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Regional Sustainable Assessment at City Level Based on CSDIS (China Sustainable Development Indicator System) Concept in the New Era, China

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Abstract: The core issue of sustainable development refers to the coordinated development of economic-social-environmental issues. In the present study, by complying with the China Sustainable Development Indicator System (CSDIS) concept, a comprehensive index system was built; besides, Natural Breaks (Jenks) Classification Method, Exploratory Spatial Data Analysis and Geographic Detector Analysis were conducted to delve into the sustainability and coordinated degree at city level in China from 2007 to 2017. The achieved results are presented as follows. First, for spatial differentiation, the overall spatial distribution pattern was characterized by the high-value units in eastern China and the low-value units in western China from 2007 to 2017. To be specific, the high-value units were radiated along the Beijing-Guangdong Axis (Jing-Guang Axis) centered on the core of Beijing-Tianjin-Hebei Region, the middle-value units were distributed in strips along the coast, and the low-value units were vastly gathered in western China and gradually break via the Hu Huanyong line (Hu Line) in south China from 2007 to 2017. More specifically, based on the five subsystems, the pattern of each system was consistent with the whole, whereas the degree of concentration was different. Second, for spatial correlation, the significant High-High (HH) areas were primarily distributed in the core of Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta Regions. The significant Low-Low (LL) areas were continuously distributed in the southwest China and broke through the Hu Line from 2007 to 2017. There were insufficient number of significant High-Low (HL) and significant Low-High (LH) areas, whereas the spatial agglomeration of them was less obvious. Third, for internal coupling coordination, the spatial differentiation between the coupling degree and the coupling coordinated degree was significantly consistent in 2007 and 2017. The Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta Regions have demonstrated a high level of coordinated evolution, and the pattern of western mountainous areas exhibited a low degree of coordinated growth. Lastly, based on the combination of quantitative and qualitative, its factors were underpinned by robust economic strength, the vitality support of the information level and the basic support function of the topography, active guidance of national policies and path dependence and industrial transfer.

Keywords: sustainable development level; spatial differentiation; city level; China

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1 Introduction

Regional sustainable development specifically indicates general sustainable development in a particular region; it is essentially characterized by fairness, continuity and commonality, *etc*. (Cheng et al., 2019). The concept was first studied at the United Nations Human Environment Symposium held in Stockholm in 1972. In 1978, the report of 'Our Common Future' defined the concept as a development that satisfied the needs of people these days without compromising the ability of future generations to meet their needs. In 2015, the convened United Nations Summit on Sustainable Development formed a novel agenda to press ahead world peace and prosperity and boost sustainable human development. In October 2019, the first Sustainable Development Forum was opened in Beijing Economic and Technological Development Zone. In brief, it is considered that promoting global sustainable development has been manifested as a recognized obligation and responsibility of the international community. Moreover, it has become a global consensus to gain insights into the concept of sustainable development and building a community of human destiny. Accordingly, studying the level of sustainable development helps reveal and identify the defects and problems of different countries; it can also boost the unification of ecological, economic and social benefits in different countries, underpinning sustainable and healthy development to be ultimately achieved in the long term.

As fueled by the rapid development of the economy-society, the concept of sustainable development continues to infiltrate, so a series of studies on sustainable development have been conducted extensively. International studies on sustainable development have been relatively mature. To be specific, 17 sustainable indicators were adopted to analyze the renewable energy strategies for sustainable development in existing studies (Uğurlu, 2019). There are also novel research methods (Vučetić, 2018; Sobhanifard and Vaeysi, 2020) in sustainable tourism development and their results in environmental protection, so tourism policy makers can be offered the optimal measures to maintain environmental quality. Overall, the spatial subject primarily consists of urban, rural and enterprise types (Ali-Toudert and Ji, 2017; Mao et al., 2018). For the indicator system, single indicators are more commonly applied for study (e.g., Human Development Index and the national wealth) (Lind, 2014). In the latest research progress, multiple indicators have been increasingly introduced in study (e.g., a comprehensive index system based on resources, economy, ecology, environment and society) (Li et al., 2014; Rodriguez et al., 2019; Lin et al., 2019). Besides, some scholars (Jeníček, 2013) have assessed the role of sustainable development in society, economy and environment (e.g., water, soil, air and waste). Moreover, other scholars (Wang, 2014) have formulated sustainable development strategies for social equity, economic growth, institutional capacity, as well as environmental protection. From the analysis method, scholars complied with conventional analytical methods (e.g., entropy method and coupled coordinated model) to determine the level of sustainable development in temporal series (Li et al., 2012; Nyerges et al., 2014), as well as adopting spatial series (e.g., spatial classification, spatial autocorrelation and spatial center of gravity transfer) (Khlobystov, 2009; Boggia et al., 2018; Yang and Fan, 2019). For the research area, most of the researches covering the global scale (e.g., the world and the country) (Asomani-Boateng, 2011), the analysis falling to the micro-scale is relatively rare. From the perspective of influencing factors, it gradually changes from a single factor to comprehensive factors (Lele, 1991), and the combination of qualitative research and quantitative evaluation is increasing (Jabareen, 2008; Lu et al., 2019). In contrast, domestic scholars largely optimized relevant theories and various assessment index systems. The research content mostly consists of ecological footprint (Chen et al., 2008), environmental protection (Wang et al., 2018), urbanization (Tang et al., 2018; Ma and Ai, 2019), strategic research and research progress (Zhang et al., 2009). The research method stresses the combination of time and space (Guan, 2007; Zhang et al., 2013; Zhao et al., 2018; Liu et al., 2019). In brief, the mentioned research has achieved some progress and laid decision-making basis, whereas the research results of regional sustainable development exhibit obvious differences for the diverse research content, complex research objects, different assessment dimensions, and inadequate coverage of the indicator system. In other words, a question is raised that whether the current indicator system complies with China's current sustainable development process. It is noteworthy that how to assess China's sustainable development level under national conditions.

To be specific, in the present study, we address the following research questions:

(1) How to use a few indicators to reflect China's level of sustainable development, and how to determine the mentioned indicators based on China's national conditions?

(2) What is the spatial characteristic of sustainability assessment at city level in China?

(3) What are the factors that lead to the mentioned spatial differentiation?

Based on the listed research questions, the following research objectives are proposed:

(1) Complying with China's novel development concept (e.g., innovation, coordination, greenness, openness and sharing), given the practical situation of China's development, an indicator system is built from five aspects, i.e., scientific and technological innovation, coordinated development level, ecological environmental quality, opening up development, as well as social welfare development.

(2) To clarify the spatial characteristics of sustainability assessment at city level with the analytical method combined spatial classification, spatial correlation and coupling coordination degree model.

(3) To elucidate the factors by combining quantitative and qualitative approaches.

2 Index System, Data Sources and Research Methods

2.1 Assessment theory, index system and data source

The CSDIS was jointly developed by the Earth Institute of Columbia University and the China International Economic Exchange Center, consisting of economic development, social livelihood, resources and environment, consumption and emissions, as well as environmental governance. Obviously, though the indicator system was developed for economy and society, it basically stresses the ecological environment. For China's current national conditions, sustainable development should consider all aspects of development (e.g., 'scientific and technological innovation, coordinated development, ecological environmental quality, opening up development, and social welfare development'), instead of blindly pursuing the governance of the ecological environment. Thus, this study was consistent with the connotation, characteristics and significance of sustainable development (Fig. 1), contacted with the China's national conditions for sustainable development; besides, abiding by the principles of systemic, comprehensive and sustainable, and referencing other relevant literature (Jiang et al., 2017; Liu et al., 2017; Lyu et al., 2019), the present study built a comprehensive index

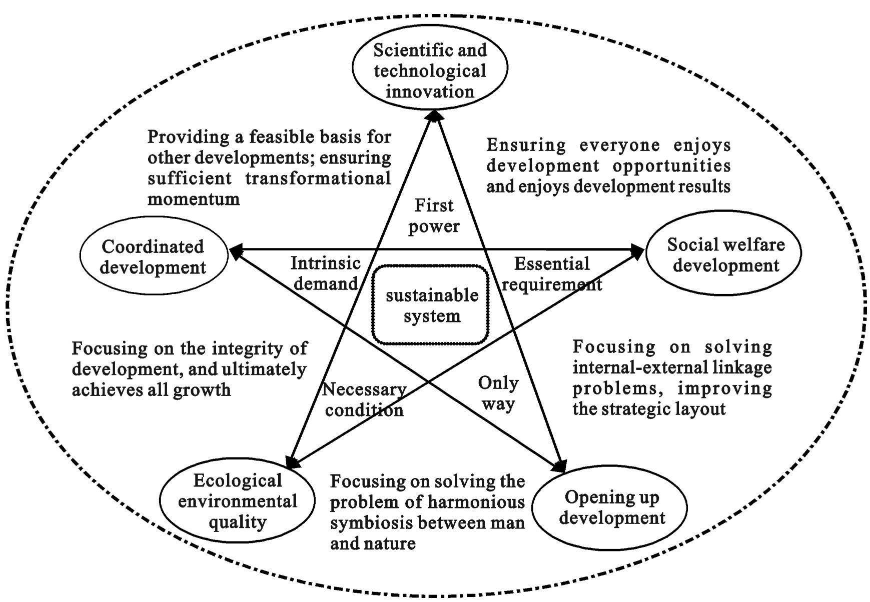

Fig. 1 The transmission mechanism of comprehensive sustainable development level in China

Table 1 Construction of indicator system

Criteria layer	Indicator layer	Nature	Weight (Indicator)	Weight (Subsystem)
Scientific and technological innovation	Scientific research expenditures/ local general public budget expenditures (x_1)	+	0.043	0.219
	Patent applications/GDP (x_2)	+	0.044	
	Number of personnel (x_3)	+	0.030	
	R&D internal expenditures (x_4)	+	0.028	
	Patent applications (x_5)	+	0.039	
	Patent grants (x_6)	+	0.035	
Coordinated development	The per capita disposable income of urban-rural residents (x_7)	–	0.017	0.196
	The per capita consumption expenditure of urban-rural residents (x_8)	–	0.031	
	Second and third industry added value/GDP (x_9)	+	0.049	
	The coordination degree index (x_{10})	+	0.099	
Ecological environmental quality	The green coverage area of the built-up area of the municipal district (x_{11})	+	0.031	0.204
	The industrial wastewater discharge (x_{12})	–	0.017	
	Industrial sulfur dioxide emissions (x_{13})	–	0.042	
	Industrial smoke discharge (x_{14})	–	0.029	
	The sewage treatment plant centralized treatment rate (x_{15})	+	0.039	
	The domestic garbage harmless treatment rate (x_{16})	+	0.046	
Opening up development	the total retail sales of social consumer goods (x_{17})	+	0.040	0.190
	The actual amount of foreign investment in the year (x_{18})	+	0.029	
	The full import of goods (x_{19})	+	0.033	
	The total export of goods (x_{20})	+	0.033	
	The inbound tourists (x_{21})	+	0.019	
	The foreign exchange income of international tourism (x_{22})	+	0.036	
Social welfare development	The number of college students owed by per 10000 people (x_{23})	+	0.052	0.191
	The number of public libraries owed by per 100 people (x_{24})	+	0.032	
	The number of beds owned by per 10000 people (x_{25})	+	0.043	
	The bus per owed by 10000 people (x_{26})	+	0.021	
	The per capita urban road area (x_{27})	+	0.025	
	The per capita disposable income of rural residents (x_{28})	+	0.018	

Note: '+' means that the indicator is a positive indicator, and '–'means that the indicator is a negative indicator

system (Table 1) based on CSDIS. Lastly, by building the indicator system, the mean square error decision method was adopted to calculate the weight of respective indicator (Table 1); subsequently, the whole sustainable development level was reflected.

The data primarily originated from the *China Urban Statistical Yearbook*, *China Environmental Statistics Yearbook* in 2008 and 2018, and some indicators were derived from the National Economic Development Statistical Bulletin or the government work report. To ensure the comprehensiveness of the indicator system, some indicators comply with the previous results of geographers; for instance, the coordinated index referenced the measured results of cities at the prefecture level and above (Pan et al., 2016). Moreover, it is more difficult to obtain indicators in the northwest regions of China; some were obtained via the *China Urban Statistical Yearbook*, whereas most of the indicators refer to regional statistical yearbooks or official statistics. In significantly few regions, the indicators were being lost, so the indicators from adjacent years were calculated with the growth rate method. Lastly, since the data are available and stable, the present study identified 344 research units.

2.2 Research methods

2.2.1 Mean square error decision method

The mean square error decision method refers to a type of weighting method following the principle of information entropy. It is one of the common ways of objective weighting method and exhibits robust objectivity, capable of effectively avoiding the subjectivity and difference brought by subjective factors (Mishra et al., 2002). The specific steps are presented below: at first, the data are subjected to an inferior standardization process to eliminate dimensions and magnitudes; subsequently, the mean of the variable, the mean square error and the weight of the calculation can be achieved; lastly, the comprehensive assessment value is calculated by a linear weighted regression model.

2.2.2 Natural Breaks (Jenks) Classification Method

Natural Breaks (Jenks) refers to a statistical method for ranking and classification abiding by the mathematical distribution law, capable of maximizing the difference between different classes (Mu et al., 2014). It is established as the default classification method with Arc GIS software, since it can measure the difference by the variance of statistical data compared with the classification methods (e.g., Defined Interval, Equal Interval, Quartile Classification, Standard Deviation, Geometry Interval, *etc*.), clearly find the breakage of the data and then achieve the results of the minimal difference in the group and the extensive difference between the groups. Accordingly, the present study adopted this method to classify the spatial differentiation pattern of comprehensive sustainable development levels at the city level in the new era.

2.2.3 Exploratory Spatial Data Analysis

Exploratory Spatial Data Analysis acts as a method to reveal the spatial agglomeration of each research unit by visualizing the data. It consists of global and local spatial autocorrelation. Overall, the global spatial autocorrelation is expressed by the Moran' I index, ranging from –1 to 1. It therefore indicates a negative correlation, no correlation and positive correlation if less than 0, equal to 0 and greater than 0 (Pu et al., 2005). It yields:

$$I = \frac{w_{ij}\sum_{i=1}^{n}\left(y_i - \overline{y}\right)\sum_{j=1}^{n}\left(y_j - \overline{y}\right)}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}} \quad (1)$$

where I denotes the Moran index; y_i is the observation of region i; w_{ij} is the adjacency relationship between regions i and j; S^2 is the variance of the observations for all regions; $\overline{y}$ represents the average of the observed values for all regions.

2.2.4 Coupling coordination model

The concept of capacity coupling in physics originally referred to the interaction between the two systems, and it is now extended to the five systems. It yields:

$$C_j = 5\left\{\left(f_j \times g_j \times h_j \times s_j \times t_j\right) / \left(f_j + g_j + h_j + s_j + t_j\right)^5\right\}^{\frac{1}{5}} \quad (2)$$

where C_j denotes the degree of coupling of subsystem i, ranging from 0 and 1; f_j, g_j, h_j, s_j and t_j represent the comprehensive development indexes of the five subsystems in the city. Referencing the existing literature, the coupling degree C is divided into 4 types, i.e., low-level coupling stage, the comparable stage, the mutual running-in stage, and the high-level coupling stage.

Moreover, the coupling coordination degree model is used to better assess the coordination level of the five subsystems under different coupling strengths. It yields:

$$D = \sqrt{C \times T}\,, \quad T = \sqrt{\left(\alpha f_j \times \beta g_j \times \lambda h_j \times \mu s_j \times \gamma t_j\right)} \quad (3)$$

where D denotes the coupling coordination degree, ranging from 0 and 1; C represents the coupling degree; T is the comprehensive coordination index of the five subsystems; α, β, λ, μ, γ are the undetermined coefficients, considered equivalent in the present study, so they take 0.2. To maintain unity, D is split into four types (Wang et al., 2014; He et al., 2017).

3 Results and Analysis

The Hu line refers to a comparison line proposed by Chinese geographer Mr. Hu Huanyong in 1935 to divide China's population density; it underpins the research of population and economy in China. In summary, the Hu line reveals the spatial heterogeneity of China's population distribution, as well as more importantly reflecting the highly spatial coupling of China's population under natural geographic background. After long exploration and conclusion, it has also turned into the dividing line of the current level of urbanization or the boundary of ecological environment for China. As the most populous developing country worldwide, China exhibits limited per capita resources. Thus, it is imperative to insist on controlling population, conserving resources, and protecting the environment in an important strategic position. On that basis, to delve into China's sustainable distribution pattern, the Hu line was introduced into the analysis of the results, and the in-depth relationship between the spatial pattern of sustainable development level and the Hu line was discussed.

3.1 Overall spatial differentiation pattern

Based on the mentioned concepts and methods, the Natural Breaks (Jenks) were adopted, and the spatial pattern was split into five types, i.e., lower-value units, low-value units, middle-value units, high-value units and higher-value units from low to high. This method refers to classifying the indicators of each system, capable of achieving the most appropriate grouping and maximizing the difference between the various types. For instance, to achieve comprehensive development system, the high-value units represent the China's sustainable development level is in a good state of development, while the low-value units suggest its development in a weak state. The relevant results are illustrated in Fig. 2.

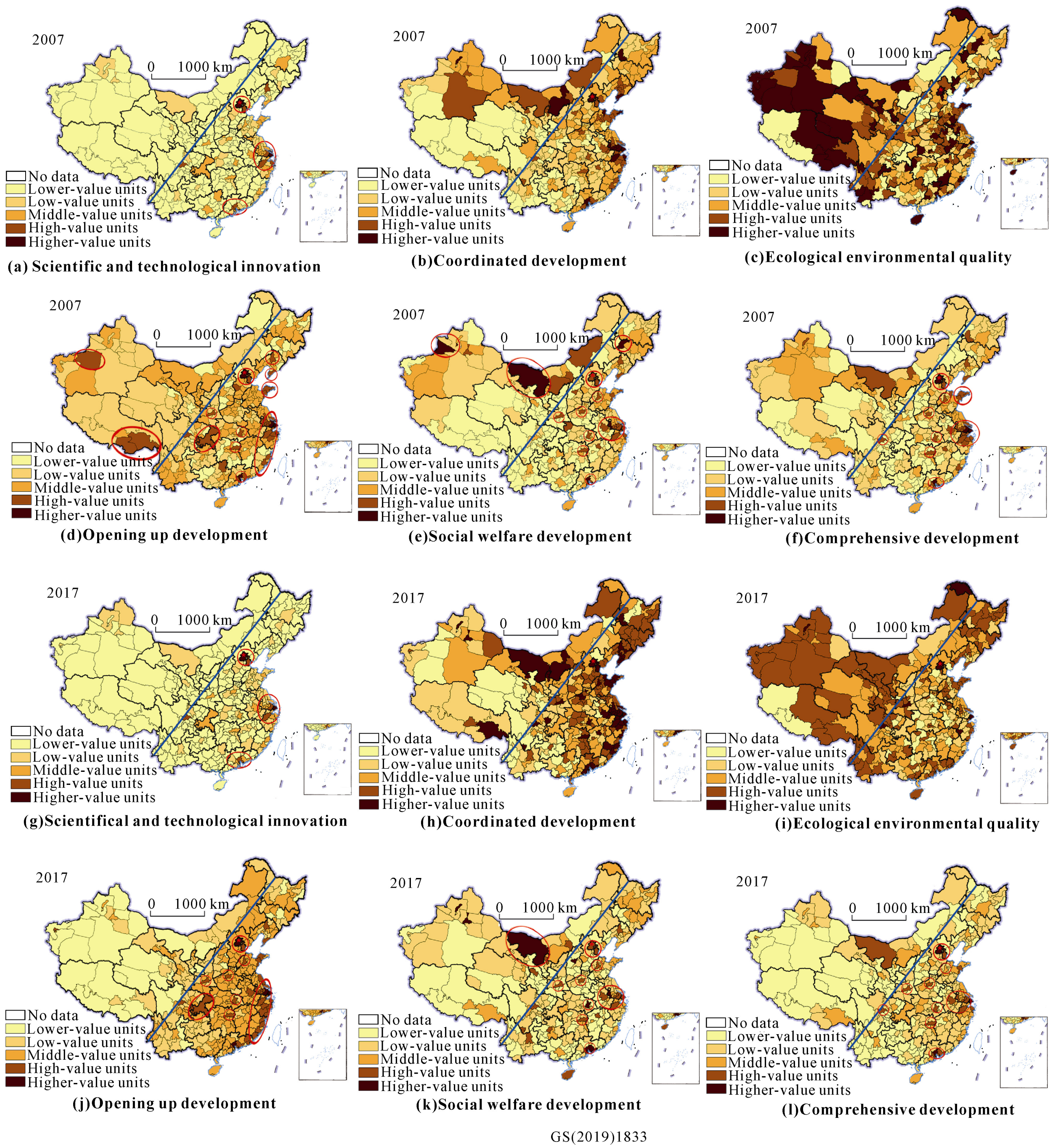

Fig. 2 Spatial distribution pattern of sustainability at city level in China in 2007 and 2017

Fig. 2 suggests that the spatial pattern of the sustainable development level exhibits an obvious distribution characteristic from 2007 to 2017. To be specific, the spatial pattern of higher-value and high-value units displays unique units in western China, while the other units are scattered from the core areas of Beijing-Tianjin-Hebei Region. Therefore, an objective expectation is confirmed that the core city has played a leading role. The spatial pattern of the middle-value units is significantly clear. On the one hand, it formed a small group in the northwest and northeast regions in China, but it gradually disappeared from 2007 to 2017. On the other hand, it formed a strip shape from north to south in the coastal region, the middle of the Pearl River Delta Region, the Yangtze River Delta Region, as well as the Jianghuai Urban Agglomeration. The number of gathered areas is dramatically increasing, indicating the objective fact that the overall sustainable development level of the eastern coastal China is high. The phenomenon of fragmentation distribution in the low-value units is of higher significance. It is not only distributed in Xinjiang, Inner Mongolia and Tibet, but also vastly distributed in central China, and the agglomeration has improved. Moreover, obviously, the low-value units gradually broke through the Hu Line from 2007 to 2017, reflecting the development level of southwest China is lower. On the whole, the development level is imbalance, and the regional gap remains relatively distinct in eastern China, central China and western China. Moreover, the difference between the southeast and northwest is divided by the Hu line, exhibiting numerous similarities to the existing research results.

From the comparison of the five subsystems, the distribution pattern is similar to the general development level, but the degree of concentration is different. It is noteworthy that the number of higher-value and high-value units in the scientific and technological innovation subsystem has nearly remained unchanged from 2007 to 2017, whereas they have been noticeably down-regulated, and the degree of agglomeration has declined compared with the overall. To be specific, it is only clustered in the core of the Beijing-Tianjin-Hebei Region, Yangtze River Delta Region and Pearl River Delta Region, confirming the fact that the eastern China is the leading area of scientific and technological innovation. The middle-value units have also been weakened, distributed in central China and the outside of Inner Mongolia and Xinjiang. The pattern lastly formed a strip shape in the coastal areas of Jiangsu, Shandong, Zhejiang, Fujian and Guangdong, the concentration of low-value units has expanded and taken up the western China, northeast China and south of the Yangtze River.

The number of higher-value and high-value units of the coordinated development subsystem surged from 2007 to 2017, which is located in outside of Inner Mongolia and Tibet, largely distributed along the Jing-Guang Axis and the coastal regions respectively. Moreover, the pattern of higher-value and high-value units forms a continuous cluster pattern which breaks the separation of the Hu line, then extends to the northwest China. The concentration of low-value and middle-value units has declined in Tibet and Xinjiang, thereby confirming the practical problems faced by the coordination of regional development, mobilizing the initiative and creativity of various regions, and narrowing the local gap. For this reason, coordination and advancement remain suffering.

The spatial pattern of ecological environmental quality subsystem is different from the whole and other subsystem from 2007 to 2017. The higher-value and high-value units formed two groups, one is basically concentrated in western China and extends to southwest China, the other is primarily distributed in northeast China. Due to the mountainous and the forest regions in west and northeast China, it exhibits relatively high ecological development level. The middle-value and low-value units are concentrated in Hubei, Hunan, Jiangxi and other provinces. On the whole, under the guidance of the 'ecological greening' strategy, the level of ecological civilization construction in the provinces has been elevated remarkably, and the environmental conditions have been optimized, whereas the development level of some regions still needs to be further improved.

The spatial pattern of opening up development subsystem is approximately identical to the comprehensive development, but it is different from the concentration. To be specific, with the Hu Line as the separation line, its spatial pattern covers almost the entire northeast China and central China, while the western China still shows low development level, which indicated that western China still faces multiple pressures to brake the imbalance. From a realistic perspective, because China adopts an open policy that is gradually promoted from the coastal to the inland, and forms a gradient difference in preferential policies, it has caused a huge gap between western China and eastern coastal China.

The spatial pattern of the social welfare development subsystem complies with the overall development level, whereas the overall concentration has been declining from 2007 to 2017. To be specific, the higher-value and high-value units are distributed in the core cities of central China and eastern China, indicating a positive economic growth and promotion effect. The middle-value units are distributed in two major groups; one has been the northern of Tianshan Urban Agglomeration and Hubaoeyu Urban Agglomeration, the other has been clustered in the Shandong Peninsula Urban Agglomeration and the middle areas of the Yangtze River Region. The number of low-value and lower-value units has declined, largely concentrated in Tibet, Xinjiang, which reveals the adverse effects exerted by the weak regional economic strength and low level of per capita construction and sharing.

3.2 Overall spatial correlation characteristics

To delve into the spatial correlation characteristics of the sustainable development level at city level, the spatial autocorrelation tool of Geo Da software is used to calculate the Moran's *I* index and *P* value, and the local spatial autocorrelation features are visually analyzed. To be specific, the weights of each system can be divided into four quadrants, falling into four different types, i.e., the significant HH areas, significant LL areas, significant HL areas, as well as significant LH areas. Lastly, by judging the number and spatial characteristics of the four types of areas, we can determine the spatial agglomeration characteristics in China. The mentioned results are presented in Fig. 3 and Table 2.

It can be seen from Fig. 3 and Table 2 that though the Moran' *I* index of the overall is declined from 0.404 to 0.399, they both pass the significance test with *P* equal to 0.001, which indicates that there is a positive correlation phenomenon in China. To be specific, its associated features are basically dominated by significant HH areas and significant LL areas. The significant HH areas are primarily distributed in the first step terrain, and the Yangtze River Delta Region has the most massive concentration range. The significant LL areas are extensively distributed in Qinghai, Tibet, Xinjiang, *etc.*, which breaks through the Hu Line and extends to Yunnan and Guizhou from 2007 to 2017. The significant HL areas are only Lhasa and Ningzhi, and significant LH areas are Shaoguan, Xuancheng and Zhangjiakou in 2017, demonstrating that the polarization effect of local development in western China remains serious.

In contrast, the significant HH areas of the scientific and technological innovation subsystem are consistent with the overall pattern, but the number of significant LL areas increases significantly from 2007 to 2017. The spatial pattern breaks through the Hu Line and gradually extends to the northeast areas, lastly formed an 'inverted *S*' barrier state.

The number of significant HH areas of the coordinated development subsystem surged, they exhibit the distribution in the core of Beijing-Tianjin-Hebei Region, Yangtze River Delta Region, Pearl River Delta Region, Ha-Chang Urban Agglomeration and Central Plains Urban Agglomeration. The significant LL areas are distributed in the northwest mountainous region, and the spatial pattern of the southwest China breaks through the Hu Line to central China in 2007 and 2017, which forms a vertical line perpendicular to the Hu Line; it is therefore reflected that the sustainable development of China from a novel perspective.

The significant HH areas of the ecological environmental quality subsystem form large groups in the eastern China, but they are eventually distributed in a small cluster around the core in eastern China in 2017, thereby forming a block around the civic group on the northern slope of the Tianshan Urban Agglomeration. Though significant LL areas are significantly reduced, they exhibit the only distribution in Yunnan and Tibet.

The significant HH areas in the opening up development subsystem have been expanded, and they are distributed in the core of Shandong Peninsula Urban Agglomeration. The significant LL areas are distributed two groups; one group is vast in eastern China and expanded from 2007 to 2017, and the other is in the core of Liaozhong Urban Agglomeration and Ha-Chang Urban Agglomeration.

The significant HH areas of the social welfare development subsystem are clustered in the core of Pearl River Delta Region, Yangtze River Delta Region and the Hubaoeyu Urban Agglomeration. Besides, the significant LL areas are largely distributed in the northwest China, and the number of them has declined in central China from 2007 to 2017.

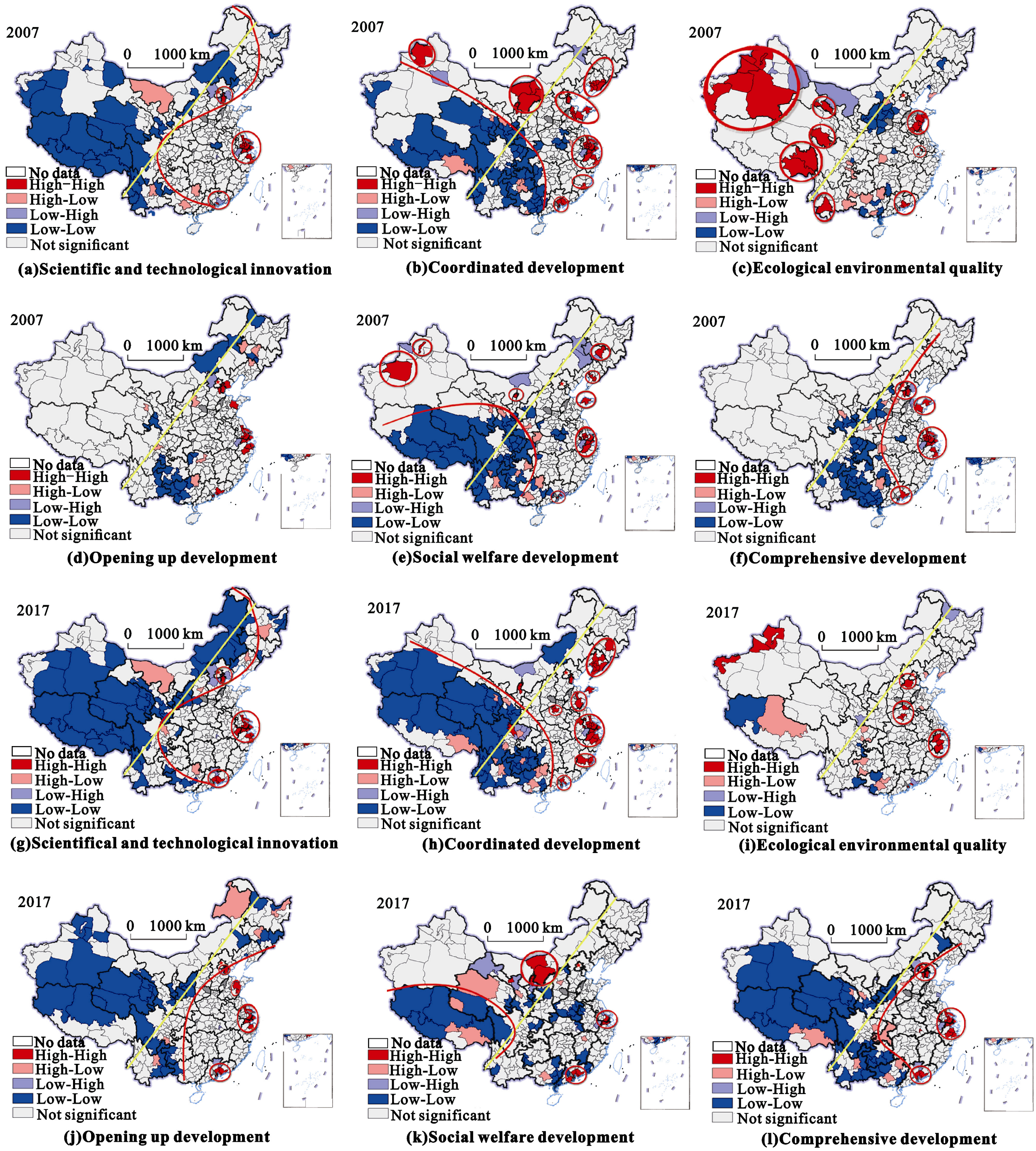

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Fig. 3 Spatial agglomeration pattern of sustainability at city level in China in 2007 and 2017

Obviously, the spatial agglomeration of the significant HL and LH areas of each subsystem is generally less. Their number is less and basically distributed in southwest China, thereby revealing the coexistence of local polarization and collapse effects in underdeveloped regions.

3.3 Internal coupling coordinated state analysis

Given the mentioned coupling coordinated degree model, the coupling degree of five subsystems is calculated and

Table 2 Analysis of Moran's *I* scatter plot of sustainability at city level in China in 2007 and 2017

Index	Comprehensive development		Scientific and technological innovation		Coordinated development		Ecological environmental quality		Opening up development		Social welfare development	
	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017
Moran' *I*	0.404	0.399	0.231	0.375	0.460	0.331	0.148	0.094	0.274	0.338	0.261	0.269
P value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.049	0.001	0.001	0.001	0.001
Z value	11.595	11.594	7.373	11.126	12.704	9.808	4.131	6.284	7.811	10.319	7.382	7.703

divided into four types, i.e., high-coupling units, middle-coupling units, lower-coupling units and low-coupling units (Fig. 4).

Fig. 4 suggests that the overall spatial pattern of coupling degree is clearer and more intuitive in 2017 year. To be specific, though the range of high-coupling units has been narrowed, they are still primarily concentrated in the Beijing-Tianjin-Hebei Region, Shandong Peninsula Urban Agglomeration, Yangtze River Delta Region and Pearl River Delta Region, some of which are scattered in the Central Plains Economic Region. The concentration of middle-coupling units has been more significantly elevated; they exhibit the distribution in a patchy region throughout central China, thereby breaking through the Hu Line and extending to northwest China. The low-coupling units remain extensively distributed in the western agglomeration areas formed by Tibet and Xinjiang, and the other refers to a small-scale concentrated region in northeast China. The overall spatial characteristics comply with scientific and technological innovation subsystem, coordinated development subsystem and opening up development subsystem, which act as the dominant factors affecting the differences in sustainable development. However, the ecological environmental quality subsystem and the social welfare development subsystem slightly impact the degree of coupling pattern. On the whole, the spatial distribution of coupling degree exhibits visible hierarchical and stepwise distribution characteristics. First, the high-coupling units are in the core of eastern coast China; second, it forms a vast region of middle-coupling to low-coupling areas in the second and third step terrains. As revealed from the existing state of sustainable development in China, it will take some time to deepen the interaction and linkage mechanism between the five subsystems to be balanced.

To comprehensively verify whether the sustainable development level is orderly in China, it is required to consider the interactive intensity and spatial correlation between the five subsystems, and its coordinated state should be analyzed. Accordingly, through the comprehensive assessment of the coupling coordinated degree model, it was reported that the spatial coordinated difference between the five subsystems is significant (Fig. 5).

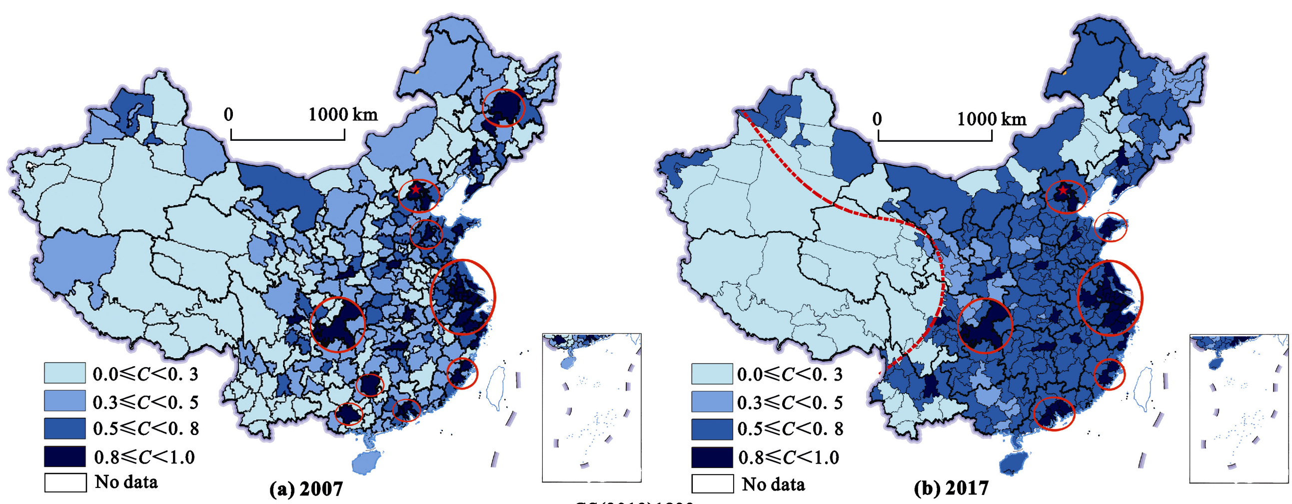

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Fig. 4 Spatial agglomeration pattern of coupling degree at city level in China in 2007 and 2017

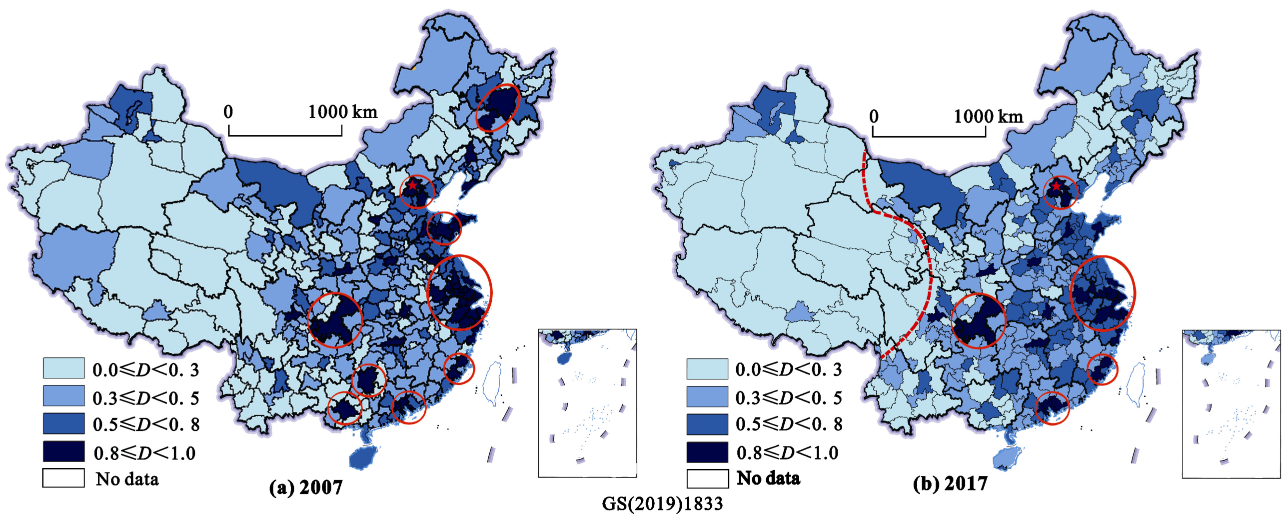

Fig. 5 Spatial agglomeration pattern of coordinating degree at city level in China in 2007 and 2017

Fig. 5 indicates the consistent spatial coordination and coupling degree of the coupling coordinated degree of the five subsystems. To be specific, the spatial pattern of high-coordinated-coupling units exhibit the distribution in the core of Beijing-Tianjin-Hebei Region, Yangtze River Delta Region and Pearl River Delta Region, whereas its coverage areas have been narrowed as compared with the pattern of high-coupling units. The spatial pattern of middle-coordinated-coupling units tends to be dissipated and disrupted by the low-coordinated-coupling units, whereas the regional difference characteristics are preserved. The spatial pattern of low-coordinated-coupling units in western China continuously exhibit a low degree of coordination, and its coverage areas have expanded compared with those in 2007; then, it tends to be dense and centralized. For the overall pattern, the subsystem of scientific and technological innovation, coordinated development and opening up development continue to be dominant factors, the subsystem of ecological environmental quality and social welfare development subsystem slightly impact their constraints. To a certain extent, the spatial pattern reveals that with the continuous development of various factors, the cities in east coastal China tend to be highly coordinated, self-organizing and self-regulating state, whereas the overall pattern in China remains unbalanced, and the task remains long-lasting.

3.4 Analysis of factors

The Geographic Detector is capable of accurately detecting the geographic spatial differentiation, acting as a novel statistical method to reveal its driving factors. Thus, the present study introduces the spatial detector method to analyze the factors of China's sustainable development level and further analyze the interaction of factors. Since the data are available and stable, per capita GDP (M_1) and industrial added value (M_2) are taken to reflect economic strength; secondary and tertiary industry employees/overall employees (M_3) and urbanization rate (M_4) are adopted to reflect the impact of non-agrochemical process; choose the Alibaba e-commerce index (M_5) and the number of Internet users (M_6) to reflect the improvement of the level of information; select the administrative area (M_7) and elevation (M_8) to reveal the role of topography. Abiding by the principle of geographic detectors, the factors are detected. The results are shown in Table 3. The order of factors is $M_1 > M_2 > M_4 > M_3 > M_6 > M_5 > M_7 > M_8$. Based on the analysis of a single impact factor, the interaction

Table 3 Detection of factors of sustainable development level in China

Factors	q statistic	P value
Per capita GDP (M_1)	0.852	0.000
Industrial added value (M_2)	0.826	0.000
Urbanization rate (M_4)	0.813	0.000
Secondary and tertiary industry employees / overall employees (M_3)	0.645	0.000
The number of Internet users (M_6)	0.603	0.000
The Alibaba e-commerce index (M_5)	0.596	0.000
The administrative area(M_7)	0.526	0.000
Elevation (M_8)	0.525	0.000

Table 4 Factors' interaction of sustainable development level in China

	M_1	M_2	M_4	M_3	M_8	M_5	M_7	M_6
M_1	0.852							
M_2	0.900	0.826						
M_4	0.877	0.860	0.813					
M_3	0.914	0.911	0.926	0.645				
M_8	0.884	0.883	0.898	0.650	0.525			
M_5	0.896	0.896	0.910	0.652	0.599	0.596		
M_7	0.872	0.862	0.825	0.881	0.836	0.859	0.526	
M_6	0.875	0.862	0.828	0.903	0.868	0.885	0.611	0.603

between the indicators is continuously calculated, and the results are listed in Table 4. Given the results of Geographic Detector, combined with the spatial differentiation characteristics of China's sustainable development level, the analysis of factors is largely performed from the following aspects.

3.4.1 Strong support for economic strength

Table 3 and 4 suggest that the economic strength represented by per capita GDP and industrial added value most effectively interprets China's sustainable development level, and the interaction between the two and the urbanization rate, employees in the secondary and tertiary industries/overall employees and other indicators reflecting the non-agricultural process is robust, fully demonstrating that China's sustainable development level is significantly supported by economic strength. For spatial pattern, the sustainable development in western China is relatively weak, whereas the resources investment and the economic development still exhibit a prominent situation in the core cities of central China and eastern China. Obviously, under the guidance of the some strategies (e.g., The Great Western Development Strategy), the core cities in the western China have experienced rapid development, whereas its development speed remains difficult to compete with the cities in central China and eastern China, suggesting that this region still lacks the internal driving force of economic development. Moreover, the limitations of the terrain, the lack of vitality of economic development, and the intrinsic support of population concentration make its overall development level relatively lag, this also confirms the objective fact that the level of regional sustainable development in western China is relatively backward.

3.4.2 Pulling support for the non-agricultural process

Table 3 and 4 suggest that the urbanization rate exhibits a strong explanatory power on China's comprehensive level of sustainable development, and its interaction with the secondary and tertiary industries employees/overall employees also indicates that the process is obvious, thereby demonstrating the impact of the accelerated non-agricultural process on China's comprehensive level of sustainable development. From a practical perspective, under the impact of the non-agricultural process, the industrial structure in eastern China has gradually evolved to a higher level, and the level of urbanization has been further improved. Accordingly, the spatial pattern of China's sustainable development level has a small clustering scope in the Yangtze River Delta and Pearl River Delta regions. The urbanization process in central China gradually accelerating, the economic strength remains strong, and the positive diffusion effect in eastern China has continuously improved its overall strength. The slow urbanization process in western China is basically revealed in the slow development of the core area of the urban agglomeration, and the low level of industrial structure in the economically underdeveloped regions, thereby exhibiting the continuous distribution of low value in western China.

3.4.3 The vitality support of the information level

Table 3 and 4 suggest that Internet users and the Alibaba e-commerce index moderately explain China's sustainable development level, whereas they are significantly related to per capita GDP, industrial added value and urbanization rate, thereby demonstrating the vitality support of the level of information to China's sustainable development level. For the reality, under the guidance of the information strategy, the improvement of the level of urban modernization represented by Internet users and the Alibaba E-commerce Index has gradually become the theme of sustainable development in the new era. For the spatial distribution pattern, the information level of the eastern China, especially the Pearl River Delta, the Yangtze River Delta, and the Beijing-Tianjin-Hebei regions have been constantly at the forefront of modernization. Though the level of information in central China and western China has improved, they still lack the intrinsic driving force for the level of information. Moreover, as impacted by the lack of vitality in economic development and the weak internal support for population aggregation, the overall level of information in the western China has been subject to serious challenges.

3.4.4 Basic influence of city topography and geomorphology

According to Table 3 and 4, though the administrative area and elevation are not strong in interpretation of China's sustainable development level, the interaction with the secondary and tertiary industries employees/overall employees, the number of Internet users, per capita GDP, and industrial added value is strong. It can be known the cities in eastern China are primarily distributed in the plains and low hills on the first tier, its infrastructure investment is large and the investment environment is superior. Moreover, the advantages of opening up and productivity are given priority, so the overall urban sustainable development level is generally high, and the high sustainable development units are formed in the core areas of urbanization development, e.g., the Yangtze River Delta, the Pearl River Delta, and Beijing-Tianjin-Hebei. The central China spans the first and second steps, the terrain is a transitional feature, and the level of sustainable urban development is reflected by the diffusion effect of the eastern China to the western China. Thus, the conditions for sustainable urban development are relatively good, but due to constraints e.g., basic strength, industrial structure, and open environment, the overall strength is not high and is largely based on the priority development of urbanized core areas. The terrain of the western China is complex and diverse, and the population is sparse. Accordingly, the overall sustainable development strength of the city is not strong.

3.4.5 Active promotion of national policy guidance

After exerting continuous efforts over the past few years, China has gained world-renowned achievements in rolling out sustainable development, and has achieved effective results in ecological construction, environmental protection, and rational development and utilization of resources. For instance, the state's investment in ecological construction and environmental governance has surged, the energy consumption structure has been gradually optimized, the comprehensive control of water pollution in critical rivers has been deepened, breakthroughs have been made to prevent atmospheric pollution, and the level of comprehensive utilization of resources has been noticeably elevated. In other words, the mentioned are inseparable from the active guidance given by the Chinese government. However, by ensuring the steady development of the sustainable development of the eastern coastal China areas, the foreign economic development of the western China has been continuously boosted, the development capability of the western China tended to be enhanced, and the capability structure of the western China has been optimized. All in all, through active policy guidance and rational optimization of space organization, the western China will gradually achieve higher levels of modernization and better-quality sustainable development.

3.4.6 Path dependence and industrial transfer

In the sustainable agglomeration development of cities, several units exhibit similar location conditions in geographical space, as well as local cultural identity and institutional environment. For this reason, the urban sustainable development level is rooted in sophisticated regional social relations. In the spatial agglomeration pattern, the sustainable base of the core area in eastern coastal China has been effectively supported, the country's macroeconomic support is also strong, so the urban sustainable development level of eastern coastal China is in a healthy evolution. In the underdeveloped agglomeration pattern of the western China, sustainable development exhibit poor objective location conditions, the basic strength is weak, and the openness of local culture is relatively weak. Thus, most cities are in a self-cycle without a breakthrough, and the path-dependent development makes the weakly connected spatial pattern exist in a wide range. The central China is located in the transitional region of the national regional economy, its resource endowment and geographical location of sustainable development is relatively good, and its urban economic strength is also constantly increasing. Thus, there remains great fear in the improvement of the sustainable development of cities in the central China.

4 Discussion

Given the CSDIS concepts and new perspectives, the present study analyzed the spatial differentiation pattern of sustainability development level and its factors in China. As indicated from the results, the Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta Regions have a high level of sustainable development, the low-value units' boundary of low-value units breaks through the Hu Line. It therefore verifies the emerging situation of spatial differentiation under the new perspective and has positive significance for the short-board identification and problem summary in the current development process. However, it should be pointed out some problems as following.

(1) The spatial distribution pattern of China's comprehensive level of sustainable development is complex and changeable. Some studies (Zhang et al., 2019; Zhou et al., 2019) reported that the agricultural sustainable development index has shown a trend of fluctuations and declines, and then continued to rise in recent years, and then continues to decline. The High-high units are basically distributed in eastern China, and the low-low units are distributed in western China. The spatial characteristics of the environmental sustainable development level and economic development level exhibit a pattern of regional differences. In contrast, the present study not only found macroscopic pattern characteristics (e.g., the comprehensive level of sustainable development in the eastern coastal areas higher than those in the central and western regions), but also found prominent local characteristics of spatial distribution patterns at the city scale, especially the formation of a new dividing line instead of Hu Line separated. In other words, this helps delve into the uniqueness of the spatial differentiation of China's comprehensive level of sustainable development at a city scale.

(2) The present study lacks a comparative analysis of different levels of China's sustainable development. Compared with existing research (Zhang et al., 2009, Tang et al., 2018), it is reported that whether it complies with the sustainable development level in the perspective of a national province or in a city, the degree of differentiation at the micro-scale is different from the macro-scale. The different patterns reflect the spatial characteristics of increasing the complexity of sustainable development at different scales. Though the present study introduces Hu line for comparative analysis, it is of noticeable practical significance to elucidating the spatial differentiation pattern of China's sustainable development level. On the whole, limited by overall perspective and analytical difficulty, the spatial differentiation pattern of sustainable development levels in different provinces and Urban Agglomeration will be refined in the subsequent research. Moreover, the type of sustainable development level at the micro-scale will be elevated, and the spatial organization from a range of perspectives will be compared. On that basis, it is the next step to identify the critical regions for sustainable development and the gradient promotion region.

5 Conclusions

First, for the spatial distribution pattern, the overall spatial distribution characteristics are nearly identical to the existing research results, as primarily revealed in the mosaic distribution pattern and the contiguous agglomeration pattern of higher-value and high-value units. The point-like cascading phenomenon of higher-value and high-value units in the eastern China remains visible, largely distributed in some core urban areas in the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta Regions, and the spatial dominant type is remarkably obvious. The middle- and low-value units are spreading extensively in the central and western China, and the degree of agglomeration has increased from 2007 to 2017, reflecting the objective reality that China's sustainable development level in central China and western China remains weak. The distribution characteristics based on innovation, coordination, and sharing are clearer. The high-value agglomeration units basically appear in the core areas of the Yangtze River Delta and the Pearl River Delta. The high-value agglomeration units in southeast coastal area have been slightly promoted, whereas some low-value units have broken through the Hu line and been extended to the south. On the whole, the spatial distribution characteristics of China's sustainable development level are consistent with the results of existing studies, whereas the difference between the southeast and northwest split by the Hu line is not as clear as the existing studies.

Second, for spatial agglomeration characteristics, the overall spatial agglomeration characteristics comply with existing research results, and the spatial agglomeration of low-value and lower-value units has increased significantly from 2007 to 2017. The significant HH areas at the comprehensive level are still primarily distributed in the Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta Regions. The significant LL areas are largely distributed in the southwest region and break through the Hu line, forming a spatial separation similar to ‘L’, which is inconsistent with the existing research results. The level of innovation is remarkable. The significant LL areas of innovation level break through the Hu line to form a new block line of ‘inverted S’, and the scope of spatial agglomeration has been expanded; the spatial pattern of coordination level and opening level forms the spatial difference of ‘Northeast-Southwest’, as obviously suggested from the existing research results, which demonstrates the novel characteristics of the pattern of spatial correlation patterns of sustainable development levels. Overall, the agglomeration pattern of China’s sustainable development level has altered dramatically. The spatial agglomeration range of the significant LL areas has been expanded noticeably, and the agglomeration trend has been promoted remarkably. The overall agglomeration pattern is especially evident in the low-value agglomeration characteristics in the western China.

Third, for the characteristics of the internal spatial coupling degree, the degree of spatial coupling agglomeration has surged from 2007 to 2017, and the horizontal coupling type with high-coupling units was of higher significance, as dominated by the southeast coastal core urban agglomeration. Moreover, the spatial agglomeration characteristic of the low-coupling units in western China was highlighted, and the agglomeration trend was more obvious, basically manifested in the increase of numbers and continuous distribution in Inner Mongolia, Ningxia and other regions, thereby demonstrating the different stages of urban sustainable development in western and eastern China. To a certain extent, it can further reveal the differentiated development status of urban sustainable development in western and eastern China with different stages and many problems. In contrast, the spatial coupling coordination degree distribution pattern is similar to the spatial coupling degree feature, except that the spatial aggregation level of the respective stage of the former is lower than the spatial coupling degree characteristic, thereby also suggesting the novel pattern of sustainable development horizontal coupling coordination spatial pattern.

Lastly, by jointly conducting qualitative and quantitative analyses, a comprehensive analysis of the factors of China’s sustainable development level was performed. For quantitative analysis, the geographical detector analysis method was adopted to analyze the factors of China’s sustainable development level, suggesting that the factors are ranked from large to small as per capita GDP>industrial added value>urbanization rate>secondary and tertiary industry employees/overall employees>the number of Internet users>the Alibaba e-commerce index>the administrative area>elevation. It is therefore suggested that the internal factors are primarily supported by robust economic strength, pulling effect of the non-agricultural process, the vitality support of the information level and the basic support function of the topography and the like. From a qualitative analysis perspective, there is largely active guidance of national policies, path dependence and industrial transfer, to a certain extent, having impacted the improvement of sustainable development.

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