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Examining the Spatiotemporal Dynamics and Determinants of Land Urbanization in Prefecture-level Cities, China

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Abstract: Examining the spatiotemporal dynamics and determinants of land urbanization is critical for promoting healthy urban development and the rational use of land resources. Based on the dataset consisting of land use change data and selected factors in 2010 and 2020, this study used visual analysis to reveal the spatiotemporal dynamics of land urbanization across prefecture-level cities in China. Meanwhile, the driving forces underlying land urbanization were examined by using geographical detector technique. Following are the findings: 1) we find that there exist notable spatial variances in land urbanization across prefecture-level cities. Currently, the differentiation in land urbanization between the northern and southern cities is more pronounced than that between the coastal and inland cities, or between the eastern and western cities. Prefecture-level cities located in central and western China have experienced the most rapid growth in land urbanization. Conversely, the growth rate in northeastern China is the lowest, while the velocity in eastern China remains relatively stable. By using spatial autocorrelation analysis, this study reveals that the land urbanization level in prefecture-level cities has significant spatial agglomeration. 2) We further find that land urbanization in China is influenced by factors related to urban land supply and demand, and urban population growth, economic growth, land financial and political incentive have greater impact on land urbanization than other factors. 3) We also find that the impacts of determinants on China's land urbanization vary over time, the explanatory power of economic development increased, while the explanatory power of state forces declined. We argue that integrating the supply and demand factors of land urbanization can provide a more comprehensive understanding of the driving mechanisms underlying land urbanization in China and other transitional countries, and help decision-makers in these countries formulate more detailed and specific land urbanization policies.

Keywords: land urbanization; spatial pattern; influencing factor; geographical detector; China

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1 Introduction

The world continues to urbanize, with half of the world's population already living in urban areas, and this proportion is expected to reach 68% in 2050 (Liu et al., 2021; Guo et al., 2022; Yang et al., 2023). The rapid urbanization and the consequent huge demand for urban land have led to a rapid expansion of urban areas worldwide, especially in developing countries like China (Huang et al., 2020). China's urbanization is happening

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at an unprecedented rate and scale (Bai et al., 2014). The urbanization rate has climbed from 17.92% in 1978 to 65.22% in 2022, and the population in urban areas has increased by 730 million, or over 2.2 times the size of the whole population of the United States. Few places in the world have gone through such a rapid urbanization process as China (Lin and Yi, 2011). Land urbanization or urban land expansion refers to the land conversion from agricultural production to urban development (He et al., 2016; Zhang and Wang, 2018; Zhou et al., 2018; Wang et al., 2023). Since the concept was introduced by Chinese scholars in 2007 (Lu and Yao, 2007), it has been widely accepted. Although this rapid land urbanization has promoted China's economic and social development, it has also produced many adverse effects, such as the erosion of green space, the 'ghost town' phenomenon and the loss of arable land (Chen M X et al., 2016; Zhu et al., 2022). These problems pose severe challenges to China's food security and ecological security (Chen M X et al., 2016; Zhang and Wang, 2018). Since Brown questioned whether China has enough food to feed its population (Brown, 1995), a growing number of researchers have focused on China's rapid land urbanization (Lin, 2014; Ye and Wu, 2014; Lin et al., 2015; He et al., 2016; Shu et al., 2018).

Scholars have scrutinized the spatiotemporal dynamics of land urbanization at multiple scales (Deng et al., 2008; Chen et al., 2014; Gao et al., 2015; Chen J L et al., 2016; He et al., 2016; Li et al., 2018). According to studies, there are notable variations among regions in terms of the size, rate and pattern of urban expansion (Seto et al., 2011; Chen J L et al., 2016; Tong et al., 2022). By quantifying the rate and size of urban expansion at the global scale, Seto et al. (2011) found that India, China and Africa had the most rapid urban land expansion between 1970 and 2000. Urban expansion often comes at the cost of farmland loss, and studies show that urban expansion will lead to a 1.8%–2.4% reduction in global arable land by 2030, with Asia and Africa accounting for 80% of the global reduction in arable land (Bren d'Amour et al., 2017). There are significant regional differences in global urban land expansion patterns, with cities whose population growth outpaces urban land expansion concentrated in Africa, the Middle East, India, and the Americas, compared to cities whose urban land expansion outpaces population growth concentrated in China, East Asia, and Southeast Asia (Mahtta et al., 2022). In China, research on land urbanization has received widespread attention from scholars, mainly focusing on specific cities and regions, such as Nanjing (Chen J L et al., 2016), Guangzhou (Li et al., 2014), Suzhou (Zhang et al., 2017), Shenzhen (Chen et al., 2014), Jiangsu Province (Gao et al., 2014), and the Yangtze River Delta (Gao et al., 2015; Zhu et al., 2022). In recent years, scholars have explored the evolution pattern of China's land urbanization at the 1-km grid scale and county scale, and found that the high-value areas of land urbanization in China are consistently concentrated in the southeast of the Hu line, forming a growth hotspot around the urban agglomeration area (Liu et al., 2014; Gao et al., 2018). Overall, studies on land urbanization in China primarily concentrate on economically developed regions and cities with rapid urban land expansion, with little attention paid to land urbanization in economically underdeveloped regions. China is a vast country, and land urbanization varies from city to city. For example, the land urbanization level in Shenzhen reaches 97% in 2020, while that of Chifeng is less than 13% (derived from the China Resources and Environment Science and Data Center). If there is a lack of comparison and analysis of land urbanization levels between cities, then it is impossible to clarify the serious imbalance between cities. However, there has been a limited number of cross-city comparative studies on land urbanization thus far. Given the significant heterogeneity among Chinese cities, particularly in terms of development level and administrative level, it is essential to undertake comparative studies on land urbanization level across different cities.

Understanding the main determinants behind land urbanization is the crucial premise for designing more effective land use policies (Mustafa et al., 2018). The factors affecting land urbanization are complex. In recent years, these factors have been increasingly studied, with the most often utilized viewpoints focusing on the supply or demand framework (Brueckner and Fansler, 1983; Liu et al., 2005; McGrath, 2005; Deng et al., 2008; 2010; Lin and Yi, 2011; Ping, 2011; Jiang et al., 2012; He et al., 2016). From the perspective of demand, economic growth, urban population growth and industrialization constitute the key impact factors (Liu et al., 2005; Deng et al., 2008; 2010; Jiang et al., 2012; Mahtta et al., 2022). Rapid economic growth promotes urban land expansion (Liu et al., 2005). Deng et al. (2008;

2010) confirmed that economic growth had the most important effect on urban land expansion in China. By using meta-analysis, Seto et al. (2011) revealed that economic growth promoted urban expansion in China, but it had little impact on urban expansion in India and Africa. Jiang et al. (2012) also found a positive relationship between economic development and urban expansion. Urban population growth is an important factor influencing land urbanization (Liu et al., 2005; Gao et al., 2015). Just as urban population growth will increase the demand for urban land, thus affecting urban land expansion. For example, a 1% increase in urbanization raises the proportion of land converted to urban uses by 0.0876% (Ho and Lin, 2004). Taking more than 300 cities around the world as an example, Mahtta et al. (2022) found urban population growth to constitute the dominant factor in urban land expansion from 1970 to 2014. The industrialization has also been found to affect land urbanization. Deng et al. (2008), for instance, found that industrialization drove urban land expansion, but its role was relatively small compared with the direct impact of economic growth. Taking 658 cities in China as the research object, Lin et al. (2015) held that industrial growth was the core driver of land urbanization in China and that the larger the city size, the greater the role of industrialization in land urbanization. Similar results were obtained by Seto and Kaufmann (2003). In addition, the expansion of urban land has also been discovered to be influenced by population density (Ho and Lin, 2004; Huang et al., 2015; Shu et al., 2018). To meet residents' production and living needs, large-scale land development is usually required in areas with high population density (Shu et al., 2018). Ho and Lin (2004) found that the higher the population density, the greater the proportion of land used for urban uses in the locality. Other impact factors include wage level and fixed asset investment (Liu et al., 2005; Lin et al., 2015; Wu et al., 2021). For example, the wage level is a proxy for income, and the increase in income will induce an increase in the demand for housing and related facilities, which leads to urban land expansion (Colsaet et al., 2018). Fixed assets investment drives the demand for construction projects, induces development zone and project fevers, and facilitates urban land expansion (Lin et al., 2015; Wu et al., 2021).

However, attributing land urbanization to neoclassical demand-side factors fails to comprehensively summarize the driving factors of land urbanization. Supply-side factors also play important roles in land urbanization, especially in China (Ping, 2011). In China, the state is the only legal land provider. The important role of the government must be, therefore, considered in China's land urbanization process (He et al., 2016). Ping (2011) even argues that China's urban expansion has nothing to do with the demand for more urban population, but with land finance. Local governments increase income and attract domestic and foreign investment through land use right selling, resulting in a sharp expansion of urban land. The introduction of the tax-sharing reform (TSS) has further stimulated local governments' enthusiasm for urban development. This policy design is regarded by many urban researchers as one of the most important driving forces behind China's urban expansion (Lin, 2007). Since local officials have the authority to manage and regulate land supply, how they benefit from urban development is important for understanding factors in the supply-side of land urbanization (Ji et al., 2020; Tong et al., 2022). Some scholars confirm that fiscal decentralization and political centralization are the fundamental driving forces that shape China's land urbanization (He et al., 2016). In addition, accessibility factors are also important in affecting urban expansion. Distances to roads and other accessibility factors, for example, are frequently considered in urban land expansion studies (Aguayo et al., 2007). Jiang et al. (2012) also claimed that the distance from the provincial capitals was associated with urban land expansion in that county, and their study showed that counties closer to the provincial capital cities were more likely to cause urban land expansion. Policy factors, such as land management laws and regulations enacted by the state, also have impacts on urban land expansion (Liu et al., 2005; Jiang et al., 2012; Huang et al., 2015). Huang et al. (2015) suggest that under the strict supervision of the central government, China's land expansion showed a downward trend from 2005 to 2008. Further, elevation, precipitation, temperature and slope must also be considered, as these factors affect the expansibility of urban space in a region (Liu et al., 2005; Deng et al., 2008, 2010; Jiang et al., 2012). In general, the existing studies have effectively explored land urbanization's demand-side and supply-side factors. These studies enrich our understanding of the driving forces behind land urbanization in China, but there are also some obvious deficien-

cies in these studies, that is, whether land urbanization is attributed to demand-side factors or supply-side factors only tells part of the story and does not fully illuminate the factors influencing land urbanization in China. Therefore, this study will consider supply-side and demand-side factors affecting land urbanization to enrich the research case of land urbanization in China and scientifically understand its driving forces.

To address the gap identified above, our study examines the spatial and temporal dynamics of land urbanization in China's prefecture-level cities, which include cities in the economically developed eastern region and those in the less developed central and western regions. Moreover, since there are two concomitant processes of demand and supply factors in China's land urbanization process, we have developed a new systematic framework including the supply-demand factors of land urbanization to understand the land urbanization process in China. This framework can better reveal the influencing factors of land urbanization in China.

2 Materials and Methods

2.1 Analytical framework and initial selection of factors behind land urbanization

To gain a more comprehensive understanding of the drivers of land urbanization in China, we develop a new systematic framework that takes into account the supply and demand factors of land urbanization based on the monocentric urban model and the theory of local state corporatism (Fig. 1). From the point of view of urban land demand, the following variables are selected: population urbanization (PU), GDP per capita (PGDP), percentage of secondary industry (PSI) and population density (PD). From the point of view of urban land supply, land transfer income (LTI), foreign direct investment (FDI), the relief degree of land surface (RDLS) and administrative level (AL) are selected as basic variables. The following are the reasons for variable selection.

Urban population growth (denoted by population urbanization): on the one hand, the economic disparity between urban and rural regions pushes large-scale population movement from rural to urban areas. Cities, on the other hand, can provide more job opportunities than rural areas, attracting rural excess labor to cities, resulting in an increase in urban population and increased demand for homes and associated amenities, pushing urban land growth (Liu et al., 2005; Tan et al., 2005; Lin et al., 2015).

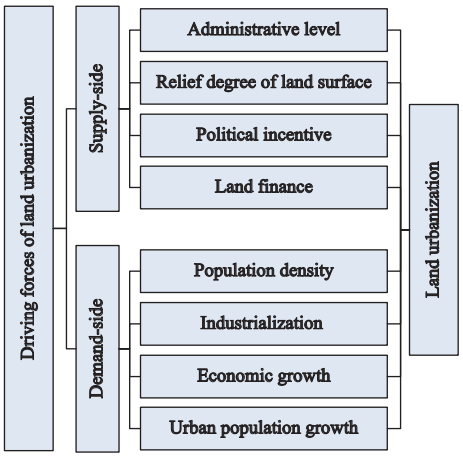

Fig. 1 An analytical framework designed to comprehend land urbanization in China

Economic growth (denoted by GDP per capita): with economic development, the average wage level is also rising synchronously, which lays the foundation for the increase of per capita living space and other infrastructure space, thus directly stimulating urban land expansion (Liu et al., 2005; Seto et al., 2011; Shu et al., 2018). Deng et al. (2010) also emphasize economic growth to constitute an important determinant in urban land expansion, identifying that a 10% growth in GDP raises urban land expansion by 4%.

Industrialization (denoted by the percentage of secondary industry): on the one hand, the secondary industry tends to be the industry with high demand and consumption of land resources, and its increased share will further promote land urbanization (Yang and Lu, 2021). On the other hand, industry also creates jobs and absorbs population, thus stimulating urban land expansion (Lin et al., 2015).

Population density: population density and urban population growth have similar effects on land urbanization. It is generally believed that more people mean more demand for land (Huang et al., 2015; Shu et al., 2018; Wu et al., 2021). Ho and Lin (Ho and Lin, 2004) also find a positive correlation between population density and urban land use; that is, the greater the population density, the larger the percentage of urban land usage.

Land finance (denoted by land transfer income): in 1994, the central government launched a new TSS. The fiscal relationship between the local and central govern-

ments was substantially altered with the implementation of the TSS. The central government's revenue share increased under the TSS, while the local government's share decreased. Facing huge financial distress, local governments are currently highly motivated to secure extra-budgetary revenue, with one of the principal sources of such revenue being the income from land transfers that is under the direct control of county and city governments. As a result, land acquisition and leasing of land use rights have emerged as the primary means by which local governments generate extra-budgetary revenue, which inevitably triggers China's unprecedented land urbanization (Lin and Yi, 2011; Ping, 2011; Gao et al., 2015; Huang et al., 2015; He et al., 2016).

Political incentive (denoted by actual utilized foreign direct investment): political centralization has resulted in local governments being incentivized to promote local economic growth. As China's economy is still an investment-driven model to a large extent, the competition for local economic growth can be viewed as a competition for investment, but domestic mutual investment is severely hampered by local protectionism. As a result, local governments have engaged in fierce competition to attract foreign investment as a means of promoting local economic growth, with the supply of land emerging as a crucial tool in this competition (Huang et al., 2015; He et al., 2016). Previous literature has also shown that FDI plays a vital role in urban land expansion (Liu et al., 2005; Jiang et al., 2012; Gao et al., 2014; Huang et al., 2015; Wei et al., 2017), as foreign investment requires land to build industrial sites, which leads to rapid urban expansion (Huang et al., 2015).

Relief degree of land surface (RDLS): RDLS is a vital index to describe geomorphology at the macro scale. It has been extensively employed to evaluate the influence of natural factors on regional development (Feng et al., 2008). Few studies have reported RDLS as a driving factor in determining land urbanization, but there have been many studies on the impacts of geophysical conditions related to RDLS on urban land expansion (Liu et al., 2005; Deng et al., 2008, 2010; Jiang et al., 2012; Mustafa et al., 2018). For example, slope has a significant impact on urban land expansion, and plain areas with low slopes are more conducive to urban land expansion (Liu et al., 2005).

Administrative level: there are multiple administrative levels in Chinese cities, such as ordinary prefecture-level cities, sub-provincial cities or provincial capitals and municipalities directly under the central government. Higher administrative levels usually correspond to greater decision-making and urban land development power (Gao et al., 2015; Huang et al., 2015; Li et al., 2015). Existing studies also indicate that urban land expansion aligns with the administrative level, meaning that the pace of urban expansion tends to be faster at higher administrative levels (Li et al., 2015; Wu et al., 2021).

2.2 Data

This study takes 287 prefecture-level cities in China as the research object (Fig. 2). Hong Kong, Macao and Taiwan Province of China were excluded from the scope of this study due to data access limitations. The urban and rural construction land data were derived from the China Resources and Environment Science and Data Center's (RESDC) 1 km resolution land use remote sensing monitoring data for 2010 and 2020 (https://www.resdc.cn/). Eight socio-economic and natural variables are selected as driving factors, among which PU, PSI, PGDP, PD, FDI, and AL were sourced from the China City Statistical Yearbook (NBSC, 2011a; 2021). The data for LTI were obtained from the China Land and Resources Statistical Yearbook (NBSC, 2011b; 2018). Limited by the availability of data, the LTI data in 2020 was replaced by data from 2017, which may have some impact on the research results, but not too much. The RDLS was collected from the RESDC. We collected data for 2010 and 2020. On the one hand, considering China's sixth and seventh national population censuses (conducted every ten years), the data in 2010 and 2020 are more comprehensive than in any other year. On the other hand, China's aggressive land urbanization reached its peak in 2010, and 2020 is the end of the National New Urbanization Plan (NNUP). It is imperative to explore and compare the driving force and its evolution trend over the particular two years, which is conducive to promoting the healthy urbanization of land in China.

2.3 Methods

(1) Land urbanization measurement

Previous empirical studies on land urbanization mainly measured the land urbanization level in a region

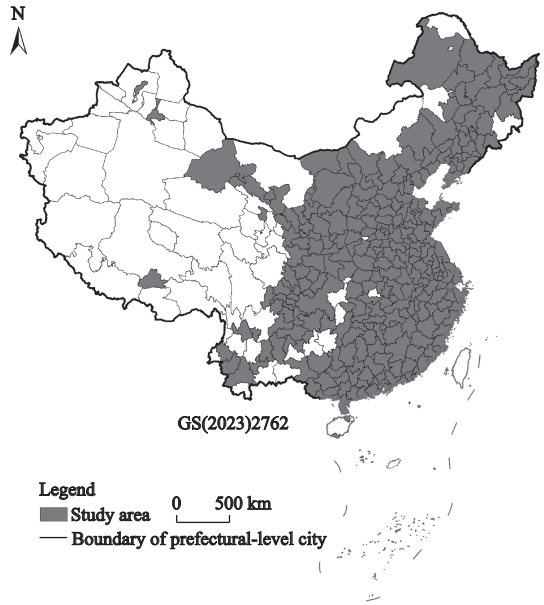

Fig. 2 Location of the prefecture-level cities, China

from two types of indicators: the change amount (rate) of urban built-up area and the proportion of urban built-up area or urban construction land area in the total area of the region. However, these two types of indicators for measuring land urbanization levels do not correspond with the population urbanization rate in geographical space. This paper adopts the method proposed by Li et al (2012). to measure the level of land urbanization by the ratio of urban construction land to urban and rural construction land, so as to make up for the lack of spatial mismatch between land urbanization and population urbanization in previous studies. The calculation formula is as follows:

$$LUR = \frac{UCL}{URCL} \times 100\% \tag{1}$$

where *LUR* stands for the land urbanization rate, *UCL* and *URCL* are the scales of urban construction land and urban and rural construction land, respectively.

(2) Spatial autocorrelation analysis

The spatial clustering characteristics of land urbanization in China are explored from both global and local perspectives. The global spatial autocorrelation index, Moran's *I*, is used to analyze the spatial patterns of land urbanization distribution in China. The local Moran's *I* index is further used to detect the local spatial pattern characteristics of land urbanization and identify the spatial locations of land urbanization clusters and dispersions. See reference (Zhang and Wang, 2018; Zhou et al., 2018) for specific mathematical formulas.

(3) The geographical detector

The geographical detector technique is an effective analysis method to detect the magnitude and degree of the influence of independent variables on dependent variables. It has been widely used in many fields of natural and social sciences (Wang et al., 2010). Although this method is widely used, its application in the study of land urbanization mechanisms is still limited to date. In this study, we assume that if land urbanization is affected by a specific factor, the distribution of this factor is similar to that of land urbanization (Wang et al., 2017; Yang et al., 2019). The model is as follows:

$$q = 1 - \frac{1}{n\sigma_U^2} \sum_{i=1}^{m} n_{D,i}\sigma_{U_{D,i}}^2 \tag{2}$$

where q denotes the magnitude of impact of each independent variable on the dependent variable; n_D,i represents the number of cities located in the sub-region; n is the total number of samples in the study area; m is the number of sub-regions; σ_U^2 and $\sigma_{U_{D,i}}^2$ are the variances of land urbanization in the study area and sub-region respectively. The explanatory power of the influencing factor (X) on the level of land urbanization (Y) becomes stronger as the q value increases, and weaker as it decreases.

3 Results and Analysis

3.1 Spatial and temporal dynamics of land urbanization

3.1.1 Land urbanization patterns in 2010

We map land urbanization distribution at the prefectural city level. It can be seen from Fig. 3a that there was a substantial spatial variation in China's land urbanization in 2010. Specifically, the eastern coastal region has the highest land urbanization level, while that in central, western and northeastern China is relatively low. In addition to the spatial variation in land urbanization among the four economic regions mentioned above, the north-south divergence in land urbanization level in prefecture-level cities is also noticeable. The land urbanization levels in southern prefecture-level cities bounded by the Qinling Mountains-Huaihe River are significantly higher than those in northern prefecture-level cities. In particular, many urban agglomeration areas in southern China have become high-value regions for land urbanization. However, traditional agricultural areas in north-

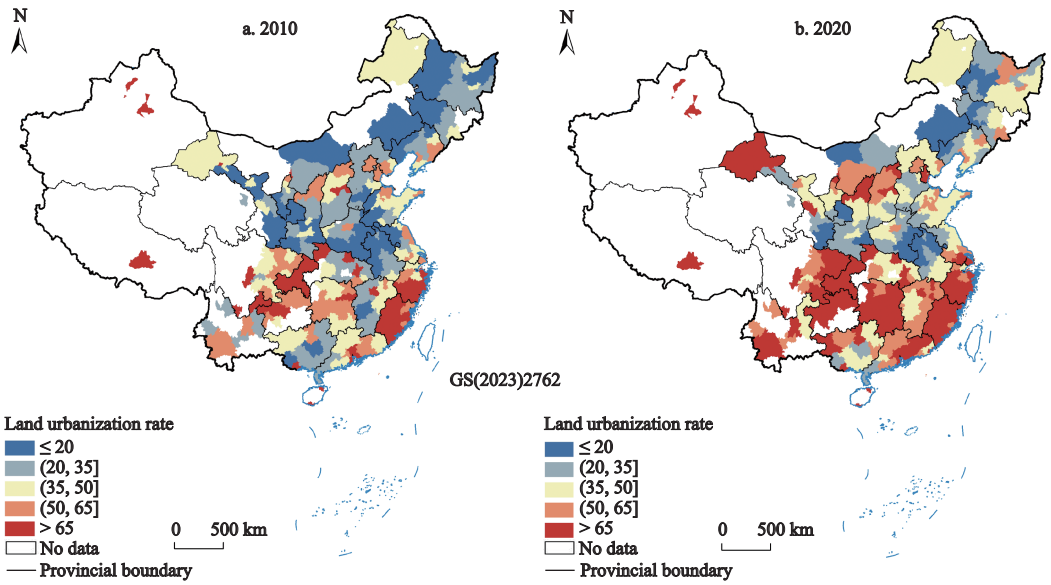

Fig. 3 The spatial distribution of land urbanization in China in 2010 and 2020

ern China, such as the Yellow-Huaihe-Haihe Plain, Shaanxi-Gansu-Ningxia and northeastern China are the low-value regions for land urbanization.

3.1.2 Land urbanization patterns in 2020

As shown in Fig. 3b, as the process of population urbanization continues to advance, the land urbanization level also increases accordingly. At present, the regional disparities in land urbanization levels across the four economic zones are insignificant. Instead, the differentiation in land urbanization level between northern and southern Chinese prefecture-level cities is more pronounced than that between coastal and inland or eastern and western cities. The high-value regions for land urbanization are almost all concentrated in southern China, which is the result of the continuous southward movement of China's population and economic center of gravity over the past decade (Liang et al., 2021). During this period, the nation enacted the NNUP in response to 'aggressive' urbanization, which helped to reduce regional disparities in land urbanization level to some extent, with the coefficient of variation for land urbanization at the prefecture-level falling from 0.529 in 2010 to 0.406 in 2020.

3.1.3 Evolution of land urbanization patterns in Chinese prefecture level cities

As Fig. 4 shows, from 2010 to 2020, most prefecture-level cities in China achieved positive growth in their land urbanization level. Among them, the central and western regions have the most rapid growth due to their lower base. Affected by economic recessions and population shrinkage, the northeastern region has the lowest growth rate, and the eastern region has witnessed steady growth due to its larger base. By comparing the coefficient of variation in the two years, it was discovered that regional differences in land urbanization in prefecture-level cities tended to converge, the urban primacy of land urbanization gradually decreased, and the growth of big cities shifted from incremental expansion to vitalizing stock land, while small and medium-sized cities (SMSC) continued the land urbanization characterized by rapid development. Faced with the pressures of population shrinkage and the new normal of economy, urban land expansion in SMSC has become more inefficient. Therefore, the key to realizing the transformation of urbanization lies in SMSC. Perhaps via the functional dispersal of major cities, coordination and complementarity between large, medium, and small cities is an efficient solution to overcome the current challenge of excessive land urbanization (Gao et al., 2018).

3.1.4 Spatial autocorrelation analysis for land urbanization in 2010 and 2020

To further depict the spatial dependence of land urbanization distribution, this study conducts a spatial autocorrelation analysis on land urbanization distribution in 2010 and 2020. The results indicate a positive spatial correlation in land urbanization. Over time, the spatial dependence on land urbanization distribution in China increased as evidenced by the global Moran's *I* index

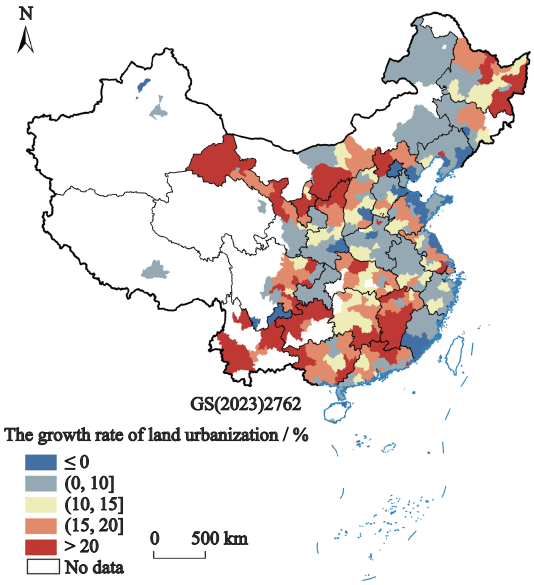

Fig. 4 Changing patterns of land urbanization in 2010–2020

which rose from 0.467 in 2010 to 0.578 in 2020. Moreover, as shown in Figs. 5a and 5b, several features have been confirmed in the spatial pattern analysis of land urbanization. For example, many urban agglomerations in southern China have high levels of land urbanization, while the traditional agricultural regions like Yellow-Huaihe-Haihe, Shaanxi-Gansu-Ningxia and northeastern China are low-value areas for land urbanization. Furthermore, south-central China and southeastern China are hotspots for land urbanization, while land urbanization in the traditional agricultural areas tends to be more spatially segregated. Due to the lagged market reforms in traditional agricultural areas, more importantly, these regions are restricted development zones under the National Plan for Major Function-oriented Zones. Constrained by the positioning of the national main grain production functional zone, the inter-regional competition in traditional agricultural areas may not be as intensive as that in southern China. Moreover, core cities, as economically developed locations, expand urban land usage and polarize economic development, reducing opportunities for land urbanization in the surrounding areas (He et al., 2016).

3.2 Determinants of land urbanization

An in-depth understanding of the impact factors driving land urbanization is an important precondition for advancing healthy land urbanization (Lin et al., 2015). We, therefore, use geographic detector technology to estimate the strength of association between the potential determinants investigated and China's land urbanization. Table 1 shows the influence of each factor on China's land urbanization level, and the findings suggest that there are notable variations in the explanatory power of each influencing factor on land urbanization level in 2010 and 2020. The explanatory power of the eight factors on land urbanization can be ranked by the magnitude of q statistic (q value) in the geographical detector, as shown below: LTI > PGDP > PU > FDI > AL > PD > PSI > RDLS in 2010, and PGDP > PU > LTI > FDI > PD > AL > PSI > RDLS in 2020. It is evident that China's land urbanization is impacted by the comprehensive effects of supply-side and demand-side factors. Next, the influencing mechanisms in relation to land urbanization will be analyzed in detail.

From the demand-side of land urbanization, urban population growth, economic growth, industrialization and population density constitute the determinants influencing land urbanization, with economic growth and urban population growth as the most important drivers. 1) Economic development is critical to China's land urbanization (q values are 0.493 in 2010 and 0.581 in 2020), and the variation in the level of economic development has emerged as a critical factor in the spatial differentiation of land urbanization. Cities with high economic development levels have self-reinforcing functions in economic growth, and often have higher investment returns, which make them the destination for labor and capital inflows, and require more land resources as spatial carriers for urban development to increase the demand for land resources, thus promoting urban space growth, while the impetus for urban land expansion in underdeveloped areas is relatively weak. 2) The impact of urban population growth on land urbanization is significant, as it has been observed to have a higher q value (0.485 in 2010 and 0.412 in 2020). Population migration and agglomeration directly influence

Table 1 Factor detection result of land urbanization in 2010 and 2020

Year	PU	PGDP	PSI	PD	LTI	FDI	RDLS	AL
2010	0.485	0.493	0.278	0.365	0.517	0.423	0.143	0.370
2020	0.412	0.581	0.235	0.331	0.406	0.382	0.164	0.267

Notes: PU, PGDP, PSI, PD, LTI, FDI, RDLS and AL represent population urbanization, GDP per capita, percentage of secondary industry, population density, land transfer income, foreign direct investment, relief degree of land surface and administrative level, respectively

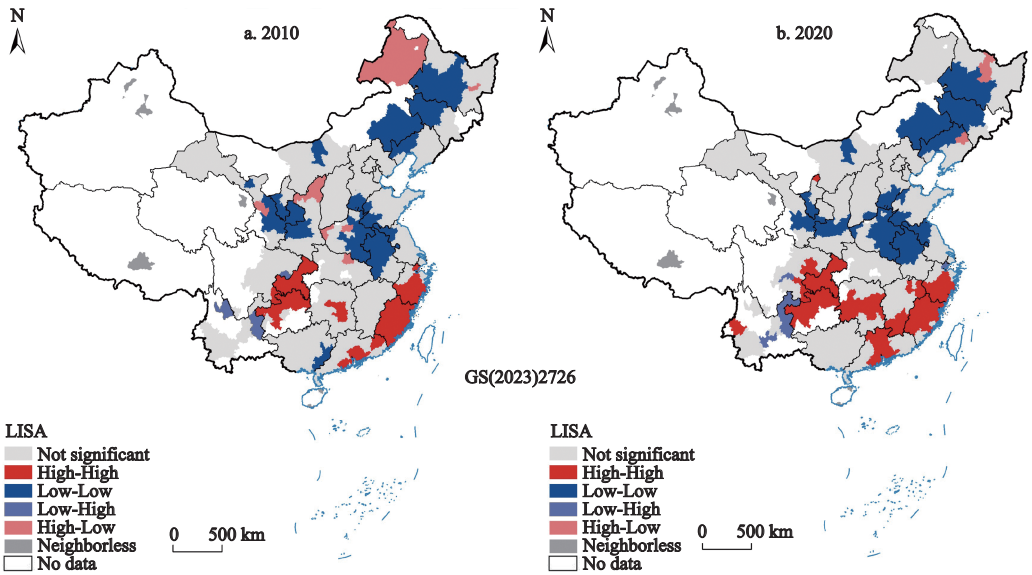

Fig. 5 Local indicators of spatial association (LISA) for land urbanization in 2010 and 2020

urban spatial expansion, which can induce a strong demand for urban land and is a vital force driving land urbanization, thus accelerating the land urbanization process. 3) The explanatory power of industrialization is 0.278 (2010) and 0.235 (2020), which indicates that industrialization does have an impact on land urbanization, but it is not significant. This does not only deviate from our expected results but also different from existing results obtained by Deng et al. (2010) and Lin et al. (2015). Theoretically, regions with high industrialization levels need a considerable amount of land to fulfil the demand for land for industrial development, which leads to a higher level of land urbanization. However, the impact of industrialization on land urbanization varies across regions, as some regions experience a positive effect on land urbanization while others experience the opposite effect (Wu et al., 2021), which is one of the reasons why industrialization has less influence. More importantly, when industrialization develops to a higher level, on one hand, urban land will be increasingly dedicated to the development of tertiary industries. On the other hand, local governments will also actively carry out industrial transformation and upgrading rather than simply expanding. Land urbanization may be more affected by the development of tertiary industries at this time. 4) Similar to the effect of urban population growth, population density has an important impact on land urbanization, as it is found to have a higher q value (0.365 in 2010 and 0.331 in 2020). This demonstrates that natural population growth and net migration in an area boost demand for urban land usage. In other words, the greater the population, the greater the demand for construction land. It should be pointed out that the distribution of population density is consistent with that of land urbanization in the eastern coastal area. However, some agricultural areas in central China, such as Henan Province and the surrounding cities, are densely populated in China, but their land urbanization level is not high, which may explain the low q value of population density relative to urban population growth.

From the supply-side of land urbanization, land finance, political incentive, administrative level and the RDLS constitute the factors driving land urbanization, with land finance and political incentive as the most important drivers, which is in line with the results of previous research (He et al., 2016). 1) The q value of land finance is 0.517 in 2010 and 0.406 in 2020, indicating that land finance exerts a pivotal role in driving land urbanization. Cities with more land transfer income have higher levels of land urbanization. Land transfer income is not only an important source of local government revenue but also an important means to alleviate local financial pressure. Local governments have shown great enthusiasm for the 'land-for-money' model, in which they exploit the difference in price between land acquisition and sale to make a profit. Land finance has stimulated the expansion of urban construction land area, which is an essential driving force of land urbanization. This finding provides further evidence for the argument of land finance, indicating that China's land

urbanization process is strongly linked to institutional arrangements associated with fiscal decentralization. 2) Political incentives significantly impact the inequality of land urbanization, resulting in a higher q value (0.42 in 2010 and 0.382 in 2020). The rapid growth of foreign investment has stimulated the demand for urban use, confirming the importance of foreign investment-driven urban development in China's political concentration. China has always been politically centralized. In order to gain promotions, local governments spare no effort to seek economic development and compete for urban development resources. At present, China's economy remains largely an investment-driven model. Local governments strive to attract foreign investment and promote local economic growth by creating development zones and industrial parks. Drawing on the aforementioned analysis, which emphasizes the critical role of land finance in China's urbanization process, it can be concluded that 'vertical competition' (the competition for revenue between local and central governments) and 'horizontal competition' (the competition among local governments for development resources) constitute the unique mechanisms operating behind land urbanization in China (Gao et al., 2014). 3) The administrative level has a significant impact on land urbanization, with high q-values in both years (0.370 in 2010 and 0.267 in 2020), indicating that higher-ranking cities usually have higher land urbanization levels. This result is in line with Li et al.'s (2015) study. The correlation between a city's administrative level and urban land expansion is typically self-evident in China. On the one hand, higher ranking cities tend to offer more employment opportunities, and have good infrastructure and public service facilities, which attracts a large population to gather, leading to an increased demand for residential land use, thus promoting urban land expansion. On the other hand, cities with high administrative levels often have more decision-making power and greater jurisdiction over land conversion. They are more likely to draw the attention of the central government and foreign investment, resulting in more urban land growth. 4) The RDLS is found to contribute a little, its q value was only 0.143 in 2010 and 0.164 in 2020. Generally speaking, the smaller the RDLS, the more favorable it is to carry out various urban construction activities. The larger the RDLS, the higher the urban construction cost will be, which indicates the restriction effect of the RDLS on land urbanization. China has a three-tiered distribution of terrain, which means that the RDLS has a minimal role in urban land development. However, many cities in central and northeastern China are traditional agricultural regions with small RDLS, but their land urbanization level is not high. Although western China, especially southwestern China, is limited by its terrain, the level of land urbanization is relatively high, which explains why the RDLS contributes little to land urbanization but does have a certain influence.

The explanatory power of some factors changed significantly from 2010 to 2020. For example, PU (0.485 vs. 0.412), PGDP (0.493 vs. 0.581), PSI (0.278 vs. 0.235), LTI (0.517 vs. 0.406) and AL (0.370 vs. 0.267). The explanatory power of urban population growth on land urbanization decreased; from 1995 to 2013, 'aggressive' urbanization appeared in China, which was manifested by the population gathering in cities and the significant expansion of urban land. The high explanatory power of urban population growth on land urbanization in 2010 was the result of the large-scale urban land expansion caused by population agglomeration. In March 2014, the nation enacted the NNUP. The most notable feature of the plan is the shift from the past emphasis on land-centered urbanization to the current people-centered urbanization, focusing on sustainable urbanization and vitalizing stock land. Moreover, coastal urban agglomerations exhibit relatively high levels of population and land urbanization, so it is difficult for urban population agglomeration to promote further land urbanization, which leads to a decline in the explanatory power of urban population growth. The explanatory power of economic growth on land urbanization is significantly enhanced, which can be understood in combination with the significant decline in the explanatory power of land finance. With the deepening of the marketization process, economic factors, represented by per capita GDP, play an increasingly important role in increasing urban non-agricultural employment opportunities and improving urban public services, which makes the role of economic development in land urbanization increasingly important. The decline in the explanatory power of land finance is the result of the transformation from the 'land for wealth' urban development model pursued by 'active' urbanization to the 'people-oriented' urbanization model. In addition, affected by the imbalance between supply and demand and the COVID-19

epidemic, the real estate market has been depressed in recent years, which has directly slowed down urban land development. The role of administrative level in land urbanization has also declined. On the one hand, as a regional socio-economic center, the land urbanization level of high-level cities has reached a high value. The further concentration of population can hardly bring about synchronous growth of land use scale. On the other hand, NNUP regards 'stock priority' as the basic principle of urbanization development. Urban development will change from the past incremental expansion to vitalizing the stock land at present. In principle, megacities will not develop new construction land. All these factors lead to a decline in the role of the administrative level in land urbanization. Finally, the explanatory power of industrialization level on land urbanization decreased. Under the background that the advanced economic development requires the economic structure to shift from manufacturing industry to the service industry, seeking high-quality economic development has become the primary economic development goal for cities at all levels, especially big cities. Some big cities have formulated the industrial development policy of 'transitioning from a labor-intensive sector to a service-based economy', and the industrialization level is no longer an important factor in driving land urbanization.

4 Discussion

In the past decade, the spatial variations in China's land urbanization have undergone significant changes, from the coexistence of 'east-west' and 'north-south' differentiation patterns to the 'north-south' differentiation pattern. The shift can be attributed to the relocation of China's population and economic centers towards the south over the past decade (Liang et al., 2021). Over the past few years, the development gap between China's northern and southern regions has significantly widened, resulting in a shift from the previous imbalance between the eastern, central, and western regions to a new one between the north and the south. This illustrates the important role of population agglomeration and economic growth on land urbanization from one side, which has been verified in this article. Additionally, this study also supports the theories of urban economics and urban science, such as the monocentric urban model, which considers population and income as the main factors driving urban land expansion. Urban population growth and economic growth are two primary elements influencing land urbanization, and their significant roles in land urbanization suggest that it is reasonable and effective to investigate the formation mechanisms of land urbanization from the perspective of neoclassical 'demand-side'. While demand-side factors certainly play a role in land urbanization, it is overly simplistic to attribute this phenomenon solely to such factors (Ping, 2011). In fact, supply-side factors also play significant roles in land urbanization, especially in China, a country in transition. Since China's economy is inherently political (Lin and Yi, 2011; Yang et al., 2019), it is impossible to acquire a satisfactory understanding of China's land urbanization process without taking into account the role of local governments. As Friedman emphasized, it is obviously too simplistic and deterministic to assess the drivers underlying the land urbanization in China only from an economic perspective (Friedmann, 2006). Given that the government is the sole legal provider of land in China, its role in land urbanization can not be understated. Land leasing not only provides significant extra-budgetary revenue for local governments but can also further expand the tax base by promoting local economic growth. Moreover, land may be exploited as a valuable asset to boost local capital accumulation by luring foreign investment, hence facilitating local economic progress. This is the operational logic of China's land urbanization under the background of fiscal decentralization and political centralization, which is reflected in the research conclusions of this study and also corroborates the findings of previous studies (He et al., 2016). In short, this paper examines the driving mechanisms behind land urbanization through the supply-demand perspective, highlighting the crucial role played by the demand and supply of urban land in this process, which makes up for the shortcomings of existing studies that often examine the impact factors and mechanisms of land urbanization from a single perspective, as well as having important theoretical value.

China's land urbanization is a mixed process. The phenomenon of rapid land urbanization in this process is the result of the combined influence of supply and demand factors of urban land; in particular, the factors such as population agglomeration, economic growth, land finance and political incentives play crucial roles. Population urbanization has an important impact on land

urbanization. However, with the deepening of the people-oriented new-type urbanization strategy, the land development intensity of many urban agglomerations has reached its ceiling, and further population agglomeration is difficult to achieve comparable scale land use growth. It is expected that the importance of population concentration in land urbanization would diminish in the future. Economic growth plays a critical role in land urbanization. If our conclusion is correct, against the background of relieving the non-core functions of big cities and alleviating the pressure of land use growth brought about by the development of big cities, SMSC must strive to improve their economic development level if they want to achieve population and industrial agglomeration to improve the urbanization level. Our research results also show that China's rapid land urbanization is affected by both political centralization and fiscal decentralization. Fiscal decentralization gives local governments a strong financial incentive to realize urban development, whereas political centralization gives local governments a political incentive to improve economic development through urban development. This land-centered urbanization has also caused many negative impacts, which has become a severe challenge to the sustainable development of Chinese cities (Chen M X et al., 2016; He et al., 2016; Yang et al., 2019). In the long run, as a strategy of urban development, land development is unsustainable, and the financial and political benefits associated with land development are likely to diminish over time. Therefore, for sustainability reasons, there is no doubt that the current excess supply of urbanized land urgently needs to be restored to a sustainable level coordinated with economic development and population growth. It is heartening to see that Chinese policymakers have recognized the serious challenges posed by the past land urbanization model to China's sustainable development. In the NNUP, the Chinese government first acknowledged the existence of aggressive urbanization and its many adverse effects. In the future, China will need to avoid these negative impacts during the process of urbanization, as they have the potential to affect the institutional basis of land urbanization in the country.

Our research deepens the understanding of the spatial variations and driving mechanisms of land urbanization in China. However, our research also needs some improvement. First of all, this paper's research scope is limited to prefecture-level cities in China and does not cover the entire country. In fact, there are three types of prefecture-level units at the same level as prefecture-level cities: regions, autonomous prefectures, and alliances. Most of these administrative units are located in ecologically fragile areas in western China and limited by data access, the status quo and mechanisms of land urbanization in these areas are still unclear. Second, scale dependence and scale effect have important impacts on land urbanization, and the development trend and underlying mechanisms of land urbanization at different spatial scales may be different. Therefore, we should understand the development trend and internal mechanism of land urbanization from a multi-scale perspective. Third, future research should focus on the spatial dependence of land urbanization, because spatial dependence may lead to the amplification of the effects of land urbanization drivers.

5 Conclusions and Suggestions

The significant urbanization process and rapid economic growth in China have resulted in a substantial expansion of urban land. There are evident regional disparities in China's land urbanization level due to variances in population gathering capacity, economic development level, foreign investment intensity, and government policies among different regions. Urban population growth and economic development have generated a tremendous demand for converting rural construction land into urban land, and local governments and officials have also scrambled to provide land for urbanization to obtain more fiscal revenue and realize their career advancement. The research on land urbanization will benefit from the adoption of a comprehensive analysis framework that can consider the supply and demand factors. The conclusions are as follows.

According to this study, there are significant regional disparities in land urbanization levels at the prefecture level, and these differences vary over time. China's land urbanization exhibited regional disparities both in terms of east-west and north-south directions in 2010. With China's population and economic center of gravity shifting southward, the disparity in land urbanization levels between the north and south regions is more pronounced in 2020 compared to that between the east and west or coastal and inland areas. From 2010 to 2020,

most of China's prefecture-level cities achieved positive growth in land urbanization level. Among them, the central and western regions have experienced the most rapid growth due to their smaller base. Affected by economic recession and population shrinkage, northeastern China has the slowest growth rate; the eastern region has a relatively stable growth rate due to its larger base. Land urbanization also has spatial dependence, especially in southern and southeastern China, suggesting that the competition in politics and economics is not limited to cities with similar levels of economic development, but also extends to neighboring cities.

Urban land supply and demand factors influence land urbanization in China. The explanatory power of factors affecting land urbanization varies, and their impact may change over time. Among the explanatory factors, urban population growth, economic growth, land finance and political incentives play crucial roles. With the proposal of the NNUP, the explanatory power of many factors declined, and only the economic growth and RDLS increased. On the one hand, this suggests that the driving factors behind land urbanization in China will become more complex. On the other hand, it also indicates that the impacts of land finance and foreign investment, represented by government forces, on land urbanization decreased, while the impacts of economic growth factors, represented by market forces, on land urbanization increased.

This study provides policy recommendations for promoting healthy urbanization and the rational and efficient use of land resources. First, Chinese policymakers should be aware of the large differences in regional land urbanization levels, which are not conducive to coordinated regional development in China. Given this, preferential policies should be undertaken in northern China to draw more people and industries to cities and towns and increase the land use efficiency in northern cities, thereby minimize the growing land urbanization disparity between the northern and southern regions. Second, accelerate the transformation of land urbanization from expansion to intensification. With the further development of urban economy, more and more people will continue to enter the cities and towns, which will bring huge pressure on the supply of construction land. One of the primary goals of land urbanization in China should be to improve population density in built-up areas and maintain a reasonable balance between population growth and land expansion in the future. Third, to eliminate reliance on 'land finance' and resolve the 'land game' dilemma between the central and local governments. Only by changing the structure of local fiscal revenue and establishing a system that matches the financial power with the duties and responsibilities can local governments avoid being addicted to 'land finance' and acting as land operators who 'expropriate land at a low price and sell it at a high price'. Finally, change the appraisal system based on GDP, which is an important performance indicator under China's current official evaluation system. Local governments often establish development zones and industrial parks to attract foreign investment, to promote local economic development and gain recognition from higher authorities for their success.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

YANG Zhen: conceptualization, methodology, resources, supervision, writing-review and editing. ZHU Huxiao: data curation, investigation, methodology, software, writing-original draft. ZHANG Xinlin: conceptualization, funding acquisition, resources, writing-review and editing. Ou Xiangjun: conceptualization, funding acquisition, resources, writing-review and editing.

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