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Study on Changes in Comprehensive Land Prices for Expropriation Zones Based on Land Use Changes

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Abstract: Comprehensive land prices for expropriation zones can effectively alleviate many conflicts in China's land expropriation practices. This contributes to achieving sustainable development goals such as "SDG-10: Reduced Inequalities" and " SDG-11: Sustainable Cities and Communities". The reasonable delineation of expropriation zones and scientific calculation of zone prices have become crucial. This study used the Cangzhou urban area in Hebei Province, China, as a case study. By integrating the CA–Markov model, multiple linear regression model, coupling coordination degree model, relative development degree model, and GIS spatial analysis techniques, the study deeply analyzed the spatiotemporal coupling relationship between land use and comprehensive land prices for expropriation zones from 2009 to 2021. Furthermore, it simulated and forecasted the changes in land use, expropriation zones, and zone prices in 2027. The study yielded the following conclusions: (1) The changes in land use reflected land economic value, land resource condition and land location condition shifts, which formed an interactive feedback mechanism with the comprehensive land price for land expropriation zones. (2) Land use impacted zone distribution through the spatial distribution characteristics of construction land, with recent development zones in the central urban area primarily extending east and southeast due to planning and policies related to land use for construction. (3) The coupling coordination and relative developmental degree between land use degree and zone price gradually develop in a good direction. A linear relationship is observed among land economic value, land resource condition, and land location condition concerning the zone price. Based on this, the predicted adjustment ranges for zone prices from high to low in 2027 will be 2.6400 to 2.7210, 2.1900 to 2.2537, and 1.8300 to 1.9306 million CNY/hectare. This study provides a new method for studying comprehensive land prices for expropriation zones, supporting decision making.

Keywords: coupling coordination degree; CA–Markov model; multiple linear regression model; conversion rules; zone distribution; zone prices; Cangzhou urban area

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1. Introduction

Land expropriation is a common practice employed by governments worldwide for infrastructure development, urban expansion, and public service projects [1,2]. Since China's economic reform and opening up, the process of industrialization has been accelerating, the urban economy has been growing rapidly, and the quality of economic development has been improving. The urbanization rate rose from 17.92% in 1978 to 66.16% in 2023 and is still in a growth state. In the post-pandemic era, the economic slowdown has led to a decline in demand for construction land, particularly for real estate development in

China. However, the introduction of policies related to new infrastructure construction and urban–rural integration in China will not only facilitate a shift in the economic growth model but also generate new demand for construction land to some extent [3,4]. In fact, urban construction land expansion has always been the driving force behind land use change [5]. The government has to expropriate large quantities of rural collectively owned land [6], convert it to state-owned land (land urbanization), and then transfer it through bidding, auction, or agreement in the land market. Farmers that lose land receive fair and reasonable compensation for their lost land property rights, ensuring that their living standards should not be affected [7–9]. With the development of the land market economy, farmers' awareness of their land assets has gradually increased, highlighting the conflicts within China's land expropriation process. Land issues account for over 65% of collective actions taken by farmers to protect their rights, with 73.2% of these issues involving land expropriation [10]. The primary reasons include a lack of fair and just compensation mechanisms, inequitable distribution of benefits during land expropriation, and even illegal land expropriation, which significantly impact farmers' short-term livelihoods [11,12]. Farmers that lose land often do not receive adequate compensation, leading to decreases in their economic living standards compared to before the government's land expropriation. This situation frequently results in collective petitioning events, which have profound implications for rural development, societal progress, and political stability [13,14]. Narrowing the gap between land expropriation compensation and market land value can effectively reduce the opposition of farmers that lose land to land expropriation efforts [15,16]. This approach helps avoid conflicts and disputes arising from discrepancies in compensation and actual development differences between adjacent areas, thereby accelerating the land expropriation process. However, this does not imply that higher compensation amounts are always better [17].

Land expropriation systems vary across different countries in terms of compensation scope, calculation methods, and legal frameworks (Table 1), but they generally follow the principle of public interest and provide corresponding compensation. Internationally, compensation standards for expropriated land can be roughly divided into the following three categories: First, standards that emphasize fair market value, based on optimal use and the highest revenue that the land could potentially generate, ensure that the compensation price reflects the current market value and the expected maximum revenue of the land. Such standards are used in the United States and Canada [18–20]. Second, standards that focus solely on the current market value of the land and emphasize the "leveling" of the land rights holder's interests mean that the interests of the person whose land is being expropriated will neither decrease nor increase as a result of the land expropriation process. The compensation amount ensures that the person whose land is being expropriated is at the same level before and after the expropriation, and such standards are used in the United Kingdom, Germany, and Japan [21–23]. For the third category of standards, the complete market value of the land is not known and a unified expropriation compensation standard is formulated based on market factors that exist before the expropriation occurs. Such standards are used in China and South Korea [24,25]. Obviously, China's land compensation standards are lower compared to other countries, which increases the likelihood of social conflicts and dissatisfaction among displaced farmers [6]. The "Land Administration Law of the People's Republic of China" (2019 Amendment) for the first time elevated the compensation principle proposed in Document No. 28 of the State Council in 2004, which stipulated "ensuring that the original living standards of the displaced farmers are not reduced and their long-term livelihoods are guaranteed", to a legal provision. Additionally, this law replaced the previous annual output value multiple method with comprehensive land prices for land expropriation zones (referred to as "zone land price"), adjusted or republished at least every three years, thus legally establishing a more robust protection mechanism for farmers whose land is being expropriated. The formulation of zone land price mainly involves dividing expropriation zones and calculating zone prices. The term "zone" is short for expropriation zone and refers to a spatially enclosed

unit with uniform collective land resource conditions; a uniform location, population, and socio-economic development level; and identical standards for land compensation fees and resettlement subsidies. Zone prices, which are determined through a comprehensive assessment of various factors including original land use, land resource conditions, land output value, land location, supply and demand of land, population, and socio-economic development level, are publicly declared by the government following the law. It applies to the land compensation fees and resettlement subsidies for the expropriation of collective agricultural land. Compared to the annual output value multiple method, the zone land price system has raised land compensation standards to some extent, thereby increasing farmers' motivation and cooperation. It alleviates issues such as arbitrariness and inequity in the land expropriation process, enhancing the rationality and transparency of policy implementation. This represents an important improvement in China's land expropriation system [26,27]. As of 2024, China has adjusted zone land price six times, specifically in the years 2009, 2012, 2015, 2018, 2021, and 2024. Notably, in 2018 and 2021, China continued to use the updated results from 2015 and reissued them for implementation.

Table 1. Land expropriation compensation standards in different countries.

Country	Compensation Range	Measuring Method	Legal Framework
America	Fair market value, rights compensation, loss compensation, residual compensation, unemployment compensation, compensation for other damages	Comparative method, cost method, income method	"Fifth Amendment" "Property Act"
Canada	Fair market value, compensation for harmful or adverse effects, compensation for disturbance, compensation for difficulties in relocation	Comparative method, cost method, income method	"Canadian Federal expropriation Act"
Britain	Land market value, damage compensation, residual land compensation, disturbance compensation, loss-of-home compensation/loss compensation, compensation for related expenses	Comparative method, cost method, income method	"Compulsory Land Purchase Act" "Land Compensation Act"
Germany	Market value of land, compensation for business losses, compensation for all incidental losses incurred in requisitioning the subject matter	Comparative law, income law	"Federal building Act"
Japan	Land market price, compensation for the few remaining, compensation for business losses, compensation for the departed, compensation for damage	Market comparison method, replacement cost method	"Land expropriation"
China	Land compensation fees, resettlement fees, compensation fees for ground attachments and green seedlings	Income law, basic land price revision law, social and economic indicators update law	"Land Administration Law"
Korea	Land price compensation, residual land compensation, compensation for relocation costs, compensation for other losses	Multi-factor comprehensive evaluation method	"Constitution" "Land Expropriation Compensation Act"

During the land expropriation process, land use types typically change; that is, the original use of the land is altered. For example, agricultural land can be transformed into industrial, commercial, or residential land. The revenues generated by these new uses far exceed the output values of traditional agriculture and forestry, significantly increasing the economic value of the land. As land use changes, the conditions of land resources will change accordingly. Soil and water resources originally used for agricultural production may no longer be suitable, necessitating large-scale land transformation and infrastructure construction, which can alter vegetation and socio-economic conditions. Agricultural

land originally located in the suburbs may become an area with high commercial value due to urban expansion, thereby enhancing the land's locational advantage. Changes in these factors will ultimately influence the formulation of land expropriation compensation standards. Therefore, compensation standards need to be flexible and adaptable, reflecting dynamic changes in market and resource conditions over time, to ensure that the interests of farmers that lose land and land users are protected. The rise in zone price represents increases in land acquisition costs and consequently increases in the land price. Land prices serve as crucial manifestations of land use changes [28], and increases directly reflect the enhanced economic value and development potential of land. Higher land prices lead to greater interest and enthusiasm from developers and investors, who anticipate higher economic returns [29,30]. This increases the likelihood of land being converted into built-up areas, allowing cities to continue expanding, which presents greater challenges for land expropriation efforts [31]. Construction land layouts and planning policy conditions guide the division of expropriation zones. Rationally dividing zones helps enhance the internal homogeneity within zones and the heterogeneity between zones to avoid different prices occurring in the same region [32]. Such a method not only bolsters the contentment of land-losing farmers but also mitigates land expropriation conflicts. It ensures that the government maintains a proactive stance and facilitates a swifter expropriation process. Obviously, a mutual feedback mechanism exists between land use and land expropriation, underscoring their interdependent and reciprocally influential nature. It can be seen that there is a mutual feedback mechanism between land use and land expropriation (Figure 1).

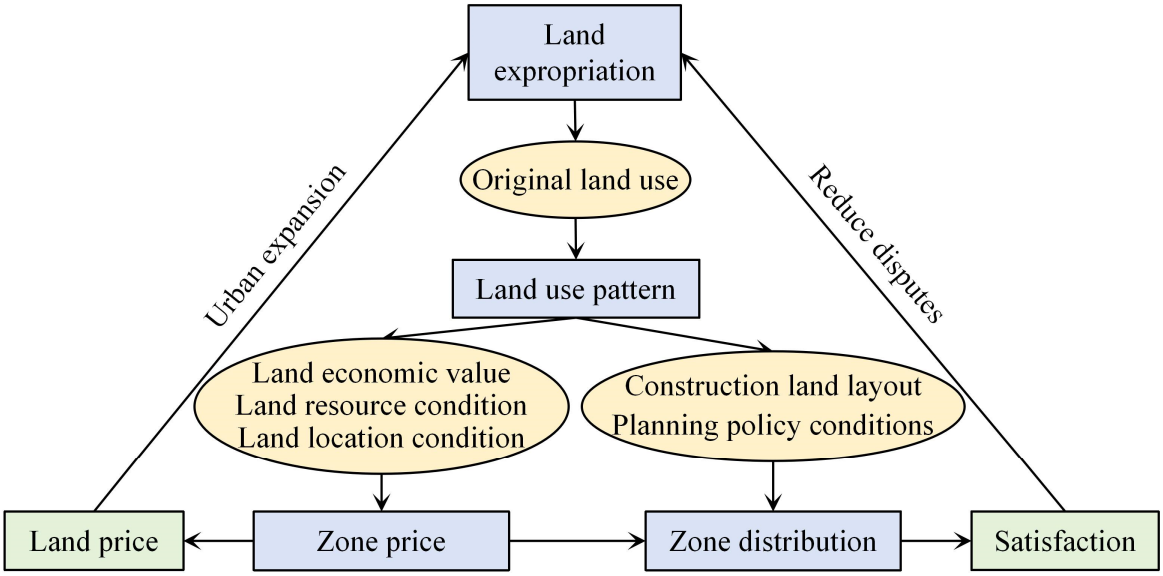


Figure 1. Interaction mechanism between land use and land expropriation.

Specifically, the driving forces of land use change are the key to causing the transformation of land use types. In a narrow sense, research on driving forces typically focuses solely on identifying the dominant driving factors. These drivers can be influenced by spatial and temporal scales, with significant variations in their effects across different regions and times [33]. The driving force system of natural resources generally exhibits significant differences across macro and meso spatial scales and over extended temporal scales. [34]. Conversely, the socio-economic driver system tends to have noticeable impacts at any scale [35,36]. Therefore, when selecting factors driving land use, it is important to consider the specific situation of the research area and objectives to enhance the relevance of the factors [37]. Broadly, research on driving forces also encompasses the simulation of driving processes [38]. This involves constructing models to predict the impacts of various driving factors on land use change, thereby revealing the dynamic relationships and interactions among these factors, and ultimately forecasting future land use patterns.

The CA–Markov model, a hybrid approach that integrates the ability of Cellular Automata (CA) to simulate complex spatial systems with the predictive advantages of Markov chains for long-term temporal changes [39,40], has been widely applied in the simulation of land use changes [41].

In the process of urbanization, the expropriated zone will expand under the impetus of urban expansion and development demand, government planning, and policy orientation. The key to simulating and predicting the expansion of expropriation zones lies in accurately identifying the interaction mechanisms between land use changes, policy measures, and zone expansion. The CA–Markov model integrates multi-criteria evaluation methods and multi-objective decision support systems to flexibly define zone transition rules and dynamically adjust these rules to accommodate different regional characteristics and planning objectives [42]. The characteristics of the model make it possible to accurately predict the distribution of expropriation zones. The price of the zone is the result of the combined effects of various factors, and to some extent, these factors overlap with the drivers of land use change [43]. Clarifying the contribution of different influencing factors to the zone price is an important link in predicting the zone price. Existing studies have shown that the multiple linear regression model is simple, efficient, and easy to interpret, and can well reveal the quantitative relationship between the zone price and influencing factors [44].

Extensive scholarly exploration has been dedicated to the realms of land expropriation and compensation standards, encompassing a variety of aspects. This includes an examination of the types, causes, and spatial and temporal distribution of land expropriation conflicts [14,45,46], as well as the effects of land expropriation on the livelihoods of farmers [47,48]. Additionally, research have identified the factors that influence the zone land price [43], traced the spatiotemporal development of zone land price [49], and explored the methodologies for calculating zone price [50], forming a rich theoretical and practical foundation. Nevertheless, current international research exhibits a scarcity of studies focusing on zone land price through the lens of land use changes. Based on the above analysis, this study raises two scientific questions: (1) How can the impact of land use change on the distribution of land expropriation zones be quantified? (2) Can zone prices based on land use changes help narrow the gap between compensation standards and land market value? To this end, this study takes Cangzhou urban area, Hebei Province, China, as a case study and employs the CA–Markov model and multiple linear regression model for analysis. Specifically, the research objectives of this paper include: (1) revealing the coupling relationship between zone land price and land use changes as the starting point of the study; (2) simulating future land use data as the foundation of the study; and (3) predicting the distribution and prices of the zone as the core of the study. The study expands the research avenues for the zone land price, and is anticipated to offer innovative approaches, perspectives, and methodologies for the updating and adjustment of the zone land price, thereby promoting the optimal allocation of land resources and the coordinated development of regional economies and contributing to the achievement of sustainable development goals.

2. Materials and Methods

2.1. Study Area

Cangzhou City is located in the southeast of Hebei Province (Figure 2), within the Heilonggang River basin in the eastern part of the Hebei Plain, and has an elevation ranging from 2 to 17 m. The Beijing–Hangzhou Grand Canal traverses the city from north to south, where multiple major transportation arteries intersect and extend in all directions. It is a bridgehead that is integrated into the coordinated development of the Beijing–Tianjin–Hebei region. The Cangzhou urban area comprises Xinhua District and Yunhe District, situated between 116°45′ E and 116°57′ E and between 38°24′ N and 38°12′ N, covering an area of approximately 18,449.88 hectares. By the end of 2022, the permanent population of the Cangzhou urban area was 749,200, with an urbanization rate of 95.74%. The gross domestic product of the primary industry was 56.8 million Chinese Yuan (CNY), and

the industrial structure was 0.1:28.4:71.5. The urban residents had a per capita disposable income of CNY 45,442, an increase of 3.3%, while rural residents had a per capita disposable income of CNY 20,396, an increase of 6.2%. The per capita construction land area was 141.61 m^2, while the per capita arable land area was only 44.76 m^2. The total output value of the construction industry was CNY 34.6325 billion, accounting for 66.86% of the city's total, indicating a high demand for construction land and an increased likelihood of converting agricultural land for construction purposes. The city exhibits a typical development pattern of outward expansion from the center.

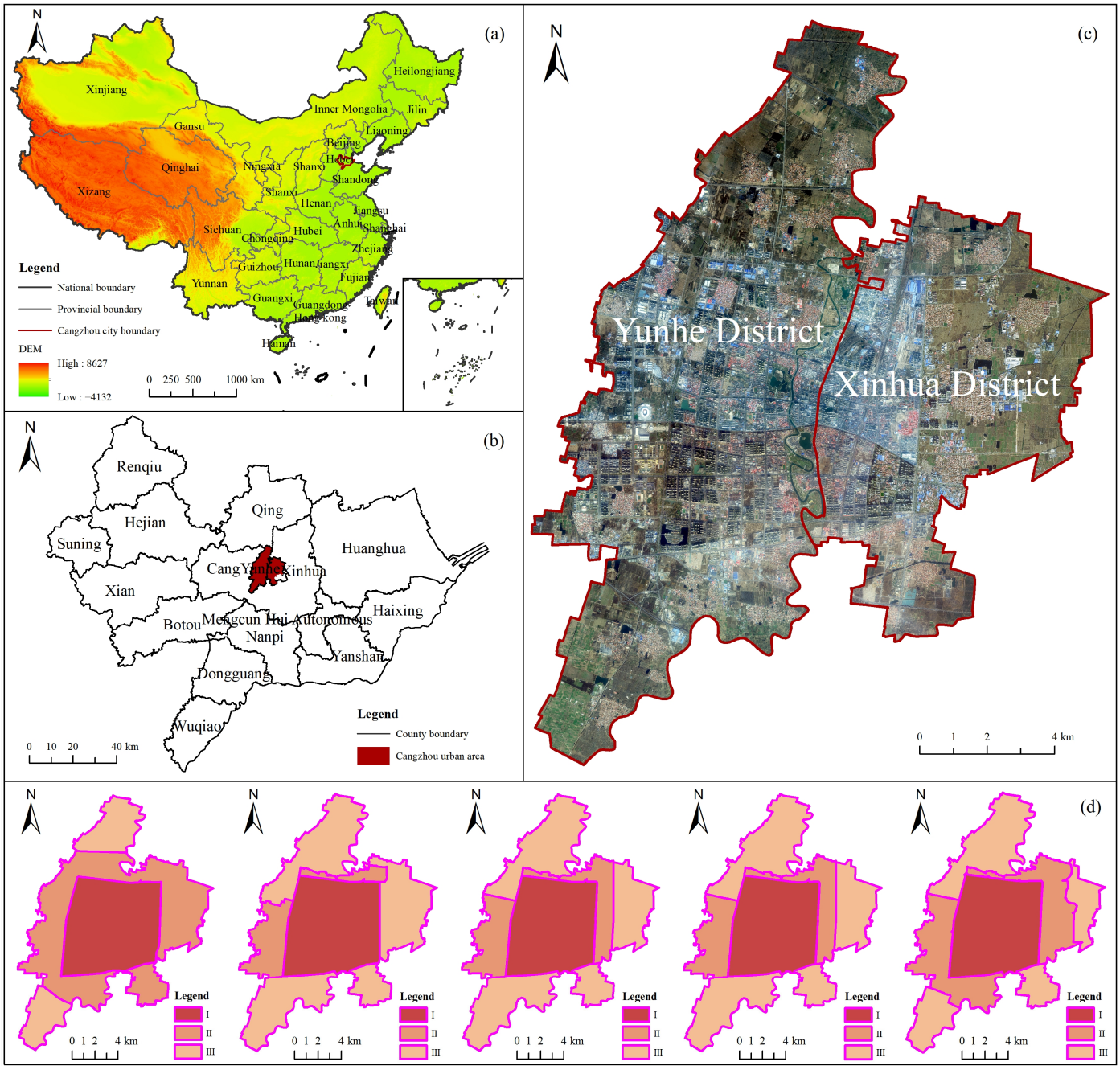


Figure 2. Location map of the Cangzhou urban area. (**a**) The location of the Cangzhou urban area in China. (**b**) The location of the Cangzhou urban area in Cangzhou City. (**c**) Remote sensing image map of the Cangzhou urban area. (**d**) Zone distribution conditions in the Cangzhou urban area, from left to right, during the following years: 2009, 2012, 2015, 2018, and 2021.

From 2009 to 2024, the Cangzhou urban area has always been divided into three zones, of which Zone I is the central urban built-up zone, Zone II is the recent development zone in the central urban area, and Zone III is the zone outside the urban core (Figure 2). In 2009, the eastern boundary of Zone I was defined by a planned road that remained unbuilt until 2015. To maintain internal homogeneity, the boundaries of Zone I were contracted. From 2015 to 2021, the development level of Zone I significantly diverged from other zones, resulting in a stable distribution range with no major outward expansion. In 2009, the areas surrounding Zone I had relatively uniform development, and Zone II had not yet entered its rapid growth phase. Between 2009 and 2012, development within Zone II was uneven, with faster growth in the western and northern parts. Consequently, in 2012, Zone II was redefined to include only these areas, ensuring heterogeneity between zones and avoiding uniform pricing for different lands. Since then, Zone II has consistently expanded, with Zone III evolving in response to changes in Zone II. Due to the non-implementation of the 2024 land change survey, the current 2024 zone land price is calculated and divided based on the 2021 land change survey data. For the sake of scientific research and data accessibility, the current zone land price is regarded as the 2021 price so that it is consistent with the land use year. Therefore, according to the legal requirements, the next adjustment is expected to occur in 2027.

2.2. Data Sources

The land use data utilized in this study were obtained from the Cangzhou Natural Resources and Planning Bureau and were reclassified into six categories: farmland, forest land, grassland, water, construction land, and other land, with a resolution of 30 m. (Figure 3). In this study, to unify the classification criteria for land types across different years, according to China's "The supplementary notice on the adjustment of the content and requirements related to the third national land survey", forest land that is readily restorable and can be restored to farmland through engineering measures is recognized as farmland. The Gross Domestic Product (GDP) data were obtained from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/ (accessed on 20 February 2024)), with a resolution of 1 km. This dataset provides detailed spatial distribution information on GDP. Due to limited data availability, the GDP data from 2010 serve as a proxy for 2009, while the GDP data for 2018 and 2021 were estimated using interpolation. The Normalized Difference Vegetation Index (NDVI) data were also sourced from the Resource and Environment Science and Data Center (https://www.resdc.cn/ accessed on 20 February 2024)), with a resolution of 250 m. These data effectively reflect the spatial and temporal distribution of vegetation cover and changes. Population density data were downloaded from the WorldPop website (https://hub.worldpop.org/ (accessed on 9 March 2024)), with a resolution of 1 km. These data are generated using remote sensing imagery and statistical models, providing detailed global population distribution information. Notably, the population density data for 2021 are derived through interpolation. Nighttime light index data were derived from the EANTLI-Like nighttime light dataset developed by Zhong et al. [51], with a resolution of 1 km. This dataset offers strong temporal continuity and high correlation with socio-economic data, offering support for urban development research. The nighttime light data for 2021 are also obtained through interpolation. Road vector data and hydrographic data were extracted from land use change survey data provided by the Cangzhou Natural Resources and Planning Bureau. These datasets are characterized by high precision. Through collection and processing, the use years of the above indicator data are 2009, 2012, 2015, 2018, and 2021. Data on urban development boundaries were sourced from the Cangzhou Natural Resources and Planning Bureau. Due to differences in the data sources, preprocessing was required to meet the requirements of subsequent data processing. This involves standardizing all indicator data and land use data to a uniform resolution of 30 m, a coordinate system of CGCS2000_3_Degree_GK_Zone_39, and a grid layout of 570 rows by 738 columns.

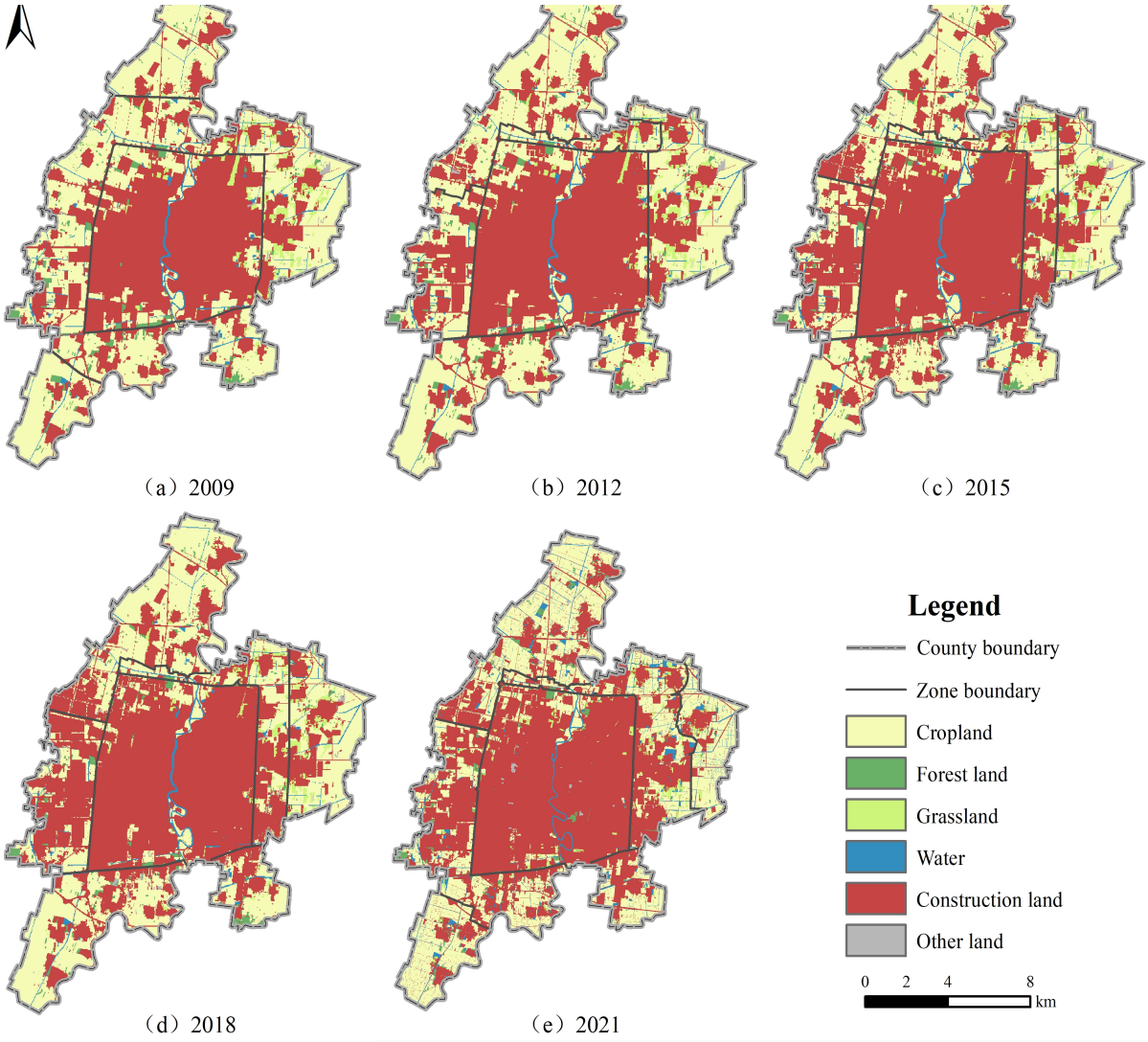


Figure 3. Land use map of the Cangzhou urban area from 2009 to 2021.

2.3. Methodological Framework

The methodological framework of this study comprised four stages (Figure 4): (1) validating and applying the CA–Markov model to simulate land use in 2027; (2) analyzing the spatial coupling characteristics of construction land and zone distribution, as well as the interactive relationship between land use and zone prices; (3) based on the 2027 land use simulation data, setting zone conversion rules to simulate the distribution of zones in 2027; and (4) using the multiple linear regression model to construct a linear functional equation to estimate the zone prices in 2027.

2.3.1. Land Use Change Simulation

This study selected nine representative influencing factors from three aspects: land economic value, land resource conditions, and land location conditions. In the Cangzhou urban area, the Jing–Hang Grand Canal, railways, and highways generally do not undergo conversions to other land use types. Additionally, land use types outside the urban development boundary are not typically converted into construction land, and these can be considered limiting factors (Table 2).

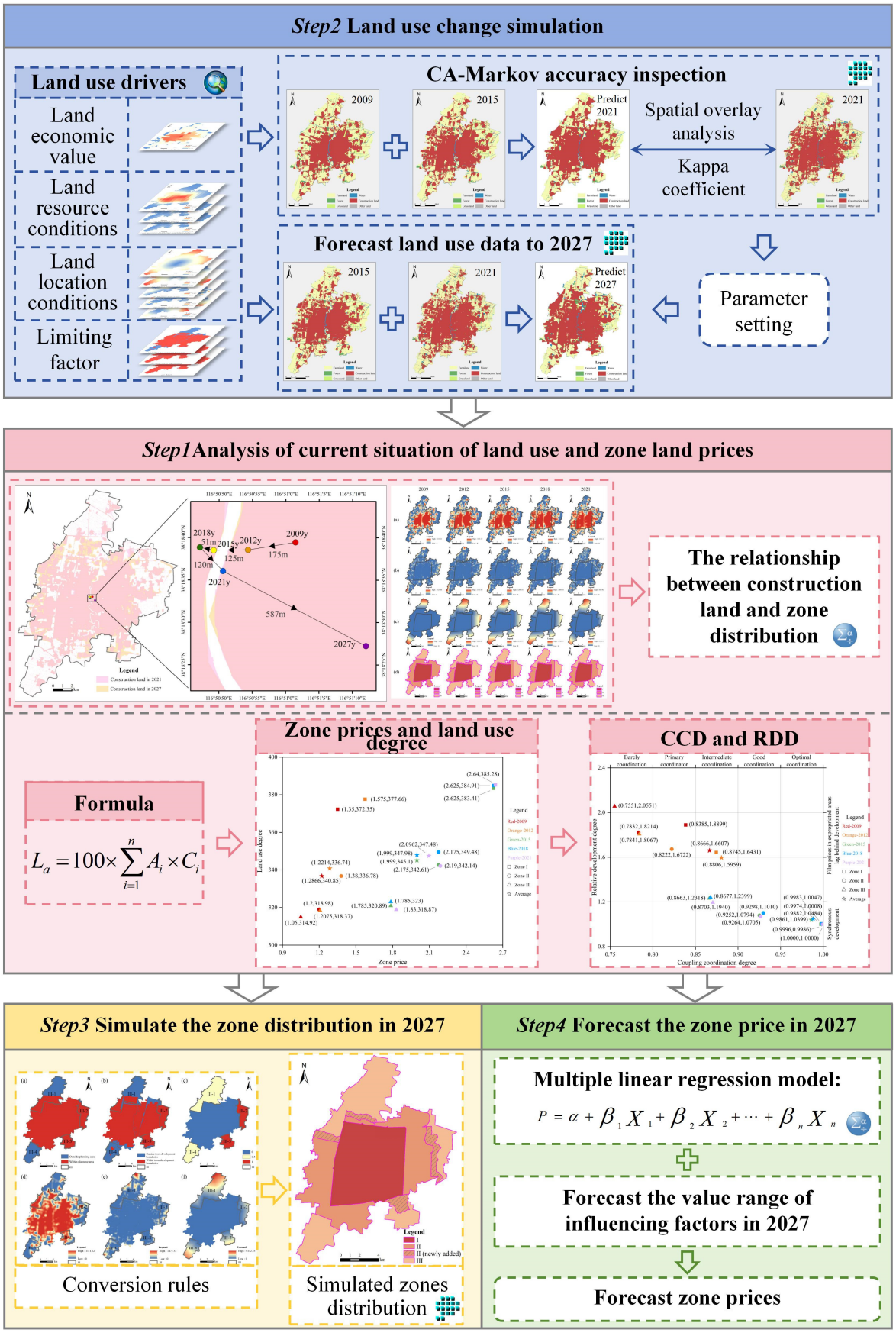


Figure 4. Methodological framework diagram.

Table 2. Index system for driving factors of land use.

Driving Factors	Type	Name	Descriptions
Influencing factors	Land economic value	GDP	Per capita GDP in each grid cell (unit: CNY/people).
	Land resource conditions	NDVI	Reflectance intensity of visible light for each land cover type in each grid cell.
		Population density	Population density in each grid cell (unit: people/km^2).
		Nighttime light index	Brightness of nighttime surface light in each grid cell.
	Land location conditions	Distance to railway	The straight-line distance from each cell to the nearest source (from cell center to cell center) was measured using the Euclidean Distance tool in ArcGIS (unit: m).
		Distance to expressway	
		Distance to road	
		Distance to water system	
		Distance to urban center	Using ArcGIS, the geometric centers of the built-up areas, the population distribution center, and the transportation accessibility center were calculated. The cluster area obtained by connecting these three centers was designated as the urban center area. Then, the Euclidean Distance tool was used to measure the straight-line distance (unit: m).
Limiting factors	Restricted area	The Beijing–Hangzhou Grand Canal	The areas where the Beijing–Hangzhou Grand Canal, railways, highways, and urban development boundaries were located were set as 0, and the other areas were set as 1. (The CA–Markov model defaults to 1 being convertible and 0 being non-convertible.)
		railway	
		expressway	
		urban development boundaries	

Utilizing IDRISI Selva 17.0, this study employed a land use transition area matrix from 2009 to 2015 and suitability maps from 2009 to determine the conversion rules of cell states, thereby predicting the land use data for 2021. A spatial overlay analysis of the predicted 2021 land use data and the actual land use data yielded a Kappa coefficient of 0.8718. According to the standards referenced in related research [52], a Kappa coefficient greater than 0.75 is generally considered to indicate high simulation accuracy. Therefore, based on the parameters mentioned above, this model could be used for subsequent land use data simulation research.

2.3.2. Land Use and Zone Distribution

This study utilized ArcGIS 10.7 to analyze the spatial and temporal evolution characteristics of the relocation of the center of gravity of the construction land and the zone distribution in the Cangzhou urban area from 2009 to 2021. On a micro level, relocation of the center of gravity of construction land reflects changes in internal quality and density, while on a macro level, it represents spatial changes [53,54]. At the same time, ArcGIS was also used to calculate the concentration degree and the distances between construction land to represent the change characteristics of the construction land. In addition, considering the influence of the original zone distribution on zone adjustments, the distances between each pixel in the Cangzhou urban area and Zones I and II were calculated.

2.3.3. Land Use and Zone Prices

(1) Land use degree

The comprehensive index of land use degree quantifies the depth and breadth of land development and utilization under human interference by grading and assigning values to different land use types [55–57]. Following existing research standards, this study assigned values of 4 to construction land; 3 to farmland; 2 to forest land, grassland, and water; and 1 to other land [58,59]. Based on this, the comprehensive index of land use degree was calculated for the entire Cangzhou urban area and each zone from 2009 to 2027. The calculation formula is as follows:

$$L_a = 100 \times \sum_{i=1}^{n} A_i \times C_i$$

In this formula, *La* represents the comprehensive land use degree index, with $L_a \in (100, 400)$; A_i denotes the grade index of the *i*th level of land use degree; C_i indicates the percentage of the area of the *i*th type of land use; and n is the number of land use degree grades.

(2) Coupling coordination degree and relative development degree models

Coupling Coordination Degree (CCD) and Relative Development Degree (RDD) play a significant role in deeply understanding the interaction mechanisms, interconstraints, and development coordination among multiple complex systems [59–61]. This model can externalize the intrinsic relationship between land use and zone land prices, providing the possibility to study the coordination capacity of complex system interactions. In this study, the maximum value method [62] was employed to normalize the data, and the CCD model was used to deeply explore the coordinated relationship between land use and zone prices interaction coupling. Based on previous studies [63,64] and actual calculation results, the CCD was classified into seven levels: [0, 0.5) indicated mild imbalance, [0.5, 0.7) indicated data on the verge of imbalance, [0.7, 0.80) indicated the data were barely coordinated, [0.80, 0.85) indicated primary coordination, [0.85, 0.90) indicated intermediate coordination, [0.90, 0.95) indicated good coordination, and [0.95, 1] indicated optimal coordination. The RDD model was further utilized to reflect the relative relationship between the two systems. The closer the value was to 1, the more harmonious the development trend between the systems [65]. This relationship could be categorized into three levels: $0 \leq E \leq 0.8$ indicated land use lag, $0.8 < E \leq 1.2$ indicated synchronized development, and $E > 1.2$ indicated zone price lag. For the specific formula, please refer to Figure 5.

2.3.4. Zone Distribution Simulation

This study analyzes the spatiotemporal coupling relationship between construction land and zone distribution and employs frequency histograms to ascertain the pattern of factor changes in zone transition areas. In light of the actual conditions of the study area, zone transition rules are established. Using zone distribution data from 2015 and 2021, the CA–Markov model within IDRISI Selva 17.0 software is utilized to modify the transition area matrix, set conversion rules, create suitability maps, and simulate the zone distribution for 2027.

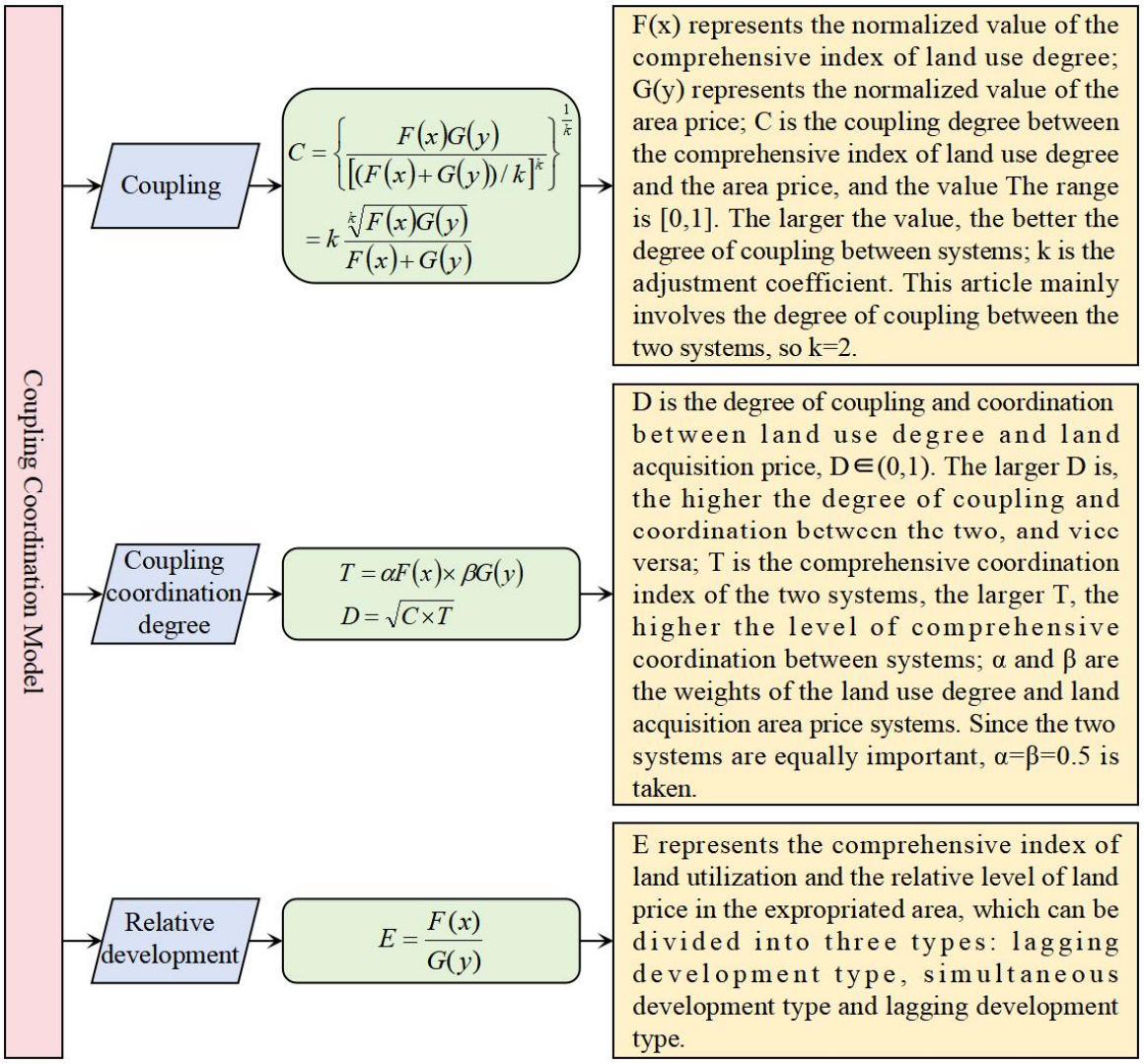


Figure 5. Framework for calculating coupling coordination degree and relative development model.

2.3.5. Zone Price Forecast

In this study, when selecting land use driving factors, full consideration was given to the interactive mechanism between land use and zone prices. Therefore, the index system in Table 2 can be directly used as the influencing factor of the zone prices. Given that the distance between each district and the expressway did not change significantly from 2009 to 2021, this study did not include this indicator in the factors affecting zone prices. To avoid redundancy in the sample data, the expropriation zones for 2009, 2012, 2015, 2018, and 2021 were converted into 150 × 150 m raster grids, which were then transformed into point data. Using the "Extract Multi Values to Points" tool in ArcGIS, the values of various indicators were extracted to the point data. For each year, 8206 research samples were obtained. The study employs the multiple linear regression model, using SPSS 27 software, with zone prices from different years for the same raster as the dependent variable and various indicators as independent variables to construct a linear function model. The indicator data for 2027 were predicted using Excel, and then the predicted values were substituted into the linear functional equation to obtain the range of zone prices for 2027. The multiple linear regression model is as follows [66]:

$$P = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

In the equation, P represents the zone price; $X_i(i = 1, 2, \ldots, n)$ represents the factors influencing the zone price; and the coefficients $\beta_i(i = 1, 2, \ldots, n)$ represent the contributions of each attribute to the zone price.

3. Results

3.1. Simulation of Land Use Data in 2027

Assuming that the land use trend of the past 6 years in the Cangzhou urban area continues from 2021 to 2027, and considering the limits of the urban development boundaries on this basis. The spatial distribution map of land use in the Cangzhou urban area in 2027 was simulated (Figure 6). The area of construction land is projected to be 11,195.83 hectares, accounting for 60.68% of the total area, which would represent an increase of 7.85% compared to 2021.

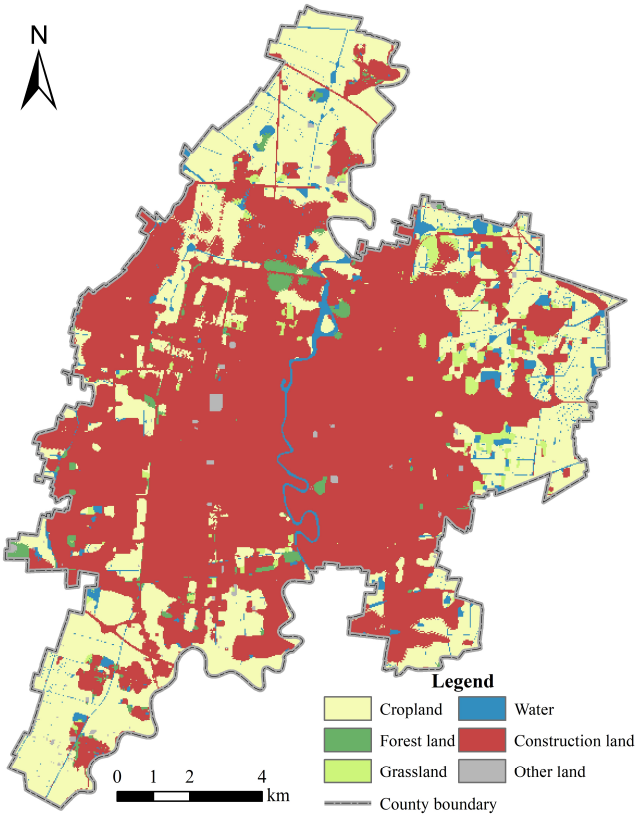


Figure 6. Simulated land use map of the Cangzhou urban area for 2027.

3.2. The Relationship Between Land Use and Zone Land Price

3.2.1. Spatiotemporal Coupling Analysis of Construction Land and Zone Distribution

According to Figures 7 and 8, the area in the Cangzhou urban area where Zone III was upgraded to Zone II exhibited the following characteristics: the kernel density of construction land was concentrated between 400 and 1100, the distance to construction land was concentrated between 0 and 100 m, and the distance to Zones I and II was concentrated between 0 and 1000 m. Regions with higher concentrations of construction land tended to have stronger radiation effects on surrounding areas, thereby increasing the probability of land expropriation. Newly added construction land tended to be located adjacent to existing construction land, leading to changes in the zone grades. The expansion of zones typically extended outward from the original distribution area, rarely resulting in discrete distribution. In other words, the closer a lower-level zone was to a higher-level zone, the higher the probability of its transition. The higher the zone level, the more significant the spatial characteristics of construction land, making expropriated land scarcer and its radiating effect stronger. Consequently, the surrounding land types were

more likely to transform into construction land, thereby influencing the distribution of expropriation zones.

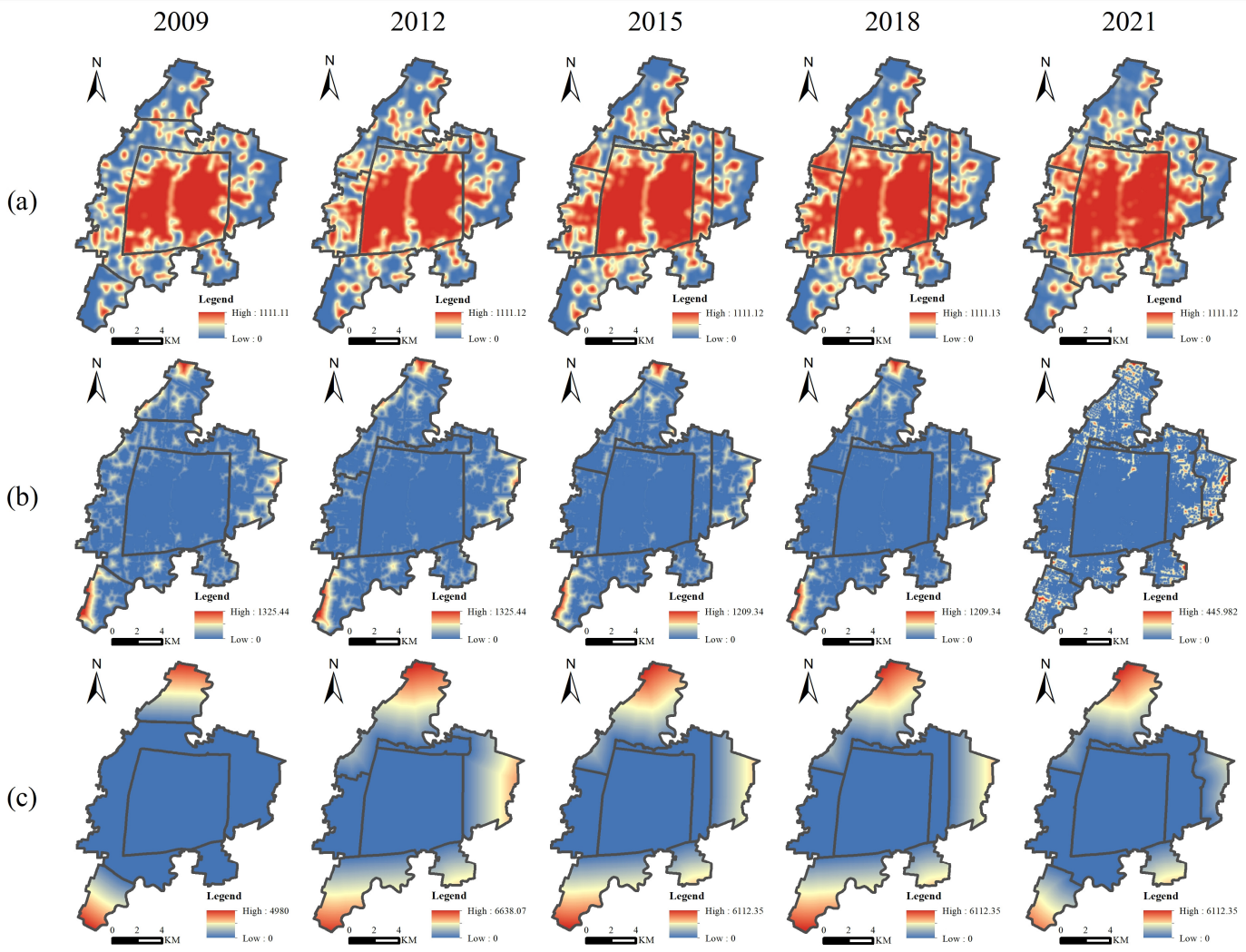


Figure 7. The spatial characteristics of construction land and the zone distribution map. (**a**) Concentration of construction land. (**b**) Distance from construction land (unit: m). (**c**) Distance from Zones I and II (unit: m).

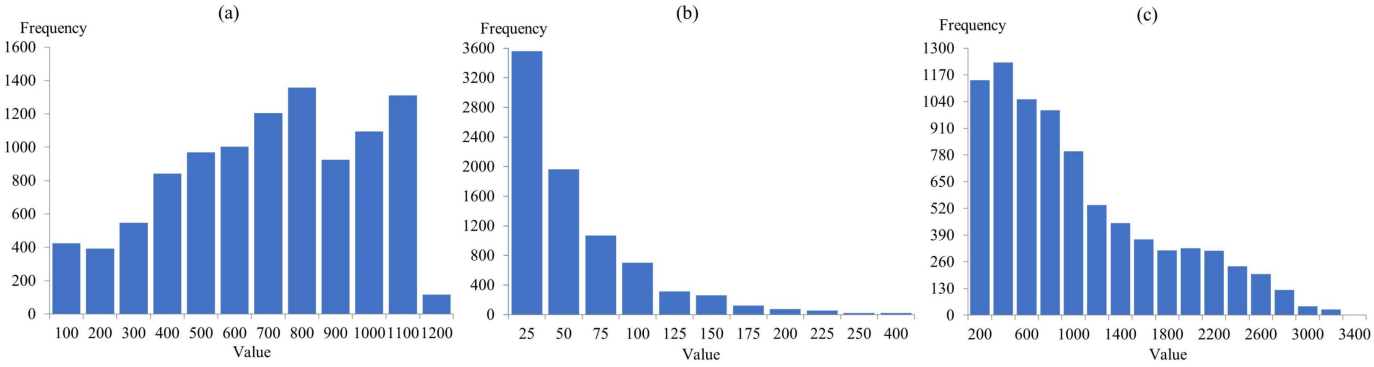


Figure 8. Histograms of factor frequency distributions of Zone III that was upgraded to Zone II. (**a**) Core density of construction land. (**b**) Distance from construction land. (**c**) Distance from Zones I and II.

As shown in Figure 9, from 2009 to 2012, the center of gravity of construction land in the Cangzhou urban area almost shifted westward. In 2021, the eastern part of Zone II experienced a significant contraction, while the majority of the western part was retained, indicating that the construction focus had shifted to the western part of Zone II. From 2012 to 2015, the center of gravity of construction land continued to move westward, but the distance was shorter compared to the 2009–2012 period, suggesting gradual eastward development of the Cangzhou urban area, with Zone II expanding eastward. The least movement in the center of gravity of construction land was observed from 2015 to 2018, and there were no changes in the zones. From 2018 to 2021, the center of gravity of construction land moved southeast, and the eastern part of Zone II expanded overall to the east, while the western part expanded southeastward. In summary, from 2009 to 2021, the direction of migration of the center of gravity of construction land in the Cangzhou urban area generally aligned with the expansion direction of the expropriation zone. In 2027, the center of gravity of construction land is expected to shift 587 m towards the southeast. This suggests that Zone II in the Cangzhou urban area is likely to expand towards the southeast.

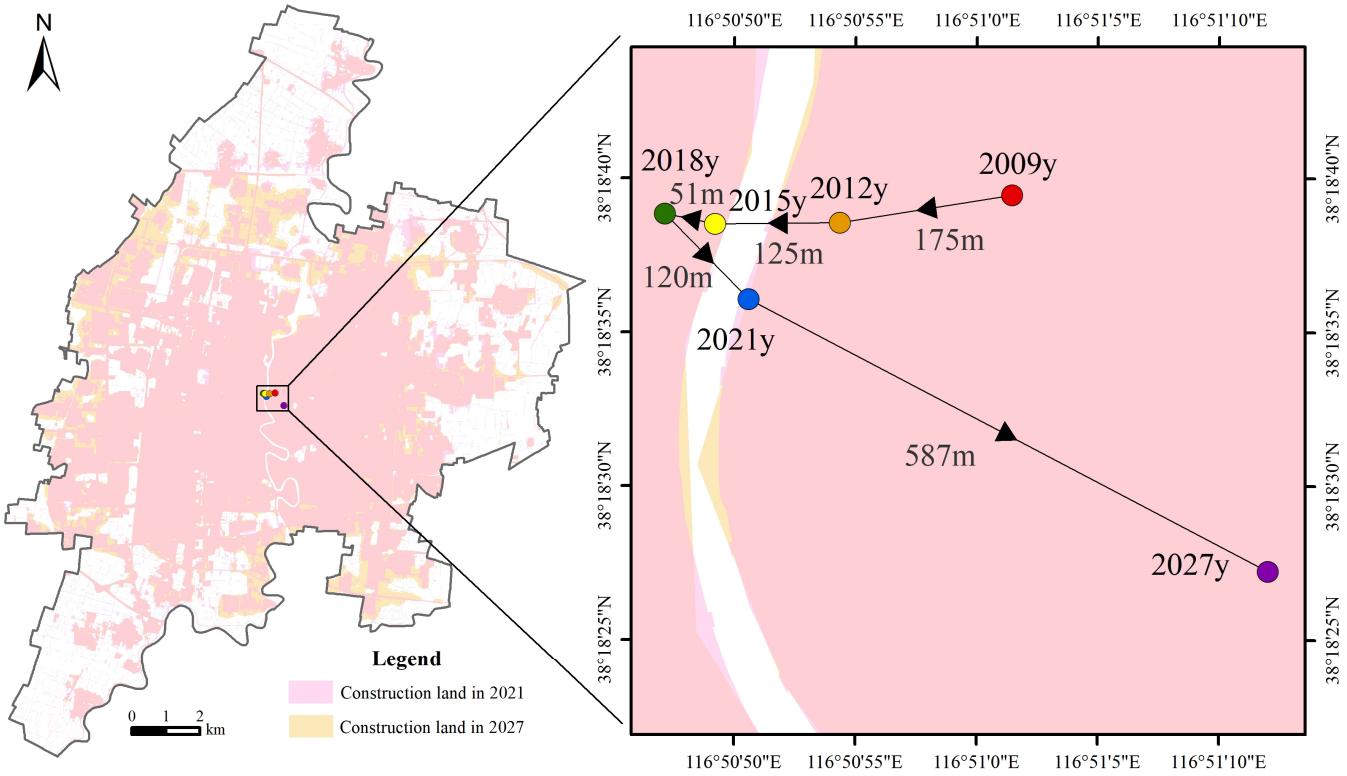


Figure 9. The migration of the construction land centroid in the Cangzhou urban area from 2009 to 2027.

3.2.2. Coupling Coordination Analysis of Land Use and Zone Prices

(1) Analysis of zone prices

According to Figure 10, following four adjustments, the price in Zone I increased by 0.0225 million CNY/hectare from 2009 to 2012, representing a 16.67% increment. In 2015, it surged by 66.67% from 1.575 to 2.625 million CNY/hectare, and it reached 2.64 million CNY/hectare in 2021, representing marginal growth of 0.57%. Zone II experienced adjustments of 15%, 57.61%, 0%, and 0.67% from 2009 to 2021. Zone III saw adjustments of 15%, 47.83%, 0%, and 2.52% over the same period. The pivotal year of 2015 marked significant increases in zone prices, with the average rising from 1.286.6 to 1.999 million CNY/hectare, a 55.37% surge. Evidently, from 2009 to 2021, both zone prices and the average showed upward trends, and 2015 was a critical juncture for a significant increase in zone prices.

The gap between zones narrowed in 2021 compared to 2015. This aligned better with local farmers' expectations and contributed to a reduction in the comparison mindset among farmers during land expropriation processes.

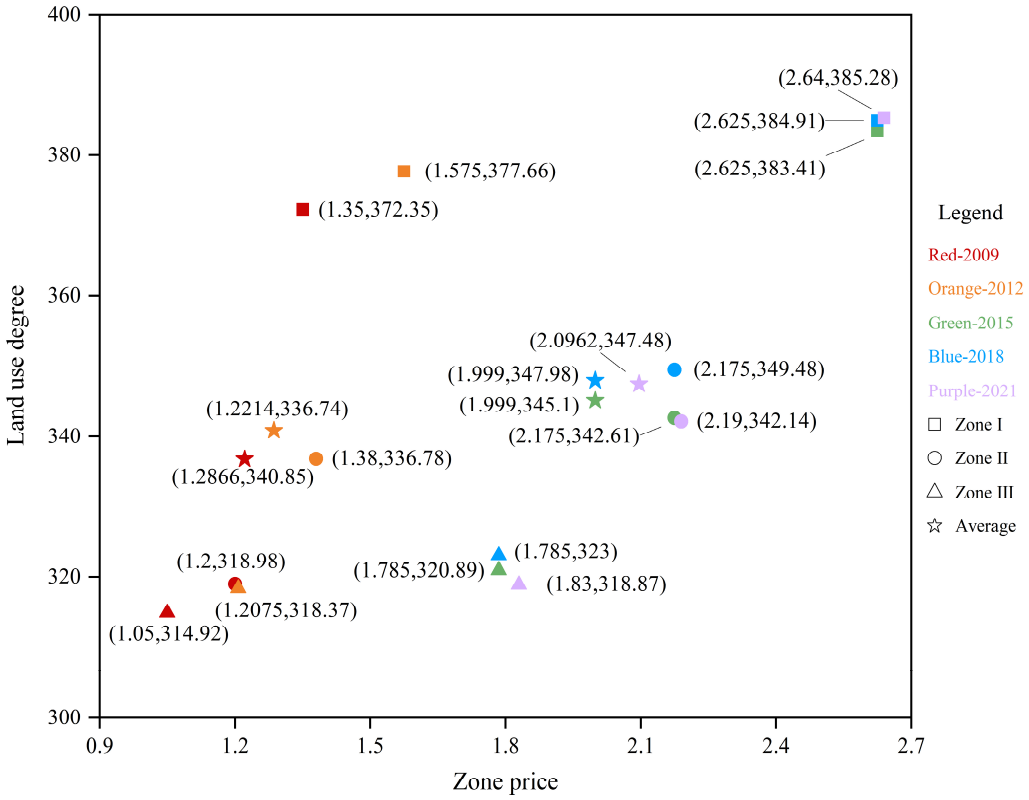


Figure 10. Scatter plots of land use degrees and zone prices. Zone price unit: million CNY/hectare.

(2) Analysis of land use degree

The calculation results in Figures 10 and 11 indicate that, from 2009 to 2021, the comprehensive index of land use degree of Zone I showed a trend of increasing first and then stabilizing. The dominant land use category was consistently construction land, with its proportion increasing from 78.82% to 90.18%. Zone I was characterized by a dense population, mature infrastructure, convenient transportation, a high level of development, and concentration of soft resources such as research and culture, resulting in a high degree of land development and utilization. In Zone II, the dominant land use category shifted from farmland to construction land, starting in 2012, and the comprehensive index of land use degree gradually increased, with a decline observed in 2021. From 2009 to 2021, the dominant land use category in Zone III was consistently farmland; the comprehensive index of land use degree first increases and then decreases. In summary, from 2009 to 2018, the comprehensive index of land use degree in the Cangzhou urban area and its zones consistently increased, but there was a slight decrease in 2021.

(3) Analysis of coupling coordination degree and relative development degree

As depicted in Figure 12, from 2009 to 2021, the CCD and RDD between the land use degree and zone prices in the Cangzhou urban area exhibited a trend with an initial increase followed by stabilization. The CCD between the land use degree and zone prices in various zones remained above 0.75, gradually increasing overall and consistently maintaining a level of barely coordinated or higher. This indicated pronounced mutual promotion of the land use degree and zone prices. In Zone I, the CCD between the land use degree and zone prices transitioned from primary coordination in 2009 to intermediate coordination in 2012 and skipped the good coordination stage to directly reach optimal coordination by 2015.

This suggests that land use significantly promotes zone prices, while zone price adjustments effectively guide land use optimization. In Zone II, the CCD between land use degree and zone prices improved from barely coordinated in 2009 to primary coordination in 2012 and progressed to good coordination by 2015, spanning three levels. This development was partially attributed to the finer division of Zone II and the gradually highlighted driving effect of Zone I. In Zone III, the CCD transitioned from barely coordinated to intermediate coordination in 2015. In 2015, after a significant leap in zone prices in the Cangzhou urban area, the lagging development of prices in Zones I and II significantly improved. The development and changes in land use and zone prices were relatively consistent. In 2021, the price gap between Zones III and II narrowed, increasing the price increment and bringing the price of Zone III into synchronous development with the land use degree. The land use degree and average zone price in the Cangzhou urban area consistently remained within the "Intermediate Coordination—Zone Price Lagging" stage in 2009 and 2012. After a significant increase in zone prices in 2015, the CCD also rose sharply to 0.9861, nearly reaching 1. This change eliminated the lag of zone prices behind land use and shifted to a synchronous development pattern. Subsequent adjustments further enhanced the CCD, reaching 0.9882 and 0.9996 and maintaining an "Optimal Coordination—Synchronous Development" stage. This indicates that the two elements mutually promoted each other at a higher level.



Figure 11. The land category proportions and land use degrees in various zones of the Cangzhou urban area from 2009 to 2021.

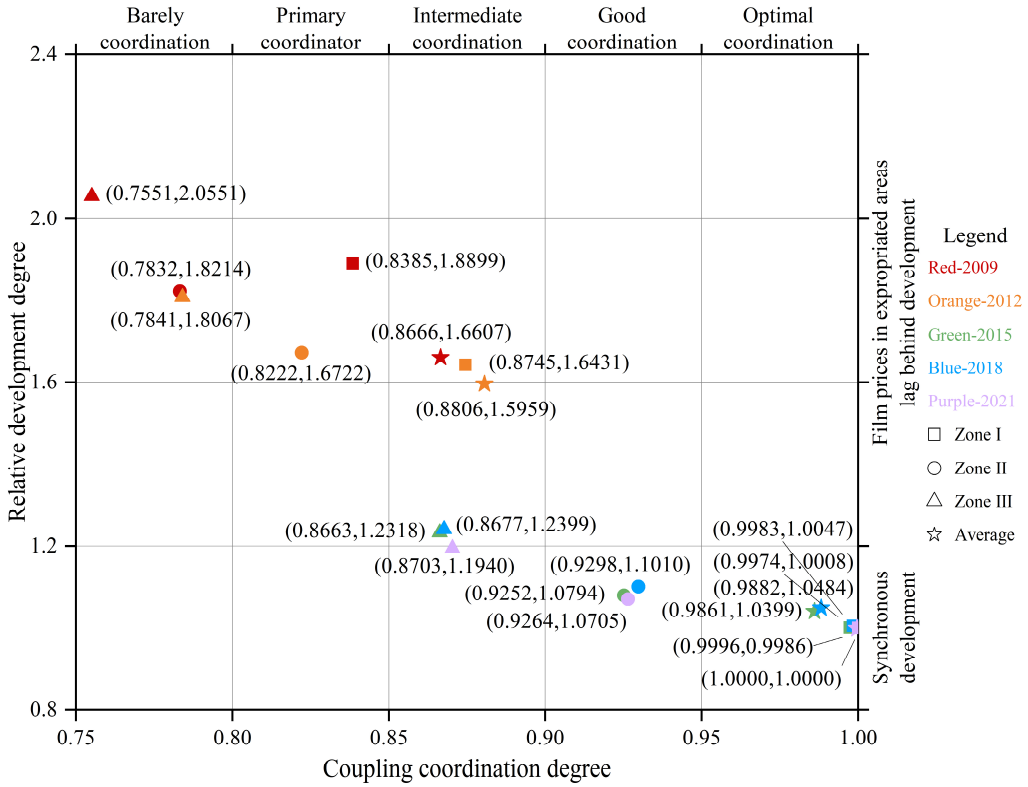


Figure 12. Coupling coordination and relative development degree diagram of zone prices and land use degree in the Cangzhou urban area from 2009 to 2021.

3.3. Simulating the Zone Distribution in 2027

To facilitate description, the northern, eastern, southeastern, and southwestern regions of Zone III in 2021 are referred to as Zones III-1, III-2, III-3, and III-4, respectively. According to the analysis in Section 2.1, the distribution range of Zone I in the Cangzhou urban area was relatively stable, and the probability of outward expansion was very small. The "Notice on Carrying Out the Adjustment of Comprehensive Land Expropriation Prices in Provinces by the Hebei Provincial Department of Natural Resources" explicitly states that "the zone price shall not be lower than the current land compensation standards", meaning that for the same plot of land, a price reduction cannot occur during the adjustment process. Considering the actual situation in Cangzhou urban area and potential risks to social stability, it is necessary to prevent the occurrence of this situation from two aspects: First, the prices of the three expropriation zone grades must not be reduced; and second, the grade of the plot cannot be reduced. Thus, in the Cangzhou urban area, zones generally do not undergo cross-level adjustments or downgrades. Therefore, Zone I will not be adjusted to Zone II or Zone III. Similarly, Zone II will not be downgraded to Zone III, and Zone III will only be upgraded to Zone II. Consequently, this study only set conversion rules for Zone III and set the transfer areas from Zone I to Zones II and III, from Zone II to Zones I and III, and from Zone III to Zone I to 0. Due to the instability in zone changes from 2009 to 2012, and the fact that the zone land price update and adjustment results of 2015 were used again in 2018, this section will not analyze the data from 2009 and 2018. The average transfer area from Zone III to Zone II in 2012, 2015, and 2021 was calculated to be 16.45% of the total area of Zone III (Table 3). This value was adopted as the projected proportion of land conversion from Zone III to Zone II in 2027.

Table 3. Zone III conversion in 2012, 2015, and 2021.

2012	Area 1	2015	Area 2	Proportion 1	2021	Area 3	Proportion 2
III	9802.67	II	951.29	9.70%	——	——	——
		III	8851.38	90.30%	I	36.63	0.41%
					II	2053.54	23.20%
					III	6761.21	76.39%

Note: The unit of area is hectares. The conversion of Zone III to Zone I in 2015 was due to the coordinate transformation from 2015 to 2021. The coordinate system in 2015 was the National Geodetic Coordinate System 1980, and the coordinate system in 2021 was the China Geodetic Coordinate System 2000.

The urban planning zone was designated for development and construction, guiding the direction of urban growth, where only land within the planning zone would be expropriated. The urban development boundary refers to the regional boundary where urban development and construction can be concentrated, urban functions can be improved, and spatial quality can be enhanced. Generally, there are no land expropriation actions outside the urban development boundary. The conversion rules for Zone III in 2021 were set as follows (Figure 13):

(a) The region within the planning zone was reclassified as 1, and the region outside this zone was reclassified as 0.
(b) The region within the urban development boundary was reclassified as 1, and the region outside this boundary was reclassified as 0 (this only applied to the suitability map for construction land).
(c) Based on the direction of the center of construction land migration in 2027, it can be inferred that: In 2021, Zones III-2 and III-3 were more easily converted to Zone II. They were assigned values of 1, while Zones III-1 and III-4 were assigned values of 0.5. The values for Zone I and Zone II were assigned as 0.
(d) Areas where the 2027 construction land aggregation degree was between 400 and 1100 were designated as high-probability transfer areas.
(e) Areas within 0–100 m of the 2027 construction land were classified as high-probability transfer areas.
(f) Regions located within 0–1000 m of Zones I and II in 2021 were designated as high-probability transfer areas.

Rules (a) and (b) are policy and planning constraints, acting as restrictive rules with exclusive binding power in the model, ensuring that the relevant conditions are prioritized and met without being affected by other rules. Rule (c) represents the zone conversion tendency. Rules (d) to (f) are spatial characteristic constraints, considered as influencing rules and assigned equal weight. For the conversion areas, restrictive rules (a) and (b) are given priority, followed by the zone conversion tendency (rule c), and finally refined by the spatial characteristic constraints (rules d to f). The final conversion probability is determined by the comprehensive probability after weighted superposition.

Based on the results of the CA–Markov simulation (Figure 14), the area of expansion of Zone II to the north will be 375.38 hectares, accounting for 11.37% of the area of Zone III-1; to the east, the expansion will cover 436.05 hectares, representing 35.05% of the area of Zone III-2; and to the southeast, the expansion will encompass 297.98 hectares, which will be 33.81% of the area of Zone III-3. In summary, the expansion of Zone II will primarily be concentrated within Zones III-2 and III-3.

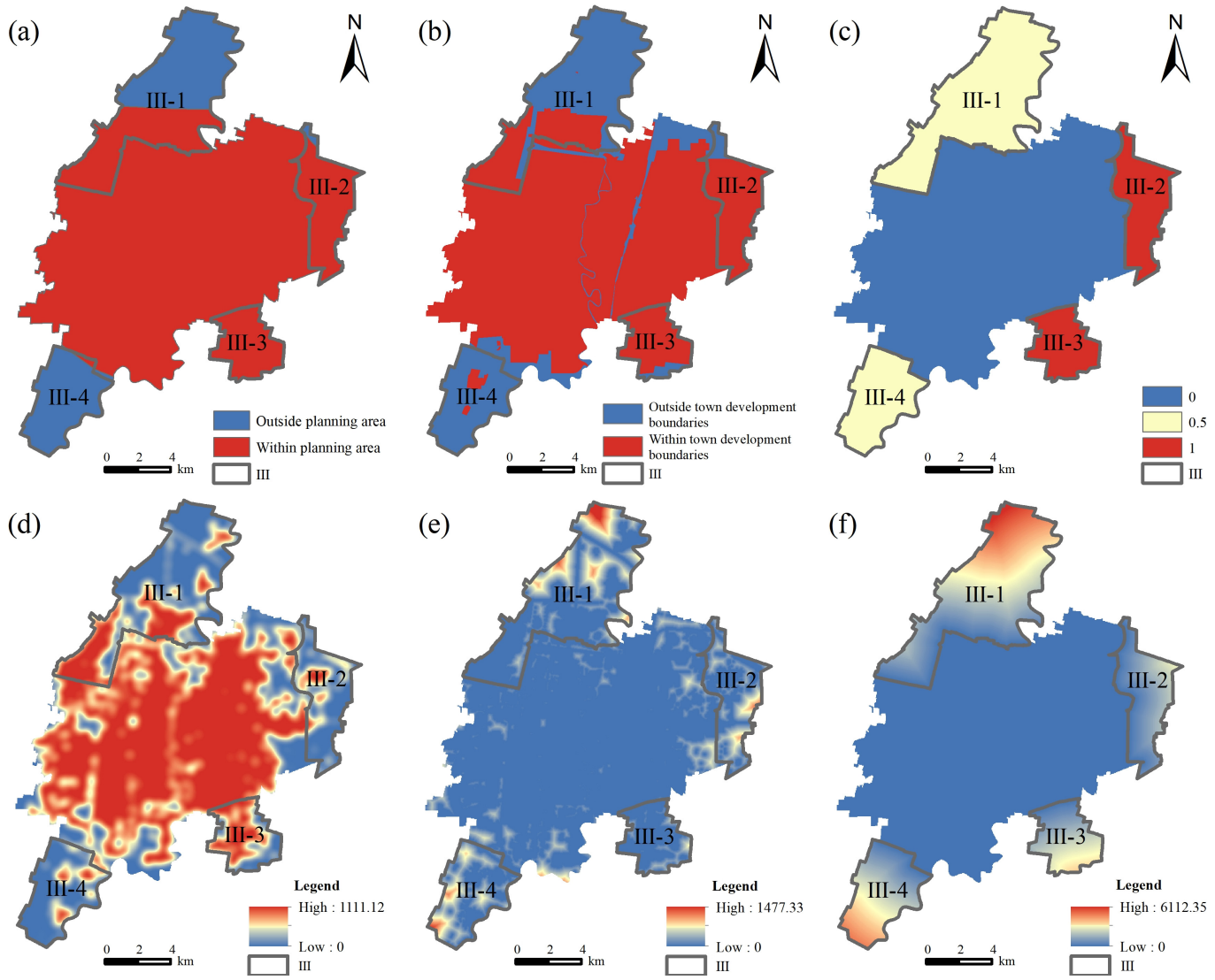


Figure 13. Zone III conversion rules. (**a**) Urban planning area. (**b**) Urban development boundary. (**c**) Zones III-2 and III-3 were more prone to conversion in 2021. (**d**) Agglomeration degree of construction land in 2027 (unit: m). (**e**) Distance from construction land in 2027 (unit: m). (**f**) Distance from 2021 Zones I and II (unit: m).

3.4. Forecasting the Zone Prices in 2027

Based on the linear functional equations of each zone and the range of values for the influencing factors (Table 4), the calculated range of prices for Zone I is 2.3659–2.7210 million CNY/hectare, for Zone II it is 1.8987–2.2537 million CNY/hectare, and for Zone III it is 1.7993–1.9306 million CNY/hectare. However, since each adjustment of zone prices tends to increase on the original basis, the final range of prices for Zones I, II, and III is set at 2.6400–2.7210 million CNY/hectare, 2.1900–2.2537 million CNY/hectare, and 1.8300–1.9306 million CNY/hectare, respectively. The level of zone price has been significantly improved.

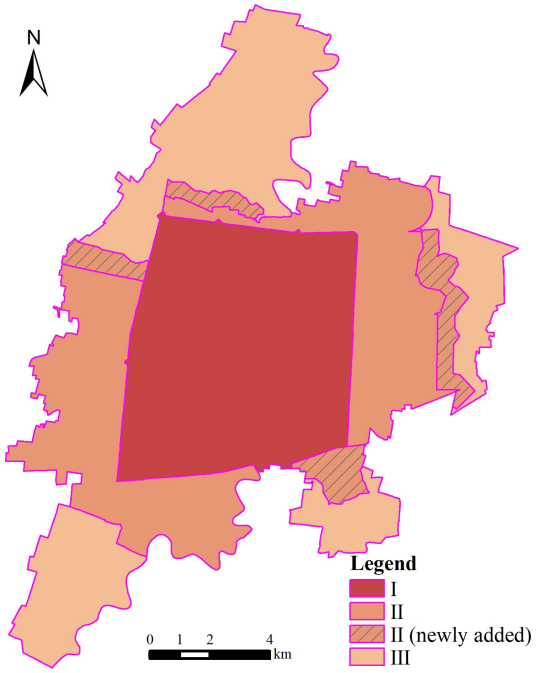


Figure 14. Simulation map of zone distribution in the Cangzhou urban area in 2027.

Table 4. Coefficient of linear function equation and the range of influencing factors in Cangzhou urban area.

Influence Factor	I			II			III		
	Coefficient	Value Range		Coefficient	Value Range		Coefficient	Value Range	
		Lower Limit	Upper Limit		Lower Limit	Upper Limit		Lower Limit	Upper Limit
Constant	230.7649	——	——	225.0487	——	——	174.9256	——	——
GDP	0.0029	44,603.9984	52,403.2634	0.0024	25,022.5821	36,839.2780	0.0018	20,989.7447	23,626.5950
NDVI	16.4729	0.4355	0.4618	−55.9621	0.5649	0.5923	−13.5164	0.6587	0.7221
Population density	−0.0081	5247.7066	5457.2008	−0.0053	2836.7405	3133.5715	−0.0012	1369.1571	1682.9081
Nighttime light index	−0.2113	202.4127	213.6268	−0.1451	102.6129	118.6136	−0.1477	47.6119	71.8894
Distance to railway	−0.0068	1535.5331	1700.4863	0.0001	3637.2584	3701.4324	0.0014	2325.7138	3265.4450
Distance to road	−0.0838	65.0262	73.7514	−0.0462	156.2391	168.0249	−0.0086	218.6094	278.7545
Distance to water system	0.0060	1355.9512	1655.1922	0.0007	1582.8356	1811.3591	0.0026	1992.4407	2417.9870
Distance to urban center	−0.0119	2257.9124	2660.7726	−0.0042	4675.4326	5006.4189	−0.0028	5390.4757	7171.7428

4. Discussions

4.1. Analysis of the Simulated Zone Distribution Results

The CA model has locality and parallelism [67]. Locality means that the state of a cell in the next moment is only related to its current state and the states of neighboring cells, independent of the overall cellular grid state. Parallelism indicates that cells transition simultaneously according to local rules, independent of each other. These properties mean that the four regions within Zone III are independent of each other and that the state transitions of the cells occur simultaneously, without the high-probability cells transferring first, followed by low-probability ones. Therefore, all four regions undergo transitions with differences in transfer degrees. The left transfer area of Sub-zone III-1 is located

within the Cangzhou High-tech Industrial Development Zone (hereinafter referred to as the "High-tech Zone"). The "Cangzhou City Territorial Space Master Plan (2021–2035)" (hereinafter referred to as the "Plan") designates the Cangzhou urban area as the core of the central metropolitan area block, emphasizing vigorous development of high-tech industries. The High-tech Zone is a crucial carrier of the economic development of the central urban area and serves as a significant growth pole for strengthening the city's economy. Given its robust momentum in boosting the economy and enhancing the competitiveness of industrial and innovation spaces, classifying this area as Zone II aligns with the developmental realities. The right transfer area of Sub-zone III-1 is relatively close to Zone I and clearly benefits from its radiative effects. This area has a concentrated distribution of construction land and is anticipated to add a new built-up area by 2027. Therefore, classifying this area as Zone II aligns with the developmental realities. Sub-zone III-2 was designated as a new industrial zone by the "Plan", with planned construction of modern educational facilities, showing a good development trend and a driving effect. Therefore, classifying this area as Zone II is in line with the actual development situation. The transition area of Zone III-3 is close to Zone I. It enjoys distinct location advantages due to the influence of the Zoo Happy World and its supporting facilities, which will effectively drive economic growth. Most of this area falls within a newly added built-up area. Thus, designating it as Zone II is in accordance with the developmental realities. Sub-zone III-4 has a small expansion, which accords with the transformation principle of the CA model, and the simulation results are reasonable.

4.2. Validation of the Zone Prices

Calculations have determined that the land use degrees for Zones I, II, and III 2027 are 385.86, 350.56, and 319.30, respectively. Considering the practical circumstances, the zone prices in 2027 may not reach the maximum values of the predicted ranges. Therefore, this study adopts the mid-values of the forecast ranges as the research data, which are 2.6805 million CNY/hectare for Zone I, 2.2219 million CNY/hectare for Zone II, and 1.8803 million CNY/hectare for Zone III. The CCD and RDD for Zone I have both achieved a value of 1, indicating an optimal coordination and synchronized development phase. For Zone II, the CCD and RDD are 0.9316 and 1.0961, respectively, suggesting a good coordination and synchronized development phase. Zone III exhibits a CCD and RDD of 0.8729 and 1.1797, respectively, marking a moderate coordination and synchronized development phase. They are consistent with the development phase in 2021. The average zone price for the Cangzhou urban area in 2027 is 2.2652 million CNY/hectare, representing an increase of 8.06% compared to 2021.

When adjusting zone prices, it is essential to ensure the healthy development of economic construction while safeguarding the legal rights of the rural collective economic organizations and farmers whose land is acquired. Referring to Sections 5.1.6 and 5.1.7.2 of the "Agricultural Land Valuation Procedures" (GB/T 28406-2012) [68], the annual net income of the land is first determined. Then, a method using the safe interest rate plus a risk adjustment is adopted to calculate the land capitalization rate. Specifically, the land capitalization rate equals the safe interest rate plus the risk adjustment value. Finally, the land price is calculated based on the term of the land use rights. According to the previous projections, the average zone price in the Cangzhou urban area in 2027 will be 2.2652 million CNY/hectare. When converted into annual net income for farmland and woodland based on the maximum contracted periods for farmland (30 years) and woodland (70 years) using a land capitalization rate of 4.1%, the following results can be obtained:

$$\begin{aligned} \textit{Annual net income from farmland}: \; & 2.2652 \times 4.1\% \div \left[1 - \frac{1}{(1+4.1\%)^{30}}\right] \\ & = 0.1326 \; \textit{million CNY/hectare} \end{aligned}$$

$$Annual\ net\ income\ from\ forest\ land:\ 2.2652 \times 4.1\% \div \left[1 - \frac{1}{(1+4.1\%)^{70}}\right] = 0.0988\ million\ CNY/hectare$$

This study converted the zone prices into annual per capita net incomes and compared them with the current living standards of farmers to analyze and validate the reasonableness of the zone prices. First, employing the Comprehensive Growth Rate Method [69], the projected population of the Cangzhou urban area was estimated to reach 788,200 individuals in 2027. Subsequently, based on forecasted values for farmland and forest land area in 2027, the per capita farmland area was calculated to be 0.0084 hectares, and the per capita forest land area was calculated to be 0.0004 hectares. Finally, by multiplying the per capita farmland area by the annual net income from farmland and the per capita forest land area by the annual net income from forest land, the per capita annual net income from farmland and forest land was derived. By adding the two, the annual average income obtained via land expropriation compensation per person was 1153.36 CNY. In 2022, the per capita disposable income of rural residents was 20,396 CNY in the Cangzhou urban area. The economic structure was 0.1:28.4:71.5 and was dominated by secondary and tertiary industries. Including incomes from secondary and tertiary industries on top of agricultural income, the total annual income exceeded the local per capita disposable income of rural residents. Therefore, according to these projections, it is ensured that the current living standards of farmers will not decrease and may improve. Adjusted zone prices are reasonable and capable of safeguarding farmers' rights and interests.

4.3. Methods for Calculating Zone Land Price

Currently, in China, the most widely used methods for dividing expropriation zones are the Homogeneous Region Adjustment Method and the Multi-Factor Comprehensive Division Method. The Homogeneous Region Adjustment Method is primarily applicable in areas where the previous land acquisition zoning results were relatively stable or where the agricultural land classification results are up to date. In contrast, the Multi-Factor Comprehensive Division Method requires the collection and analysis of large amounts of data, making it a complex and time-consuming process. This study extended the CA–Markov model to predict the distribution ranges of expropriation zones from the perspective of land use changes, offering a novel approach to zoning. Compared to traditional methods, the CA–Markov model can simulate complex dynamic systems with spatiotemporal characteristics, allowing for the customization of conversion rules based on different regional features and conditions [70]. This flexibility and adaptability make the CA–Markov model suitable for wide application scenarios, with good visualization effects of simulation results, providing the possibility to dynamically simulate changes in the distribution ranges of multiple zones.

The most widely used methods for calculating zone prices are the agricultural land value restoration method, the agricultural land price adjustment method, and the socio-economic indicator update method. Among them, the agricultural land value restoration method is based on the comprehensive annual output value of the dominant land type, while the agricultural price adjustment method needs to be based on the publicly announced land price of agricultural land, which is suitable in areas with a high degree of agricultural marketization. Both methods are based on the original land use for correction, and the calculation results are often low [71]. The socio-economic indicator update method is based on the existing regional prices and adjusted according to the magnitudes of changes in economic indicators within the region. However, in practice, adjustments to prices in a designated area are generally made at the county level, and there are few data that can be accurate at the district level. This can lead to multiple designated areas having identical indicator values. Additionally, it is worth noting that data collection requires coordination across multiple departments, significantly increasing the complexity of this process. The study employs the multiple linear regression model, based on the influencing factors of the zone land price, to construct a linear functional equation for zone price, thereby forecasting

the zone prices. This approach more accurately reflects the development of the economic and social conditions, narrows the gap between land expropriation compensation standards and the market value of land, and ensures the rationality and fairness of compensation.

4.4. Sustainable Development Goals

The reasonable division of expropriation zones is an important means to promote the rational use and allocation of land resources and is closely related to the United Nations Sustainable Development Goal "SDG 11: Sustainable Cities and Communities". This goal aims to ensure the sustainability of urbanization processes, including urban planning, housing policies, transportation systems, and the management of public spaces [72]. This necessitates achieving efficient urban land use through rational planning and allocation of land resources, preventing uncontrolled expansion, reducing encroachment on agricultural land, protecting the ecological environment, and thus promoting sustainable urban development. Furthermore, this study only divided expropriation zones from a scientific research perspective. In practical applications, decision makers also need to adjust zone boundaries according to actual development conditions and administrative management needs to avoid having different prices for land in the same village, promoting social harmony and stability [32].

Scientific calculation of zone prices aligns with the goal "SDG-10: Reduced Inequalities". Horizontal inequality is a root cause of violence and conflict, severely affecting social stability and peace [73]. When calculating zone prices, emphasizing the reduction in the gap between land expropriation compensation standards and land market values, rather than just focusing on the original use of the land, helps to ensure fairness in the utilization and distribution of the benefits of land resources among different regions and groups [17].

In summary, the reasonable division of expropriation zones and scientific calculation of zone prices are important measures that can be used to achieve multiple sustainable development goals. Together, they promote the sustainable development of cities.

4.5. Limitations

(1) Given the challenge of obtaining high-precision data, this resulted in some factors driving land use having resolutions of less than 30 m. This required the use of ArcGIS to uniformly set the pixel size to 30 m. However, this approach incurred some degree of accuracy loss resulting from the forced resolution enhancement. For example, GDP, NDVI, population density, and nighttime light index. At the same time, data for some missing years are obtained through interpolation, which somewhat reduces the rigor and scientific of this study. (2) The selection of factors driving land use in this paper was limited to the relationship between land use and the expropriation zone, neglecting the impacts of other factors such as social stability risk factors, policy measures, and price levels, which can also cause variations in the distribution and price of zones. Subsequent research could encompass a more comprehensive range of driving factors and explore the multi-dimensional mechanisms influencing zone prices based on land use changes. (3) Due to the particularity of the study area, the application scope of the results of this study is limited. It is only applicable to cities with high levels of development in the central urban area and exhibiting a typical pattern of expansion from the center to the surrounding areas. (4) The prediction results of this paper are the results of scientific research and have not been improved from the management level. This requires the government to consider the actual local situation and social stability risk factors while referring to the predicted results, and make further adjustments to the boundaries and prices of the zones.

5. Conclusions

This paper used the Cangzhou urban area, Hebei Province, China, as a case study to analyze the coupled relationship between land use and zone land price from 2009 to 2021. Furthermore, it simulated and predicted the land use data, zone distribution, and zone prices in the year 2027. The main conclusions of this study are as follows:

(1) There is a mutual feedback mechanism between land use and land expropriation. This is primarily manifested when land expropriation spatially alters the distribution pattern of construction land, thereby enhancing the land use degree and indirectly affecting the distribution and prices of zones. Conversely, appropriately setting the zone land price, which enhances intermediate factors like farmer satisfaction and land value, can effectively reduce land expropriation conflicts, promote urban expansion, and ensure the orderly and healthy progress of land expropriation efforts. Understanding and leveraging this mechanism to formulate rational land expropriation and compensation policies is crucial for optimizing land resource allocation and promoting coordinated regional economic development.

(2) The impact of land use on zone distribution is primarily reflected in the spatiotemporal coupling relationship between the spatial characteristics of construction land and zone distribution. The central urban built-up area exhibits distinct differences from surrounding regions, with a distribution pattern that is relatively mature and unlikely to undergo further adjustments in the near term. The recent development zones in the central urban area are more inclined to expand in the direction of relocation of the center of gravity of construction land. They have high concentrations of construction land and are in close proximity to existing construction land and Zones I and II. Conversely, the zone outside the urban core will contract as the recent development zones in the central urban area expand, reflecting dynamic spatial changes in urban development. Overall, the spatiotemporal coupling relationship between the two is an important foundation for understanding urban development and planning. Future research should focus on the specific manifestations of this relationship and its profound impact on the urban spatial structure.

(3) The CCD and RDD between the land use degree and the zone price are gradually improving. The economic value of land, land resource conditions, and land location conditions can well reflect the zone price situation. Predicting zone prices based on the multiple linear regression model can effectively enhance the zone prices, narrow the gap between land expropriation compensation standards and land market values, and ensure the rationality and fairness of compensation. The dynamic relationship between land use and zone prices is particularly important for urban planning and policy formulation. How to optimize land use strategies to enhance the economic value of land still requires in-depth discussion.

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