coupling and coordination evaluation index system of PHS. By employing the entropy weight method, coupling coordination degree model, and gray correlation degree to explore the influencing mechanisms of each system and indicator in the index system on the coupling coordination degree of the region. The results are as follows:

(1) The Comprehensive Evaluation Index of the central China's urban agglomerations is characterized by significant bipolar differences, clear fluctuation nodes, and an overall upward trend. The scores of the three urban agglomerations as a whole exhibit a fluctuating upward trend, experiencing a rapid increase in the period of 2012–2015, and a slight decrease in the periods of 2015–2019 and 2020–2021. The years 2012, 2015, and 2019 represent the critical fluctuation points, with significant changes in increase or decrease occurring before and after these points. The reason for this change is that, in recent years, the country has been vigorously developing new energy sources and pursuing a low-pollution and sustainable-development model, as well as the emergence of a number of societal diseases, which have greatly affected the trajectory of human activity in the PHS.

(2) The coupling degree of the central China's urban agglomerations has consistently remained at a high level, exhibiting certain spatial variations. The overall trend in the development of the three urban agglomerations shows a fluctuating upward trajectory, with the coupling degree ranging from 2011 to 2021 falling within [0.9, 1], indicating a high level of coupling. The coupling degree of the CPUA has consistently surpassed that of the CSUA and UAMRYR. Additionally, the fluctuation range in its development and change is smaller compared to that of the CSUA and UAMRYR. It shows that the CPUA's stable state of economic development and continuous policy support, etc., and its stable and RHS provide a solid foundation for the development of PHS.

(3) The coupling coordination degree of the central China's urban agglomerations has exhibited fluctuations in the disorder stage, and the development of regional nucleation is evident. It has experienced a disorder stage in terms of temporal changes and demonstrates a general trend of rapid ascent followed by gradual descent. In terms of spatial variation, it undergoes a transitional development from north to south, displaying clear distinctions

and transitions from the core to the periphery within each urban agglomeration. Regarding the distinctions within the central urban agglomeration, the CSUA exhibits prominent core circle characteristics, the CPUA manifests “tower” characteristics, and UAMRYR demonstrates the core structure of “two mains and one sub”. This is due to the differences in resource endowment, level of economic development, history and humanities among regions, which affect people’s choices in work and study, socialization and recreation, thus resulting in the phenomenon of inconsistent development among regions.

(4) The differences in development among the three urban agglomerations have gradually diminished over the study period, but within each urban agglomeration, they have steadily increased. The three central China’s urban agglomerations, along with their mean kernel density curves, exhibit an overall rightward-shifting trend, increasing height, narrowing width, a certain degree of trail conditions, and a single peak phenomenon in the study area outside the CSUA. The standard ellipse of the three central China’s urban agglomerations increases in size, and the center of gravity tends to shift first to the northwest and then to the southwest. Additionally, there is a significant inclination for the ellipse to become rounded, with the eastern and southern regions developing more favorably than the northern and western parts.

(5) Regarding the driving mechanism, the correlation results among the three urban agglomerations within the central urban agglomeration exhibit significant inconsistency. The degree of coupling coordination in the central urban agglomeration is influenced by time, space, and the combination of systems and indicators. Overall, the correlation ranking between each system and the coupling coordination degree is as follows: tool system > information system > living system > socialization system > entertainment system. Additionally, the correlation ranking between each system and the coupling coordination degree displays significant volatility.

Author Contributions: Conceptualization, S.T. and Y.W.; data and conducted analyses, S.T., Y.W. and W.W.; formal analysis, H.W. and J.Y.; investigation, W.W.; drafted the paper and proofread, S.T., Y.W., X.L., J.Y. and X.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (No. 42201221), Liaoning Province Natural Science Foundation Project (No. 2023-MS-254), Liaoning Province Social Science Planning Fund Project (No. L22CJY016), Liaoning Province Social Science Association 2021 Liaoning Province Economic and social development research topic (No. 2021lslqnt-012), and Dalian Federation of Social Sciences (No. 2022dlskzd037).

Data Availability Statement: The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Brand, M. Can internet use become addictive? *Science* **2022**, *376*, 798–799. [[CrossRef](#)] [[PubMed](#)]
2. Thadani, N.N.; Gurev, S.; Notin, P.; Youssef, N.; Rollins, N.J.; Ritter, D.; Sander, C.; Gal, Y.; Marks, D.S. Learning from prepandemic data to forecast viral escape. *Nature* **2023**, *622*, 818–825. [[CrossRef](#)] [[PubMed](#)]
3. Fox, A. Cloud computing—What’s in it for me as a scientist? *Science* **2011**, *331*, 406–407. [[CrossRef](#)] [[PubMed](#)]
4. Mitchell, M. AI’s challenge of understanding the world. *Science* **2023**, *382*, eadm8175. [[CrossRef](#)] [[PubMed](#)]
5. Vanli, T.; Akan, T. Mapping synergies and trade-offs between smart city dimensions: A network analysis. *Cities* **2023**, *142*, 104527. [[CrossRef](#)]
6. Zhang, G.; Wang, Y.; Chen, Y.; Zhou, C. Spatiotemporal characteristics and differentiation mechanism of high-quality development of urban agglomerations in China. *Geogr. Res.* **2022**, *41*, 2109–2124. [[CrossRef](#)]
7. Wu, L.Y. *Introduction to Sciences of Human Settlements*; China Architecture and Building Press: Beijing, China, 2001; pp. 62–84.
8. Lippmann, W. *Public Opinion*; Routledge: Oxfordshire, UK, 1992; pp. 3–30.
9. Tian, S.; Yang, B.; Liu, Z.; Li, X.; Zhang, W. Coupling coordination of urban pseudo and reality human settlements. *Land* **2022**, *11*, 414. [[CrossRef](#)]
10. Tian, S.; Li, X.; Yang, J.; Wang, H.; Guo, J. Spatiotemporal evolution of pseudo human settlements: Case study of 36 cities in the three provinces of Northeast China from 2011 to 2018. *Environ. Dev. Sustain.* **2023**, *25*, 1742–1772. [[CrossRef](#)]
11. Kalantari, Z. Enlivening our cities: Towards urban sustainability and resilience. *Ambio* **2021**, *50*, 1629–1633. [[CrossRef](#)]

12. Zhang, Y.; Wang, X.; Ji, M.; Chen, Y.; Yan, F. Evaluating the barrier of typical production factor flow in the Chengdu-Chongqing urban agglomeration based on multi-source big data. *Front. Environ. Sci.* **2022**, *10*, 1048378. [\[CrossRef\]](#)
13. Fang, Y.; Su, X.; Huang, Z.; Guo, B. Structural characteristics and resilience evaluation of tourism flow networks in five major urban agglomerations in coastal China: From the perspective of evolutionary resilience. *Econ. Geogr.* **2022**, *42*, 203–211. [\[CrossRef\]](#)
14. Ma, R.; Wang, T.; Zhang, W.; Yu, J.; Wang, D.; Chen, L.; Jiang, Y.; Feng, G. Overview and progress of Chinese geographical human settlement research. *J. Geogr. Sci.* **2016**, *26*, 1159–1175. [\[CrossRef\]](#)
15. Wang, L.; Zhang, X.; Li, Q.; Zhang, M.; Su, H.; Zhu, J.; Zhong, Y. Incorporating neuro-inspired adaptability for continual learning in artificial intelligence. *Nat. Mach. Intell.* **2023**, *5*, 1356–1368. [\[CrossRef\]](#)
16. Pang, R.; Hu, N.; Wei, Y. Evaluation of quality for human settlement in Xinjiang based on multi-source data. *Sci. Geogr. Sin.* **2021**, *41*, 2127–2137. [\[CrossRef\]](#)
17. Zhang, Y.; Zhu, T.; Guo, H.; Yang, X. Analysis of the coupling coordination degree of the Society-Economy-Resource-Environment system in urban areas: Case study of the Jingjinji urban agglomeration, China. *Ecol. Indic.* **2023**, *146*, 109851. [\[CrossRef\]](#)
18. Zhang, Y.; Haseeb, M.; Hossain, M.E.; Hu, M.; Li, Z. Study on the coupling and coordination degree between urban tourism development and habitat environment in the Yangtze River Delta in China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 14805–14820. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Liang, S.; Ji, S. Coordinated Time-Stepping method for coupled DEM-FEM-MBD algorithm. *Int. J. Comp. Methods* **2022**, *19*, 2150067. [\[CrossRef\]](#)
20. Zúñiga, J.; Bastida, A.; Requena, A. Quantum description of linearly coupled harmonic oscillator systems using oblique coordinates. *J. Phys. B At. Mol. Opt. Phys.* **2020**, *53*, 025101. [\[CrossRef\]](#)
21. Liu, Z.; Chen, W.; Jin, K.; Li, H. Task-space trajectory tracking control for coordinated manipulation using sampled coupling data. *IEEE Robot. Autom. Lett.* **2021**, *6*, 8434–8441. [\[CrossRef\]](#)
22. Ouyang, X.; Meng, D.; Wang, X.; Wang, C.; Liang, B.; Ding, N. Hybrid rigid-continuum dual-arm space robots: Modeling, coupling analysis, and coordinated motion planning. *Aerosp. Sci. Technol.* **2021**, *116*, 106861. [\[CrossRef\]](#)
23. Barth, M.; Jiménez-Aceituno, A.; Lam, D.P.M.; Bürgener, L.; Lang, D.J. Transdisciplinary learning as a key leverage for sustainability transformations. *Curr. Opin. Environ. Sustain.* **2023**, *64*, 101361. [\[CrossRef\]](#)
24. Hao, Z.; Wang, Y. Evaluation of socio-economic-ecological environmental benefits of urban renewal projects based on the coupling coordination degree. *Environ. Sci. Pollut. Res.* **2023**, *30*, 56946–56968. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Liang, T.; Yang, F.; Luo, Y.; Fang, M.; Huang, X.; Zhang, Z.; Wen, C.; Ren, X. The synchronous development pattern and type division of functional coupling coordination and human activity intensity based on the “Production-Living-Ecological” space perspective: A case study of wanzhou district. *Land* **2022**, *11*, 1897. [\[CrossRef\]](#)
26. Liu, S.; Zhang, Z.; Jiao, Y.; Shi, W.; Liu, N.; Wang, L. Spatial coupling mechanism of biocultural diversity: Case of Beichuan-River-Source National Nature Reserve, Qinghai, China. *Int. J. Sust. Dev. World* **2023**, *30*, 458–484. [\[CrossRef\]](#)
27. Zhang, D.; Chen, Y. Evaluation on urban environmental sustainability and coupling coordination among its dimensions: A case study of Shandong Province, China. *Sustain. Cities Soc.* **2021**, *75*, 103351. [\[CrossRef\]](#)
28. Wang, Y.; Miao, Z.Y.; Lu, Y.Q.; Zhu, Y. The impact of economic development on urban livability: Evidence from 40 large and medium-sized cities of China. *J. Geogr. Sci.* **2023**, *33*, 1767–1790. [\[CrossRef\]](#)
29. Stamopoulos, D.; Dimas, P.; Siokas, G.; Siokas, E. Getting smart or going green? Quantifying the Smart City Industry’s economic impact and potential for sustainable growth. *Cities* **2024**, *144*, 104612. [\[CrossRef\]](#)
30. Feng, Y.; Zhai, S.; Jiang, X.; Luo, J.; Yan, P.; Dong, C.; Han, J. Simulating spatio-temporal pattern of production-living-ecological space and evaluating eco-environmental effects in Zhongyuan Urban Agglomeration based on FLUS model and shared socioeconomic pathways. *Acta Ecol. Sin.* **2023**, *43*, 8292–8308. [\[CrossRef\]](#)
31. Su, Y.; Lu, C.; Su, Y.; Wang, Z.; Huang, Y.; Yang, N. Spatio-temporal evolution of urban expansion based on a novel adjusted index and GEE: A case study of central plains urban agglomeration, China. *Chin. Geogr. Sci.* **2023**, *33*, 736–750. [\[CrossRef\]](#)
32. Yin, Y.; Zhou, K.; Zhan, D.; Chen, Y. Evaluation of livability in apline ecological function zone and diagnosis of hindering factors from coupled natural and human perspectives: A case of Qinghai Province. *Acta Ecol. Sin.* **2024**, *44*, 1–17. [\[CrossRef\]](#)
33. Zhan, D.; Zhou, X.; Zhou, K.; Zhang, W.; Yu, X. The impact of perceived urban human settlement quality on subjective well-being: A case study using urban health examination data in the Yangtze River Delta region. *Prog. Geogr.* **2023**, *42*, 730–741. [\[CrossRef\]](#)
34. Liao, B.; Wang, Z.; He, J.; Wu, J.; Su, J. The driving mechanisms for human settlement and ecological environment in the upper minjiang watershed, China. *Front. Environ. Sci.* **2023**, *11*, 1097801. [\[CrossRef\]](#)
35. Yu, X.; Chen, H.X. Study on coupling coordination of the human settlement environment and tourism industry in the yellow river basin. *Front. Environ. Sci.* **2022**, *10*, 1016839. [\[CrossRef\]](#)
36. Tian, S.; Li, X.; Yang, J.; Zhang, W.; Guo, J. Spatio-temporal coupling coordination and driving mechanism of urban pseudo and reality human settlements in the three provinces of Northeast China. *Acta Geogr. Sin.* **2021**, *76*, 781–798. [\[CrossRef\]](#)
37. Hu, Q.; Wang, C. Quality evaluation and division of regional types of rural human settlements in China. *Habitat. Int.* **2020**, *105*, 102278. [\[CrossRef\]](#)
38. Li, W.; Li, P.; Feng, Z.; Xiao, C. GIS-based modeling of human settlement suitability for the belt and road regions. *Int. J. Environ. Res. Public Health* **2022**, *19*, 6044. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Tang, L.; Long, H. Simulating the development of resilient human settlement in Changsha. *J. Geogr. Sci.* **2022**, *32*, 1513–1529. [\[CrossRef\]](#)

40. Filiou, D.; Kesidou, E.; Wu, L. Are smart cities green? The role of environmental and digital policies for Eco-innovation in China. *World Dev.* **2023**, *165*, 106212. [\[CrossRef\]](#)
41. Wang, M.; Pan, Z.; Zhang, Q.; Guo, D.; Lao, J.; Lin, X. Individualization of digital rural practice and spatial reconstruction: A case study of Guifeng village, Guangzhou. *Hum. Geogr.* **2023**, *38*, 126–134. [\[CrossRef\]](#)
42. Wang, Y.; Li, T.; Meng, X. Evaluation of China's rural human settlements quality and its spatiotemporal change characteristics from 2010 to 2020. *Geogr. Res.* **2022**, *41*, 3245–3258. [\[CrossRef\]](#)
43. Yang, Q.; Chen, J.; Li, B.; Zhu, Y. Evolution and driving force detection of urban human settlement environment at urban agglomeration in the middle reaches of the Yangtze River. *Sci. Geogr. Sin.* **2018**, *38*, 195–205. [\[CrossRef\]](#)
44. Yang, Y.; Li, S.; Su, Z.; Fu, H.; Wang, W.; Wang, Y. Research on the ecological innovation efficiency of the Zhongyuan urban agglomeration: Measurement, evaluation and optimization. *Sustainability* **2023**, *15*, 14236. [\[CrossRef\]](#)
45. Li, X.; Guo, Y.; Tian, S.; Bai, Z.; Liu, H. The Spatio-temporal pattern evolution and driving force of the coupling coordination degree of urban human settlements system in Liaoning Province. *Sci. Geogr. Sin.* **2019**, *39*, 1208–1218. [\[CrossRef\]](#)
46. Wang, X.; Sun, Q. The dynamic evolution of industry matching and its impact on the High-quality economic development in the Yellow River Basin—Based on High-class service industry and advanced manufacturing industry. *Econ. Probl.* **2023**, *06*, 120–129. [\[CrossRef\]](#)
47. Bai, B.; Zhao, Z.; Zhang, P. Trends and layout of economic integration between north and south China. *Econ. Geogr.* **2021**, *41*, 1–10. [\[CrossRef\]](#)
48. Liu, C.; Sun, W.; Zhang, L. Spatio-temporal pattern of coupling coordination degree between carbon emissions and vegetation cover and its influencing factors of the Yangtze River Delta. *Sci. Geogr. Sin.* **2023**, *43*, 142–151. [\[CrossRef\]](#)
49. Jodder, P.K.; Laya, R.S.; Rahaman, K.R.; Abdulla-Al, K.; Rahaman, Z.A.; Almulhim, A.I. Modeling the impacts of residential, commercial, and industrial land use on carbon footprints using kernel density function in an urban setting. *Earth Syst. Environ.* **2023**, *7*, 237–254. [\[CrossRef\]](#)
50. Ma, H.; Lian, Q.; Han, Z.; Gong, Z.; Li, Z. Spatio-temporal evolution of coupling and coordinated development of basic public Services-Urbanization-Regional Economy. *Econ. Geogr.* **2020**, *40*, 19–28. [\[CrossRef\]](#)
51. Sun, J.; Cui, Y.; Zhang, H. Spatio-temporal pattern and mechanism analysis of coupling between ecological protection and economic development of urban agglomerations in the Yellow River Basin. *J. Nat. Resour.* **2022**, *37*, 1673–1690. [\[CrossRef\]](#)
52. Li, G.; Liu, M. The Promotion Path of Pseudo and Real Human Settlements Environment Coupling Coordination in Resource-Based Cities. *Sustainability* **2023**, *15*, 3851. [\[CrossRef\]](#)
53. Xue, Q.; Yang, X.; Wu, F. A two-stage system analysis of real and pseudo urban human settlements in China. *J. Clean. Prod.* **2021**, *293*, 126272. [\[CrossRef\]](#)
54. Zhou, C.; Yan, L.; Qin, P.; Yang, R. Urban Agglomeration Niche Measurement and Spatial-temporal Differences—Take the Central Plains Urban Agglomeration as an Example. *Ekoloji Derg.* **2018**, *27*, 363–369.
55. Chen, M.; Wang, Z.; Xie, L.; Li, Q. The spatiotemporal pattern evolution and formation mechanism of high-quality development in Central China. *Acta Geogr. Sin.* **2023**, *78*, 859–876. [\[CrossRef\]](#)
56. Zhu, X.; He, T.; Qi, W.; Zhang, G.; Zhou, G.; He, Y. Build a new pattern of regional coordination and promote the high-quality development of central China. *Acta Geogr. Sin.* **2022**, *77*, 3194–3202. [\[CrossRef\]](#)
57. Gong, S.; Li, B.Q. The digital silk road and the sustainable development goals. *IDS Bull.* **2019**, *50*, 23–45. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.