Case Study

Urban Function Orientation Based on Spatiotemporal Differences and Driving Factors of Urban Construction Land

Jintao Li, Ph.D.[1]; and Zongfeng Sun, Ph.D.[2]

Abstract: This paper examines the development trends of urban construction land in 17 cities within the Shandong province, China, and uses multivariate linear regression, a geographical detector, and a spatial neighborhood analysis to determine the spatiotemporal driving mechanisms of construction land development from 1985 to 2015. The results reveal clear differences in the scale, rate, direction, and stability of urban construction land, and the 17 cities investigated were divided into four development models, including the uncoordinated wave cities (Jinan, Yantai, and Weifang), uncoordinated stable cities (Zibo, Rizhao, Linyi, Dongying, and Binzhou), coordinated wave cities (Qingdao, Zaozhuang, Taian, Laiwu, Weihai, and Liaocheng), and coordinated stable cities (Jining, Dezhou, and Heze). A number of temporal driving factors affected the expansion scale of urban construction land, including the natural population growth rate, employment index, second industry structure ratio, and firm size index, whereas the spatial driving factors that affected the spatial pattern of urban construction land included the distance to the main railway, distance to the main road, and distance to the city center. Next, points were assigned to different levels of characteristics and spatiotemporal driving factors of the urban construction land, a composite score of urban development was obtained, and the 17 cities were divided into the following zones: core trading (Qingdao), key development (Jinan and Yantai), industrial cluster (Jining, Laiwu, Linyi, Weifang, Weihai, and Zibo), and conserving economic zones (which included the remaining eight cities). Different functions and development directions should be considered in these different zones. For instance, more international trade markets should be built in Qingdao to promote the export of industrial products, whereas Jinan and Yantai should target development into megacities, and provide technical guidance and industry driving for the surrounding cities. Finally, the study recommends the intensive use of land, industrial transformation, and upgrading, as well as multifunctional development planning and building a multidimensional transportation network to promote coordinated and integrated development in Shandong province. **DOI: 10.1061/(ASCE)UP.1943-5444.0000587**.

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Introduction

Change in land use is a unique natural and social phenomenon involving the environmental attributes of land resources and changes in human use patterns. Land is a primary factor of socioeconomic development and population settlement, which, in the context of rapid urbanization and industrialization, is being developed extensively for construction. From 1985 to 2015 in China, the urban population increased by 210%, and the urbanization rate from 23.7% to 56.1% (Qi et al. 2017); the area of urban construction land increased by 510%, and the number of cities increased by 332 (Wu et al. 2016). On the one hand, land urbanization promotes urban expansion and results in more rural residents transferring into urban populations, who enjoy high levels of education, medical care, and social infrastructure (Zienkiewicz et al. 2014). On the other hand, inefficient land use and irrational structural layouts lead to many problems including urban villages, idle land, unfinished projects, traffic congestion, and the destruction of biological habitats in the process of urban construction (Oleksyn and Reich 1994; Long et al. 2018). In addition, a lack of coordination between human settlement and land development has become increasingly prominent due to land urbanization taking place faster than population urbanization (Lin et al. 2015). Given the complexity of land use and urbanization, it is of great significance to understand the changes and driving mechanisms of urban construction land to promote coordinated regional development.

Existing research on land use in urban construction is primarily focused on the evolution process, driving mechanisms, and development forecasts (Chace and Walsh 2006). The main aim of the research is to promote land-intensive utilization and sustainable urban development through land use planning (Xu et al. 2016). Scholars have conducted substantial empirical research on the identification and analysis of urban construction land using geographic information systems (GISs) and remote sensing (RS) (Straume 2014; Montgomery and Dragićević 2016). Different countries and regions have different growth rates, patterns, and spatial changes, and urban construction land in Asia and South America have had a faster growth rate than that in Europe and America in recent years (Cao et al. 2015). Research on the influencing factors and dynamic mechanism of urban construction land use reveals the reasons behind and modes of urban construction land growth, providing critical references for urban development forecasting and planning. Primary influencing factors include population, economy, resources, traffic, environment, and policies (Liu et al. 2015; Wang et al. 2018). Population and economy affect the scale of urban construction land (Cho 2005), and traffic, resources, and environment affect the direction of urban expansion (Liu and Zhang 2012), whereas policies

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have an important effect on the scale and direction of urban development (Landry and Pu 2010). With the improvement of technology, more scholars have begun to predict the development of urban construction land using the cellular automata (CA) model for determining scale (Yao et al. 2017), and the CLUE-S model for determining the spatial pattern (Jiang et al. 2015). Although the resulting predictions are not certain, they do offer important references for urban land use planning (Baycan-Levent and Nijkamp 2009). For example, some scholars have used driving mechanisms and development predictions to study green ecology planning and the sustainable use of urban construction land (Wallbaum et al. 2011).

Owing to different resources, locations, and policies, there are substantial differences between cities, and ill-conceived prediction and urban planning may lead to uncoordinated and unsustainable development across a region. This study took 17 cities in Shandong province in China as case studies and used multivariate linear regression, a geographic detector, and a spatial neighborhood analysis to diagnose the spatiotemporal driving mechanism of urban construction land from 1985 to 2015. The results of this analysis provide a basis for dividing the cities into different functional zones with different development directions. Finally, this paper offers some policy recommendations for regional integrated development based on the findings.

Materials and Methods

Study Area

Shandong is located on the east coast of China, the lower reaches of the Yellow River, and the north-central section of the Beijing–Hangzhou Grand Canal. It is the northernmost province in East China. It is near the Yellow Sea and the Bohai and across the sea from Japan, North Korea, and South Korea. It has 17 cities and 140 counties (Fig. 1). There were more than 100 million permanent residents in 2017, which makes it the second most populated province in China. The gross domestic product (GDP) in 2017 was 7,267.818 billion yuan, which made it the fifth most economically developed province. However, although Shandong has a large population and economy, the province only occupies a relatively small portion of land (155,800 km^2). In addition, in terms of economy, there are major differences between the 17 cities in Shandong and urban construction land has been developed alongside the different growth of the population and economy over the last 30 years.

Data Sources

This study uses the land usage raster data (100×100 m^2) provided by the Resource and Environmental Science Data Center of the Chinese Academy of Sciences to analyze the spatiotemporal evolution characteristics of urban construction land of 17 cities in Shandong province from 1985 to 2015. In addition, the study is informed by the elevation and slope of the land using the digital elevation model (DEM) data provided by the National Geographic Information Center through image correction and slope analysis. In other words, we obtained the distance of each grid to the main railway, river, and highway as axis elements, and distance to the city center as the point elements by using spatial neighborhood analysis. The natural conditions affect the direction of urban construction land, and most cities are built on gentle slopes and low elevations. The location elements affect the expansion of urban construction land, such as the strip distribution along traffic lines and the circular distribution around city centers. Thus, the spatial driving factors of the point–axis–zone three-level system were formed (Table 1).

According to domestic scholars' research, there are many social and economic factors affecting the development of urban construction land including economy, population, and transportation, which have an important impact on the scale of urban expansion mode (Zhang 2009). This study selects the economic level, population scale, and industrial structure as temporal driving factors (Table 1). Economy determines the scale and speed of urban development, and provides the power for urban expansion. At the same time, urban expansion can also drive economic growth. Population provides the labor resources for urban development and increases urban land pressure. Higher population urbanization rates need more construction land to meet people's needs for life and work. Industry determines the type and scale of urban construction land such as industrial land and commercial land. Expansion of industry scale could attract more people into a city and improve the city's economic level. Thus, these factors interact with urban construction land, and as time goes by, the increase in factor size drives the expansion of urban construction land. All data of temporal driving factors come from the *China Statistical Yearbook*, *China City Statistical Yearbook*,

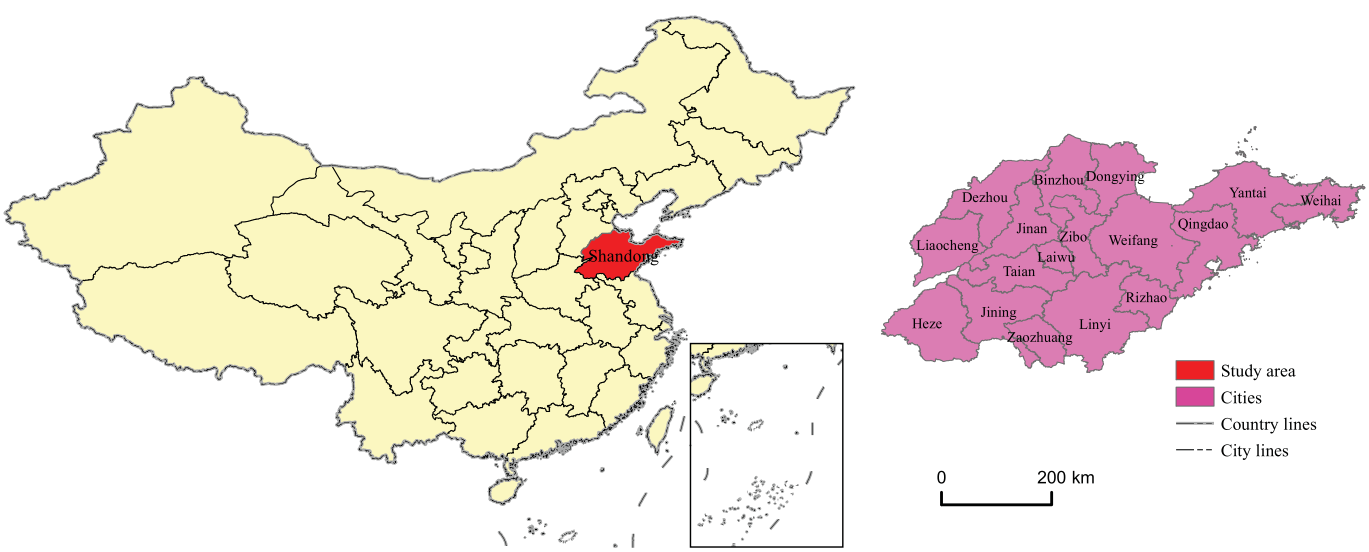

Fig. 1. Study area.

and *China Urban Construction Statistical Yearbook* according to the principles of data science and operability.

Data Processing Models

The socioeconomic data of 17 cities changed from 1985 to 2015, and each city has different development rules owing to different policies and environments. The positional and resource data are spatial scales of different cities at the grid level and each city includes different raster regions. Thus, the study detected temporal driving factors through multivariable linear regression and spatial driving factors using the geographical detector.

Multivariable Linear Regression

Multivariable linear regression is used primarily to discuss the statistical relationship between independent variables and dependent variables, and the influence of various factors on the rural transformation development in terms of quantity relationships (Zelterman 2015). This method could eliminate the collinearity effects of independent variables and obtain the linear model of socioeconomic factors and the change rate of urban construction land. There are 12 independent variables of 17 cities from 1985 to 2015 and these cities were considered a closed system in which all variables had only influenced their own urban development. For detecting the main driving factors, the study used stepwise regression to obtain the optimizing model. The confidence level (p) needs to be less than 0.01, and R^2 needs to be more than 0.9:

$$y = \sum_{i=1}^{n} \beta_i \times z_i + \alpha \tag{1}$$

where the dependent variable y = scale of urban construction land each city; the independent variables z_i = temporal driving factors of each city; β_i = coefficient corresponding to the driving factor; and α = constant of the multiple regression model.

Geographical Detector

The geographical detector obtains the correlation factor variables and outcome variables through the discrete classification of various factors with different processing methods, based on the theory of spatial difference and analyzes the influence of different variables in the same spatial scales (Wang and Hu 2012). There are six spatial variables including point–axis–region factors. All the variables were considered as in an open system in Shandong province, in which nine types were classified using the same distance method. In addition, the factor force (q) was introduced to describe the effect value of variables and used to detect the dominant spatial driving factors as follows:

$$q = 1 - \frac{1}{n\sigma^2} \sum_{h=1}^{L} n_h \sigma_h^2 \tag{2}$$

where q = factor force; σ^2 = total variance of spatial driving factor (y_i) in each city; σ_h^2 = variance of spatial driving factor in each layer (h); n = total number of samples of spatial driving factor (y_i); n_h = number of samples of spatial driving factor in each layer (h); and L = number of layers of spatial driving factor. The larger the value of force, the more obvious the influence on the change of urban construction land.

Urban Function Orientation

Urban function orientation is divided by the spatiotemporal characteristic (scale, stability, and trend) and driving factors (the number of temporal driving factors and the forces of spatial driving factors). First, the study assigns three kinds of points ("1," "3," and "5") to different indicators; the higher level the indicators, the larger the score (Table 2). Second, the study receives a composite score (P) for each city by weighting different indicators using

$$P = \sum_{i=1}^{m} k_i \times w_i \tag{3}$$

Table 1. Driving factors of urban construction land

Element type	Temporal driving factors	Element type	Spatial driving factors
Economic level	GDP index (x_1)	Regional element (Natural conditions)	Elevation (y_1)
	Fixed asset investment index (x_2)		Slope (y_2)
	Social consumption index (x_3)		
	Fiscal revenue index (x_4)	Axis element (Traffic location)	Distance to the main railway (y_3)
Population scale	Population density index (x_5)		Distance to the main river (y_4)
	Natural population growth rate (x_6)		Distance to the main road (y_5)
	Employment index (x_7)	Point element (Economic location)	Distance to the city center (y_6)
	Urbanization rate (x_8)		
Industrial structure	Second industry structure ratio (x_9)		
	Tertiary industry structure ratio (x_{10})		
	Industrial output scale index (x_{11})		
	Firm size index (x_{12})		

Table 2. Score different indicators

	Spatiotemporal characteristic			Driving factors		
Level (k_i)	Scale (k_1)	Stability (k_2)	The time when the maximum value occurs (trend) (k_3)	Temporal driving type (k_4)	Spatial driving forces (mean) (k_5)	Score
High	Large	Fluctuation rise	Late stage	Multivariate	0.1–1	5
Medium	Medium	Smooth rise	Medium stage	Double	0.08–0.1	3
Low	Small	Fluctuating decline	Early stage	Single	0–0.08	1
Weight (w_i)	0.6	0.1	0.1	0.1	0.1	—

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where P = composite score of each city; k_i = an indicator's score ($k_i = 1, 3$, or 5); w_i = weight of different indicators; and m = number of indicators ($m = 4$). The greater the value of P, the higher the developed degree of urban construction land and the urban level. Because the scale of urban construction land has an important effect on urban development, its weight is the largest (0.6) and other indicators' weights are 0.1. Finally, according to the composite score, the study divides the cities into functional zones.

Results

Spatiotemporal Characteristic of Urban Construction Land

Temporal Evolution Characteristics of Urban Construction Land

This study selected six time periods (1985–1990, 1990–1995, 1995–2000, 2000–2005, 2005–2010, 2010–2015) to analyze the evolution laws of urban construction land in Shandong province (Fig. 2). According to the area change scales of construction land (CSCL), the study divided the 17 cities into three types: the CSCL in Qingdao, Jinan, and Yantai is more than 250 km^2, making them the large cities; Zibo, Jining, Weihai, Linyi, and Weifang are medium cities because their CSCL is more than 150 km^2 and less than 250 km^2; the remaining cities are of smaller scales as their CSCL is less than 150 km^2. With changes over time, the urban construction land of the 17 cities presented different forms of fluctuations and the peak value located in different time periods. Only the peak value of Zibo existed before 2000 belonging to former change; the peak values of Qingdao, Zaozhuang, Weihai, Jining, Laiwu, Dezhou, and Liaocheng changed after 2010 and the remaining nine cities changed at the mid-term from 2000 to 2010.

According to the interception of six stages, this study divided the 17 cities into declining volatility, increasing volatility, and increasing stability. The interceptions of Jining, Dezhou, and Heze had been increasing from 1985 to 2015 and their scale was less than other cities, which were increasingly stabilized cities. The interceptions of Qingdao, Zaozhuang, Weifang, Taian, Laiwu, Weihai, and Liaocheng generally increased from 1985 to 2010; however, they declined in the mid-term, because of increasing volatility. However, there were some cities whose interceptions first rose and then fell from 1985 to 2015: declining volatility cities. The maximum value of declining volatility and increasing volatility cities occurred in 2010–2015 and the maximum value of declining volatility cities was in the mid-term. According to the temporal evolution characteristics of the 17 cities' urban construction land, there were substantial differences in change scales, change rates, volatility, and sustainability, which led to different urban development forms.

Spatial Evolution Characteristics of Urban Construction Land

This study analyzed the spatial evolution characteristics of 17 cities' urban construction land from 1985 to 2015 through a raster calculation (Fig. 3). On the whole, the change of urban construction land shows significant agglomeration and most city centers were the primary increasing region of urban construction land. Qingdao is a special region and its urban area is divided into some nonconnected parts with the urban construction land increasing along a new urban area instead of expanding around the old city center as is the case in other cities. Thus, Qingdao has developed faster than other cities since 2005 and its maximum value of interception was in the period 2010–2015. Its economy also increased from 2010 to 2015. From this, we can infer that Qingdao is developing at a higher speed different to other cities in the last 10 years.

This study extracted varying grids of 17 cities' urban construction land using decentralized segmentation and analyzed the spatial

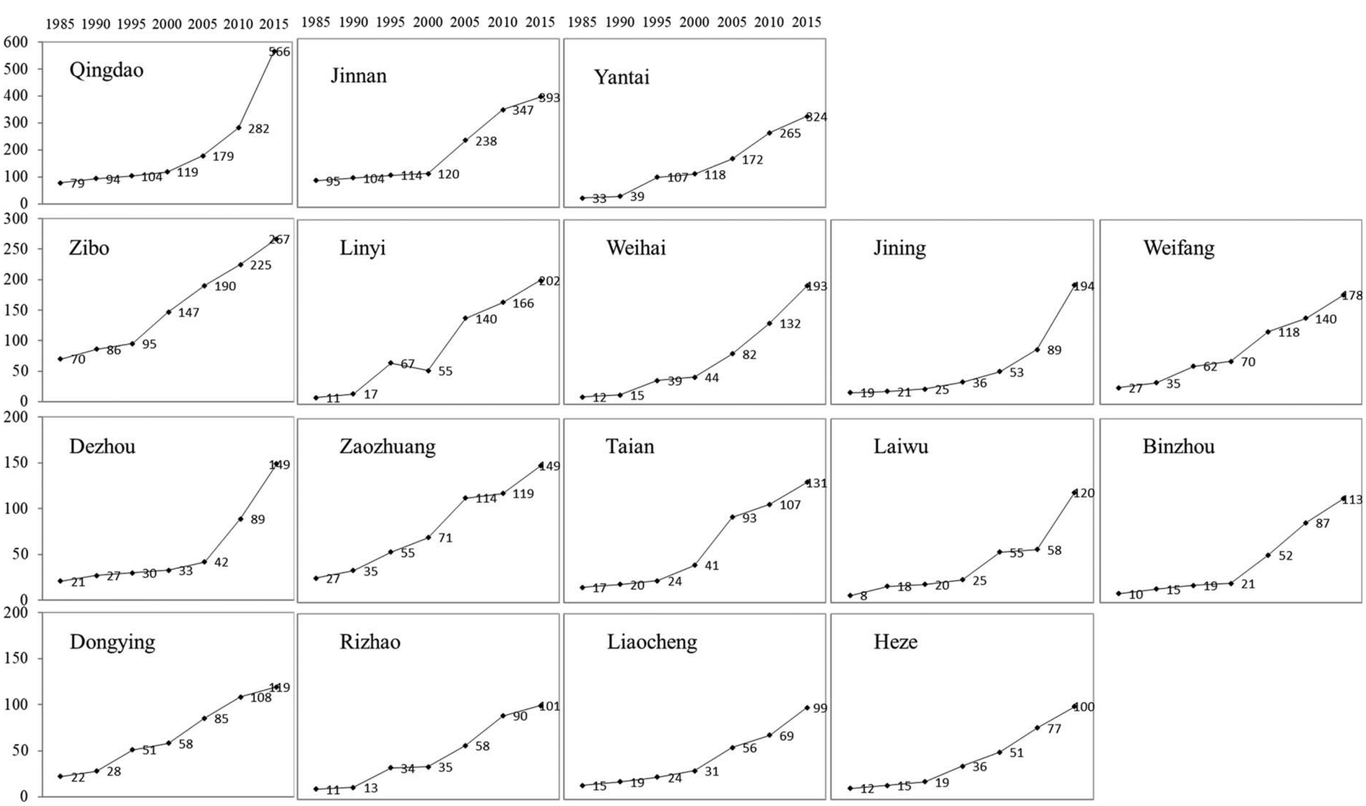

Fig. 2. The process evolution of urban construction land in Shandong province (km^2).

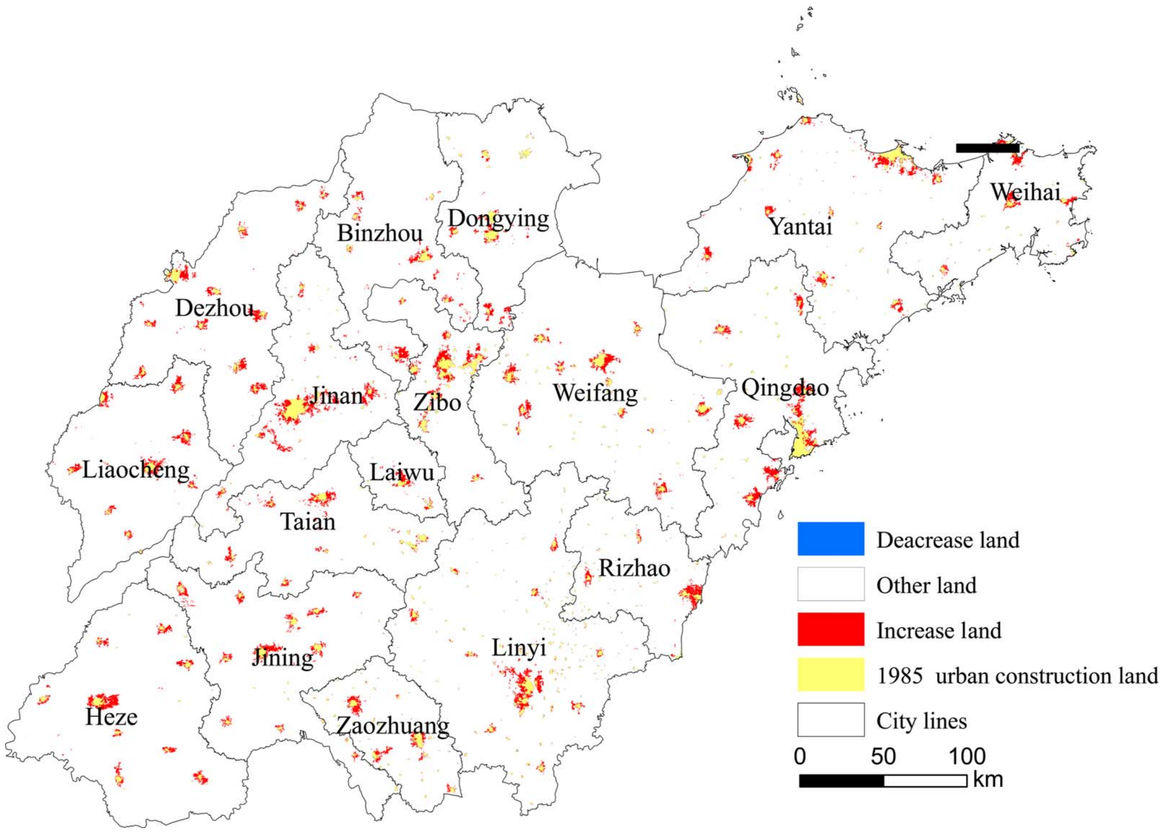

Fig. 3. The change of urban construction land in Shandong province from 1985 to 2015.

evolution characteristics of these 17 cities according to the expansion scale and the direction of urban construction land over the last 30 years (Fig. 4). Taian, Rizhao, Linyi, Liaocheng, and Heze had continued to grow around the city center from 1985 to 2015 and formed a concentric pattern of growth, belonging to diffusion types. Jinan, Zibo, Zaozhuang, Weifang, Jining, Dezhou, and Binzhou's urban construction land had been developed in the east and west region since 1985, belonging to an East–West bias, which formed the eastern and western strip increasing model. The remaining cities were a southern and northern strip increasing model and their urban construction land changed primarily along the south and north of the city center. The spatial expansion model analysis of urban construction land from 1985 to 2015 not only shows the spatial pattern changes of 17 cities but also could diagnose the main direction of urban development in the last 30 years.

Urban Construction Land Development Type

This study summarized the scale of change, the stability of change, the time at which maximum value occurred, and the direction of the land expansion in a table of urban development according to the spatiotemporal characteristics of urban construction land in Shandong province (Table 3). The 17 cities were divided into four groups using a cluster analysis method: uncoordinated wave cities, uncoordinated stable cities, coordinated wave cities, and coordinated stable cities. Jining, Dezhou, and Heze are coordinated stable cities: medium or small scale with a gradual increase. Their maximum value occurred in the later stage and, since 1985, the urban construction land expanded mainly in the west and east. Zibo, Rizhao, Linyi, Dongying, and Binzhou are uncoordinated stable cities: their change scales were fluctuating decline and the maximum value generally occurred in the early or medium stage. Two of the cities developed in the west or east and the other two developed around the city center. Jinan, Yantai, and Weifang are uncoordinated wave cities and their common characteristics are fluctuation and maximum value in the medium stage. These three cities are larger than other cities in Shandong and their economy levels are also higher than all other cities except Qingdao. The remaining six cities are coordinated wave types with fluctuating change and their maximum value occurred in the later stage.

There were great differences in the expansion scale, direction, stability, and development stage of urban construction land combining the spatial pattern change and temporal evolution characteristic of 17 cities' urban construction land in Shandong province. They formed developed models by the influence of socioeconomic resources and position factors.

Detection of Driving Factors for Urban Construction Land Expansion

This study selected the temporal and spatial driving factors that might influence the change of urban construction land according to domestic and foreign scholars' research experience. It used the multivariate regression model to analyze the influence of socioeconomic factors and detect the temporal driving factors of urban construction land evolution over time. The study used the geographical detector to measure the force values of resources and position factors and ensured the spatial driving factors of urban construction land. Thus, the two driving factors detection methods obtained comprehensive factors that influence urban construction land expansion, which is of significance to promote coordinated urban development in Shandong province.

Driving Factor Analysis of Temporal Evolution

According to the stepwise regression of the multivariate regression model, we eliminated the collinear factors and chose 17 cities' temporal driving factors to build the optimizing model (Table 4).

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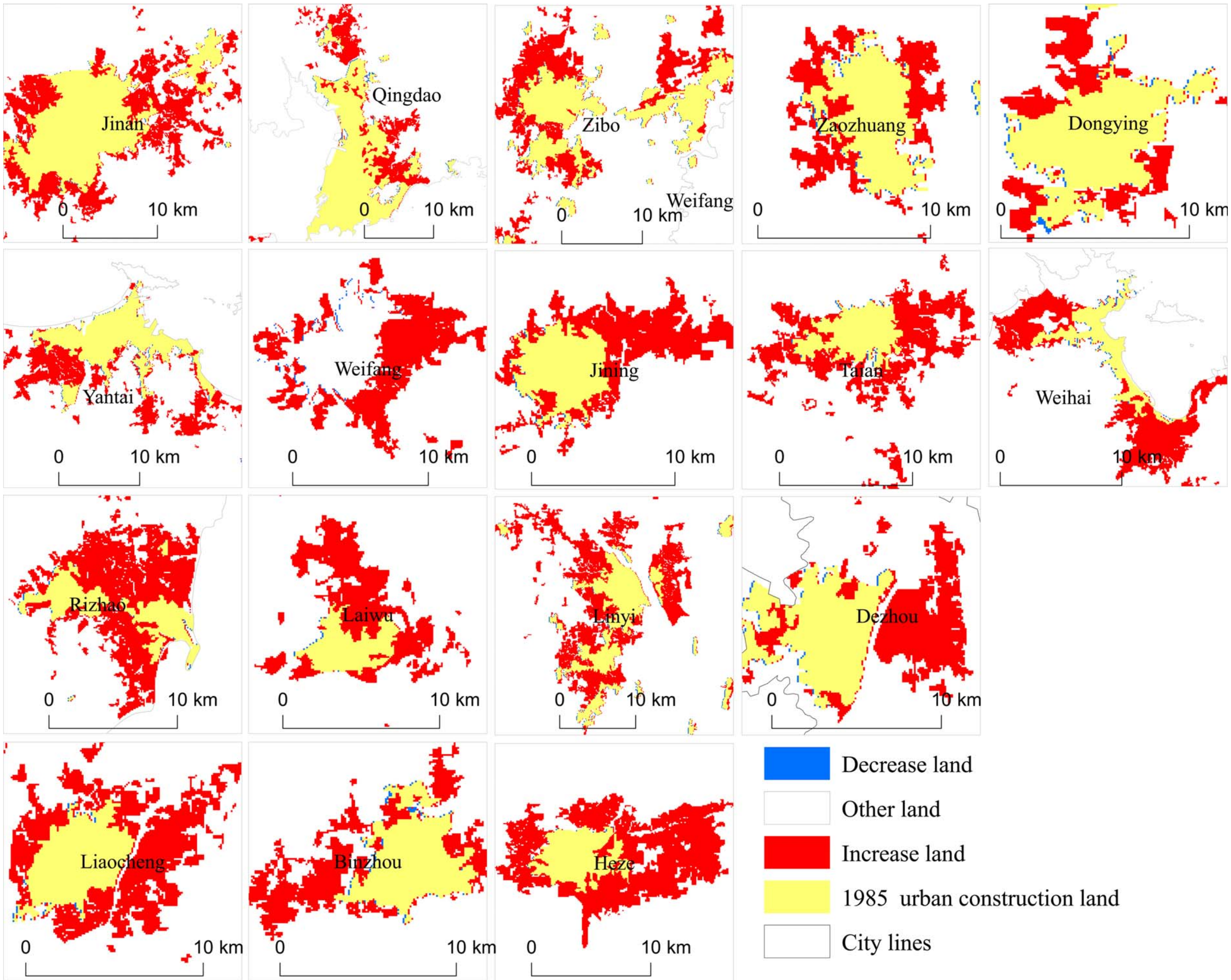

Fig. 4. The expansion process of 17 cities' urban construction land from 1985 to 2015.

Table 3. Development type of urban construction land in Shandong province

City	Scale	Stability	The time when the maximum value occurs	Direction of expansion	Type of development
Jinan	Large	Fluctuating decline	Medium stage	East–West bias	Uncoordinated wave
Qingdao	Large	Fluctuating rise	Late stage	North–South bias	Coordinated wave
Zibo	Medium	Fluctuating decline	Early stage	East–West bias	Uncoordinated stable
Zaozhuang	Small	Fluctuating rise	Late stage	East–West bias	Coordinated wave
Dongying	Small	Fluctuating decline	Medium stage	North–South bias	Uncoordinated stable
Yantai	Large	Fluctuating decline	Medium stage	North–South bias	Uncoordinated wave
Weifang	Medium	Fluctuating rise	Medium stage	East–West bias	Uncoordinated wave
Jining	Medium	Smooth rise	Late stage	East–West bias	Coordinated stable
Taian	Small	Fluctuating rise	Medium stage	Diffused	Coordinated wave
Weihai	Medium	Fluctuating rise	Late stage	North–South bias	Coordinated wave
Rizhao	Small	Fluctuating decline	Medium stage	Diffused	Uncoordinated stable
Laiwu	Small	Fluctuating rise	Late stage	North–South bias	Coordinated wave
Linyi	Medium	Fluctuating decline	Medium stage	Diffused	Uncoordinated stable
Dezhou	Small	Smooth rise	Late stage	East–West bias	Coordinated stable
Liaocheng	Small	Fluctuation rise	Late stage	Diffused	Coordinated wave
Binzhou	Small	Fluctuating decline	Medium stage	East–West bias	Uncoordinated stable
Heze	Small	Smooth rise	Medium stage	Diffused	Coordinated stable

These driving factors had a significant relationship to change of urban construction land with 5% confidence and these models passed a test. Then, the study divided the 17 cities into single, double, and multivariate driving types according to the number of main driving factor types. Jinan, Qingdao, Zaozhuang, Weifang, and Rizhao were single driving types; Dongying and Liaocheng belonged to the double type and the remaining 10 cities were multivariate driving types. Most cities developed through the role of

Table 4. The regression model of urban construction land and socioeconomic driving factors

City	Driving factor type	R^2	Regression model	Driving type
Jinan	Industrial structure	0.9926	$y = 83.8105 + 0.0036\ x_{11}$	Single
Qingdao	Economic level	0.9963	$y = 78.7764 + 0.0374\ x_4$	Single
Zibo	Economic level, Population scale, Industrial structure	0.9964	$y = 799.5985 + 0.0056\ x_1 - 0.8483\ x_7 - 0.0012\ x_{11}$	Multivariate
Zaozhuang	Industrial structure	0.5789	$y = 223.5992 - 3.5064\ x_9$	Single
Dongying	Population scale, Industrial structure	1.0000	$y = -90.3473 + 0.0543\ x_5 + 3.0684\ x_6 - 2.9501\ x_7 + 3.3019\ x_8 + 0.7757\ x_9 + 0.0454\ x_{12}$	Double
Yantai	Economic level, Population scale, Industrial structure	1.0000	$y = 99.5319 + 0.0026\ x_1 + 0.0001\ x_5 - 9.6046\ x_6 + 0.0336\ x_7 - 1.0212\ x_8 + 0.0163\ x_{12}$	Multivariate
Weifang	Industrial structure	0.6589	$y = 81.2643 - 0.0150\ x_{12}$	Single
Jining	Economic level, Population scale, Industrial structure	9.0000	$y = 13.7443 - 0.0146\ x_4 + 0.0472\ x_5 - 1.4164\ x_6 - 1.0728\ x_7 + 0.0052\ x_9 + 0.0229\ x_{12}$	Multivariate
Taian	Economic level, Population scale, Industrial structure	1.0000	$y = -730.5013 - 0.0124\ x_3 + 0.7165\ x_5 - 1.1876\ x_6 + 6.64348\ x_9 - 0.5049\ x_{10} + 0.0252\ x_{12}$	Multivariate
Weihai	Economic level, Population scale, Industrial structure	1.0000	$y = -21.0529 - 0.0027\ x_4 - 7.3495\ x_6 + 0.7566\ x_7 + 1.7284\ x_9 - 1.5473\ x_{10} + 0.0114\ x_{12}$	Multivariate
Rizhao	Population scale	0.6218	$y = 76.1297 - 6.4363\ x_6$	Single
Laiwu	Economic level, Population scale, Industrial structure	1.0000	$y = -98.7557 - 0.0013\ x_2 + 0.1112\ x_5 - 3.0451\ x_6 - 0.8246\ x_7 + 1.6187\ x_9 + 0.1008\ x_{12}$	Multivariate
Linyi	Economic level, Population scale, Industrial structure	1.0000	$y = 76.581 + 0.0065\ x_3 - 0.0899\ x_5 - 0.0642\ x_7 + 1.1232\ x_8 + 0.0751\ x_9 - 0.0286\ x_{12}$	Multivariate
Dezhou	Economic level, Population scale, Industrial structure	1.0000	$y = 1.4403 - 0.0022\ x_2 + 0.0084\ x_3 - 0.0093\ x_6 + 0.1475\ x_8 + 0.00003\ x_{11} + 0.0092\ x_{12}$	Multivariate
Liaocheng	Economic level, Industrial structure	0.9879	$y = 0.9317 + 0.5786\ x_9$	Double
Binzhou	Economic level, Population scale, Industrial structure	1.0000	$y = -43.1141 + 0.0096\ x_3 + 0.0163\ x_6 + 1.1709\ x_7 - 1.6794\ x_8 + 1.4961\ x_9 - 0.0190\ x_{12}$	Multivariate
Heze	Economic level, Population scale, Industrial structure	0.9966	$y = 17.1003 - 0.737\ x_8 - 0.0057\ x_{11}$	Multivariate

economy, population, and industry, and these result in different scales in each stage.

According to the driving factor types, Jinan, Zibo, Zaozhuang, Dongying, and 10 other cities were influenced by their industrial structure, and each city had its most advantageous industry; for instance, trade and tourism in Qingdao, Zibo, Yantai, Jining, and nine other cities were driven by economic level and their economy was important to improve the expansion of urban construction land. Zibo, Dongying, Yantai, Jining, and another seven cities were affected by population scale. The influence of industrial structures on urban construction land was larger than economic level and population scale, and 10 cities were affected by the three types of driving factors. Thus, 17 cities in the Shandong development and urban construction land expansion from 1985 to 2015 required more financial investment and economic support. Population growth increased the pressure on land in the conditions of a limited land area. In addition, industrial structure adjustment promoted economic development and increased human revenue and forced more arable land to be transformed into construction land. Finally, the temporal driving factors detected by multivariate regression model were the natural population growth rate (x_6), employment index (x_7), second industry structure ratio (x_9), and firm size index (x_{12}).

Driving Factor Analysis of Spatial Evolution

This study used spatial near analysis to obtain the nearest distance of the sampling point to the city center, the main road, railway, and river, and divided them and resource factors into nine classes using an equal distance method. There were also substantial differences in the pattern of spatial factors in the 17 cities of Shandong province (Fig. 5). High elevation is reflected in the central region of the province including Taian, Jinan, Linyi, and Yantai, and the slope had the same pattern. The substantial distance to the main railway affects Dongying and Binzhou, which lacked railways altogether. The substantial distance to the main river located in Yantai reflects that the city had no large river. Substantial distance to the main road is reflected in Binzhou and Heze, which have few highways across their city center. The distance to the city center showed a concentric structure around the city center, with more points at high value than with other factors.

The results show that Yantai has the most spatial driving factors and its average force of driving factors was smaller than other cities. Dezhou had the least spatial driving factors and its average force was larger than half of the cities. The average force of driving factors in Rizhao was the largest in Shandong province (Fig. 6). According to the size of forces, Zibo and Rizhao belong to natural environment constraint types with elevation as driving factors. Some cities, such as Jinan, Zaozhuang, Dongying, Weifang, Jining, Weihai, Dezhou, Liaocheng, and Binzhou, are primarily driven by the distance to railway, river, and road, rendering them traffic position constraint types; their urban construction land expands along the traffic lines. The other cities, such as Qingdao, Yantai, Weifang, Taian, Weihai, Rizhao, Laiwu, Linyi, Binzhou, and Heze, belong to economic position constraint types, and their driving factor is the distance to the city center, in which the closer the region is to the city center, the easier the land is developed. From the results in Table 2, cities expanding around the city center were influenced by the distance to the city center and cities expanding along an east–west or north–south bias were affected by traffic factors. In summary, the spatial driving factors detected by the geographical detector were the distance to the main railway (y_3), distance to the main road (y_5), and distance to the city center (y_6).

Discussion

Driving Mechanisms for Urban Construction Land Expansion

According to the established driving results for urban construction land, the spatiotemporal driving factors of 17 cities included

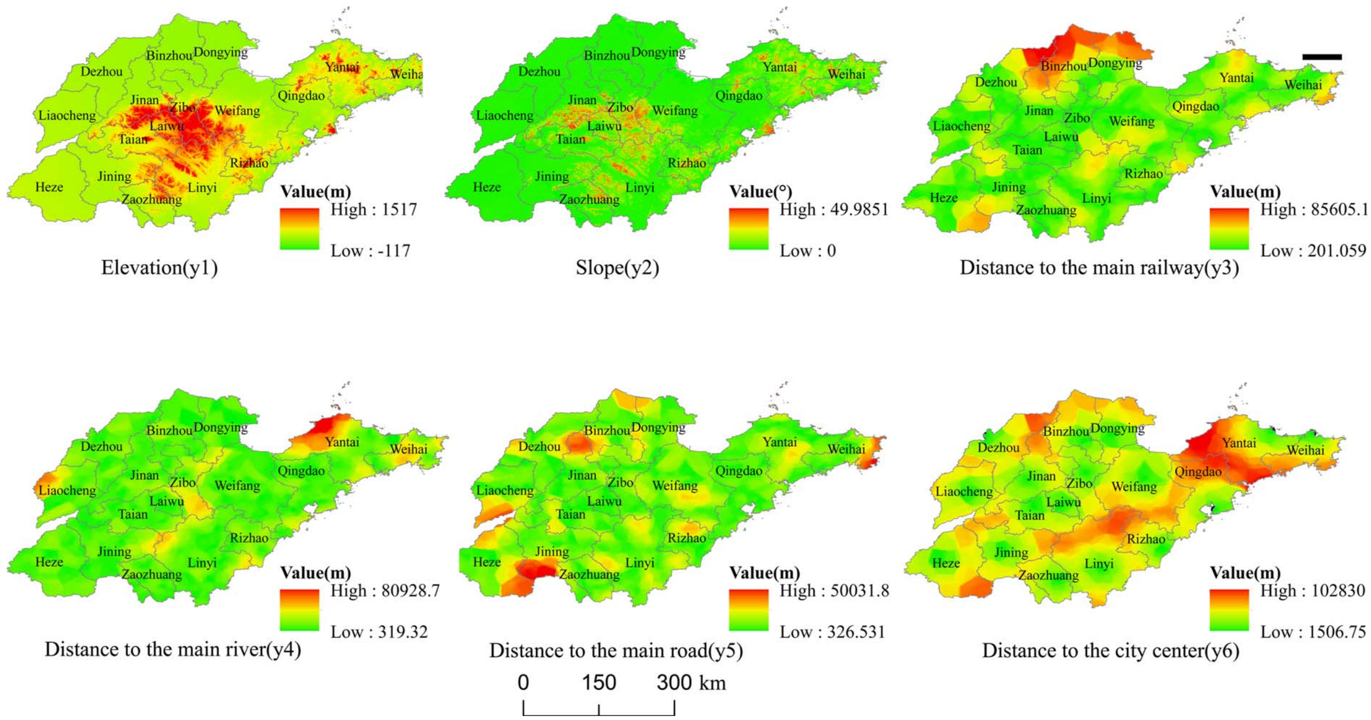

Fig. 5. The level of spatial driving factors.

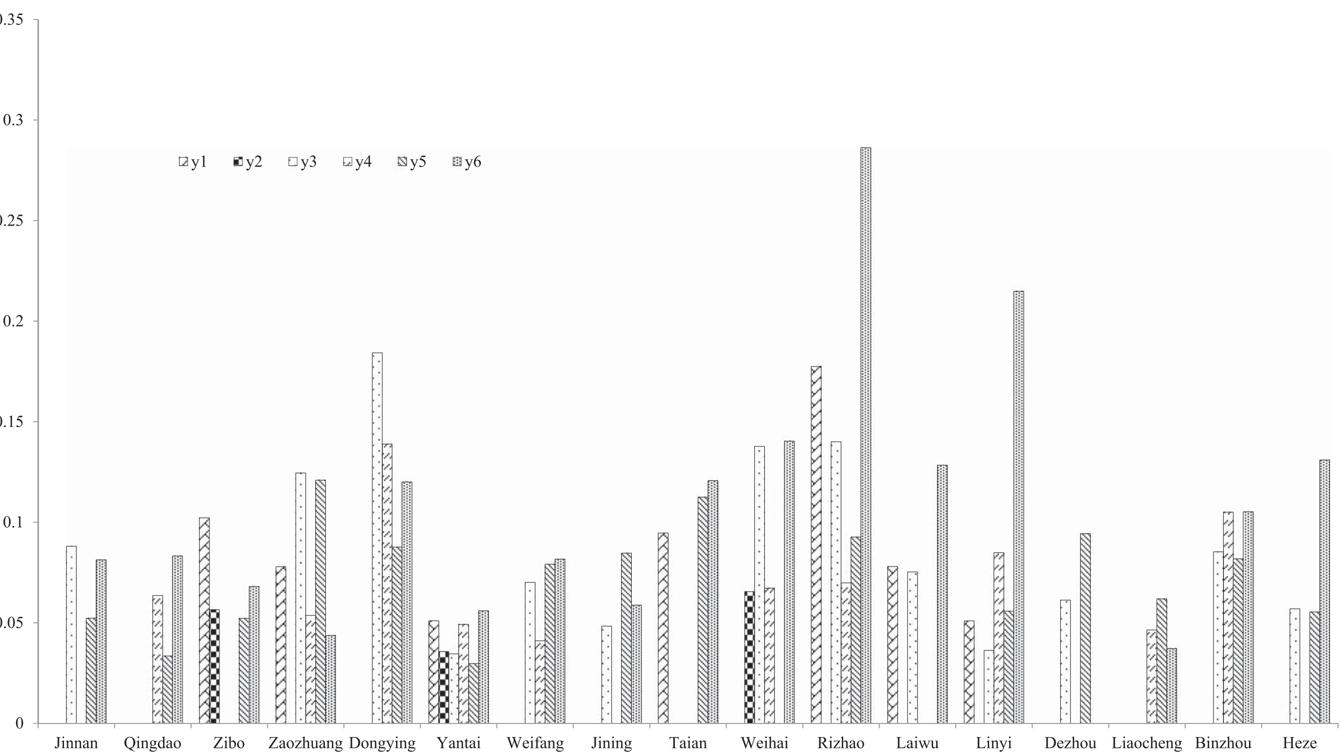

Fig. 6. The force of driving factors of urban construction land in Shandong province.

primarily the natural population growth rate (x_6), the employment index (x_7), the second industry structure ratio (x_9), the firm size index (x_{12}), the distance to the main railway (y_3), distance to the main road (y_5), and distance to the city center (y_6). Each driving factor had different influences on urban construction land. The study further analyzed the action mechanism of spatiotemporal dominant driving factors (Fig. 7), which provided references for dividing the functional orientation of urban development in Shandong province rationally towards the region's scientific planning in future.

1. The population scale indices included the natural population growth rate (x_6) and the employment index (x_7), which indicated an increase in population when their value increased. Population increase placed pressure on the land: increasing numbers of

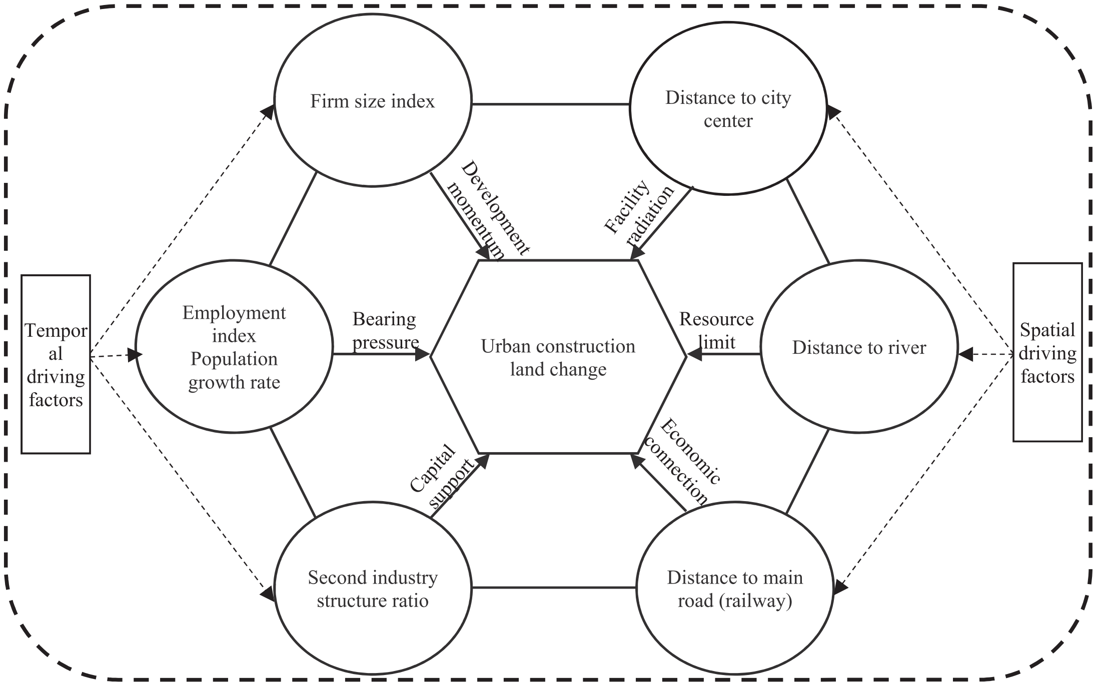

Fig. 7. The driving mechanism of urban construction land.

people are living and working in the city since the reform and opening of China and urban residential land and commercial land demand has also continued to increase over the last 30 years. Cities with large populations such as Jining, Yantai, and Linyi, in particular, had to expand urban spaces by occupying a large amount of cultivated land.

2. The industrial structure indices included the second industry structure ratio (x_9) and firm size index (x_{12}), which reflect the economic development conditions. Several firms had driven local industrial development and increased industrial output, which provided power support for urban development and pushed the city to expand to the periphery, as is the case in Jining, Dongying, Laiwu, and Zibo. In addition, more firms supplied more employment opportunities and attracted more people to work in the city. Thus, industrial development promoted urban expansion.
3. Distance to the city center indicated the economic geographical location of urban construction land and reflected the difficulty of its exposure to urban policies and public services. Land closer to the city center had higher influencing levels, was more attractive, and was easier to transform into urban construction land. Thus, the distance to the city center formed a concentric circle around city centers. In the study, Taian (0.12), Rizhao (0.29), Linyi (0.21), and Heze (0.13) demonstrated diffusion development models with urban construction land.
4. Distance to major rivers indicated the geographical location of resources in urban construction land change areas. Urban development is inseparable from water sources, both for drinking water and industrial use. Urban extension along rivers could guarantee the demand for water resources and convenience for residents. Thus, land closer to large rivers was more likely to be used for urban construction land. For example, Binzhou (0.11) and Dongying (0.14) expanded outward along the Yellow River.
5. Distance to the main road and railway reflected the geographical location of traffic. Traffic was the link between the interior and exterior of the city, which is a necessity to promote economic ties. Convenient transportation could change the economic development structure of regions and accelerate urban economic development. Shandong province has a rich road network connecting 17 cities in the region, which strengthens the links between them. Thus, the closer the distance to main roads and railways, the faster the city developed. Changes in urban construction land such as in Jinan (0.09), Zaozhuang (0.12), Jining (0.08), and Dezhou (0.09) were significantly affected by the distance of major road and railway.

The expansion scale and spatial pattern of urban construction land were affected by various factors. This study used the multiple regression model and the geographical detector to detect the dominant driving factors of urban construction land and analyzed the driving mechanism of various elements to urban construction land, which aimed to better explore the characteristics of urban development and to classify urban types and development models rationally. The urban construction land with fewer leading driving factors had smaller scales, slower development speeds, and a single expansion direction, such as was the case in Zaozhuang, Rizhao, Liaocheng, and Heze. The construction of land with more dominant driving factors had larger scales, faster speeds, and a more scattered direction, such as was the case with Qingdao, Jinan, and Yantai. Thus, the study carried out scientific planning and reasonable functional positioning for different cities based on the dominant driving factors, which could ensure the coordinated, stable, and sustainable development of cities in the region.

Urban Development Function Positioning

According to the characteristics and spatiotemporal driving factors of urban construction land, the study calculated a composite score of urban development in 17 cities of Shandong province. The highest value is 4.2 in Qingdao, and its urban development is of a higher level; the lowest value is 1.6 in Rizhao, and its urban development is of a lower level than others (Table 5). The study divided 17 cities into core trading zones ($P > 4.0$), key development zones ($4.0 \geq P > 3.5$), industrial cluster zones

Table 5. Composite score of urban development in 17 cities in Shandong province

	Scale		Stability		The time when the maximum value occurs (trend)		Temporal driving type		Spatial driving forces (mean)		
Cities	Types	Values	Types	Values	Types	Values	Types	Values	Types	Values	Composite score
Qingdao	Large	5	Fluctuation rise	5	Late stage	5	Single	1	0.060	1	4.2
Yantai	Large	5	Fluctuating decline	3	Medium stage	1	Multivariate	5	0.043	1	4
Jinan	Large	5	Fluctuating decline	3	Medium stage	1	Single	1	0.074	1	3.8
Weihai	Medium	3	Fluctuation rise	5	Late stage	5	Multivariate	5	0.797	1	3.4
Jining	Medium	3	Smooth rise	5	Late stage	3	Multivariate	5	0.064	1	3.2
Linyi	Medium	3	Fluctuating decline	3	Medium stage	1	Multivariate	5	0.089	3	3
Zibo	Medium	3	Fluctuating decline	1	Early stage	1	Multivariate	5	0.070	1	2.8
Weifang	Medium	3	Fluctuation rise	3	Medium stage	5	Single	1	0.068	1	2.8
Laiwu	Small	1	Fluctuation rise	5	Late stage	5	Multivariate	5	0.102	3	2.6
Dezhou	Small	1	Smooth rise	5	Late stage	3	Multivariate	5	0.078	1	2
Zaozhuang	Small	1	Fluctuation rise	5	Late stage	5	Single	1	0.084	3	2
Taian	Small	1	Fluctuation rise	3	Medium stage	5	Multivariate	5	0.892	3	2
Binzhou	Small	1	Fluctuating decline	3	Medium stage	1	Multivariate	5	0.094	3	2
Heze	Small	1	Smooth rise	3	Medium stage	3	Multivariate	5	0.081	3	2
Liaocheng	Small	1	Fluctuation rise	5	Late stage	5	Double	3	0.049	1	2
Dongying	Small	1	Fluctuating decline	3	Medium stage	1	Double	3	0.133	5	1.8
Rizhao	Small	1	Fluctuating decline	3	Medium stage	1	Single	1	0.153	5	1.6

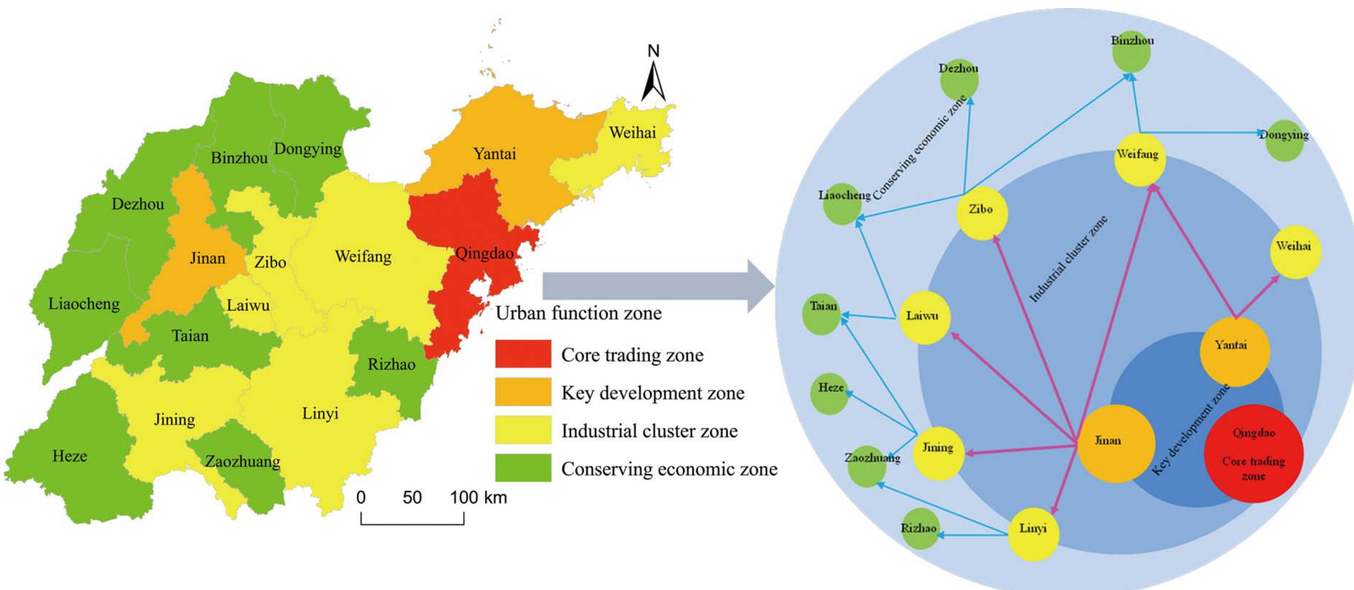

Fig. 8. The function operation of urban development and its principle in Shandong.

$(3.5 \geq P > 2.5)$, and conserving economic zones $(P \leq 2.5)$ (Fig. 8), which define the role and development trend of each function zone and provide decision support for regional planning in Shandong province in the future.

1. Core trading zone. Qingdao is the most developed city and the economic center of Shandong province, which has obvious traffic and economic location advantages and is an important hub connected to Japan and South Korea. Thus, Qingdao, as the core trading zone, should continue to expand urban land and build more international trade markets to promote the export of industrial products in Shandong province. This will drive the economic development of other cities by providing a free trade market. However, the city center of Qingdao has been fully developed and most land has already transformed into urban construction land. Thus, policy and planning should regard other counties and districts such as Jimo and Huangdao in the city as the development focus and build a variety of trade exchange centers in those locations.
2. Key development zone. This zone includes Jinan and Yantai, which have urban scales higher than 300 km^2. These are important transportation centers in the east and west of Shandong province. The former is the provincial capital and political center in Shandong province and the latter is another important port city and the second largest economically developed city. However, the two cities are far behind Qingdao in urban scale and economic level because their advantages are not maximized. Thus, Jinan and Yantai should be prioritized as key cities for economic development in Shandong to target development in megacities and undertake the function of technical guidance and industry driving to surrounding cities.
3. Industrial cluster zone. This zone includes Jining, Laiwu, Linyi, Weifang, Weihai, and Zibo. Their scale of urban construction

land exceeds 150 km^2. Each city has its own development industry advantages: Zibo and Laiwu have a developed steel industry; Linyi and Jining have rich land and labor resources; and Weifang has famous modern agriculture. They make an important contribution to the economic development of Shandong province. However, although their products have a certain advantage in Shandong province, they are not well known in China. Thus, these cities should focus on their strengths and gather small-scale and scattered resources to build industrial parks and talent centers.

4. Conserving economic zone. There are eight cities belonging to this zone, which show slow development and an urban scale of less than 150 km^2. They have relatively poor traffic conditions and economic levels and rich arable land resources with higher agricultural production than other zones. Owing to their location in the North China Plain, these cities have to undertake national food security functions and urban development was substantially limited in the west and north of Shandong. Thus, these cities should promote economic development through land transfer and labor export. Scattered land needs to be gathered to form farm production by introducing mechanical technology and liberating the labor force to work in big cities. In addition, they should gain access to construction land indicators through a series of land remediation measures to promote urban development as a background to basic farmland protection.

Conclusion

This study used a multiple regression model and geographical detector to detect driving factors of urban construction land in the differences of temporal evolution and spatial patterns and analyzed the spatiotemporal evolution driving mechanism innovatively. Through grid aggregation and different scale conversions, the change rate of construction land was converted into grid values to realize the application of geo-detector to single land cover change. This article calculated a composite score of each city by assigning three kinds of points to the spatiotemporal evolution characteristics of urban construction land and the main driving factors. The 17 cities were divided into four zones according to the composite score: core trading zone, key development zone, industrial cluster zone, and conserving economic zone. These zones should inform different development orientations and directions according to the characteristics of each. Based on the result of spatiotemporal differences and the driving mechanism of urban construction land, this study proposes the following suggestions to promote coordinated urban development in Shandong province.

1. Intensive use of land. The three cities with a rapid expansion of construction land, Qingdao, Jinan, and Yantai, have scarce arable land and large population densities. Thus, the government should adopt an intensive land use policy and protect cultivated land from being occupied. These cities should pay more attention to the development of high-tech industries and develop old parts of the cities to meet the needs of urban development.
2. Industrial transformation and upgrading. The industrial cluster zone was the gathering place of agriculture and industry, and each city has its own advantages and produces key products in Shandong. However, these industries are limited in scale and the cities have developed slowly in recent years. Thus, the government should upgrade and transform the industry by increasing the industrial chain and expanding sales channels and increasing the visibility of local products and export to foreign countries.
3. Multifunctional development planning. Good planning is the basic condition for ensuring the smooth development of the city. According to the urban development functional zone, the government should implement policy measures to promote regional urban development. In the conserving economic zone, in particular, policy should aim to expand urban scale through industrial transformation primarily for the development of service industries.
4. Building a multidimensional network. According to the driving mechanism, the distance to the main road and railways had an important effect on urban development. Each city relied on traffic networks to connect with other cities. Thus, the government should increase the construction of transportation facilities in slow-growing cities and build a provincial transportation network.

With the socioeconomic development, land urbanization continues to increase expansion, and differences between cities also continue to increase. Regional urban integration is a major strategy in China. Thus, urban function positioning and planning are an important foundation to realize regional urban integration. This article used scale, direction, and driving factor detection of urban construction land to define urban function zones, which is a scientific quantitative research method and provides reference value for regional planning and functional positioning from a macro perspective. It clarifies the functional positioning of different cities in the region and provides a basis for urban planning.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

Acknowledgments

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