Environ Monit Assess (2019) 191: 120
https://doi.org/10.1007/s10661-019-7250-5

Study on the variation of arable land use and management countermeasures under rapid urbanization: the application of a gravity model in a regional perspective

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Received: 2 January 2019 / Accepted: 17 January 2019 / Published online: 31 January 2019

Abstract Scientifically determining the characteristics of arable land use in different regions is significant in promoting arable land protection. Most studies on the changes in arable land focus on an isolated analysis of the impact of urban development on arable land. Studies on the influence mechanism of regional spatial forces in different cities from the macro perspective are limited. A gravity model and ArcGIS spatial analysis methods were used to analyze the characteristics and driving mechanisms of arable land changes in different urban function orientations from the perspective of interregional economic interaction. We hope to provide guidance for the establishment of arable land protection in a similar city circle. The results indicated the following: (1) During the study period, the geographic range of arable land with strong dynamic changes (average annual change exceeding 1.5%) gradually widened from the core area to the surrounding area, while the annual change rate decreased. (2) There is a strong correlation between the change in arable land use and the scope of gravitational action. The dynamic changes in arable land in areas with strong gravitational relationships with the core area are strong, while in the weak gravitational areas that are less affected by the core area, the average annual rate of change is nearly below 1%. (3) In the 10-year study period, the overall changing trend of the radiation circle in the core area expanded. The gravitational value where the breaking point falls within its own administrative division is more related to the change of its arable land area, and the greater the gravitational attraction is, the more likely the correlation. In a city circle, it is essential to both protect arable land resources and promote coordinated economic development. Future research on arable land utilization in different city circles should consider overall area development. Different functional areas can be determined by calculating the gravitational value, then regional development potential and key development types can be determined, and arable land protection measures can be optimized based on these functional areas.

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Keywords Arable land use · Gravity model · City circle · Urban function · Arable land preservation

Introduction

Land use/land cover change (LUCC) has become fundamental in reflecting the development, management, and utilization of natural resources by humans (Foley et al. 2005; Ustaoglu et al. 2016). However, since farming is one of the basic land use activities (Liu et al. 2013), with the rapid development of urbanization, LUCC is especially important in China (Li et al. 2017), where the contradiction between humans and land is more prominent (Xin et al. 2017). Furthermore, research on the change of arable land resources has become widespread and represents the frontier in land use change research since limited arable land resources are faced with multiple pressures (Zhu and Huang 2007). These include urban and rural construction, economic development, food production, and ecological protection. From a macro perspective, China's recent rapid economic growth, urbanization, and industrialization have gradually slowed down and reached a higher level (Chen et al. 2017). This is the most difficult and crucial period for the protection of arable land resources (Wu et al. 2017). From a micro perspective, driven by a decline in comparative interests, crop farming, which is closely related to arable land, has pushed forward a transformation of the traditional agricultural production structure to a land use and management mode with higher economic benefits, resulting in a gradual increase in the non-agriculturalization of arable land (Liu et al. 2016).

The functions of arable land in developed countries, such as Japan, the USA, and across Europe, have already been transformed (Song et al. 2014). From the initial stages of urbanization, the food production function, led by the top-down system, gradually transitioned to the coexistence of multifunctional values, such as ecosystem services, dominated by bottom-up market demand during rapid urbanization. These countries have accumulated rich experience in the establishment and development of ecological service markets for arable land. Research on the related problems of arable land change in these countries is thus not very active (Song et al. 2014). China, however, is the world's most populous country and the largest developing country. Its urbanization level rose from 33.35% in 1998 to 58.52% in 2017, and its per capita GDP increased from 6860 RMB/person in 1998 to 5.80 million RMB/person in 2017.[1] Its rapid socioeconomic growth and urbanization have sharpened the contradiction between humans and land. Therefore, the change in arable land, which ensures food security, has attracted scholarly attention to the question of whether China can meet its own food needs (Chen 2007). Accordingly, arable land use change and protection in China have become a special Chinese issue to be solved urgently (Liu et al. 2017). Since the reform and opening-up, the Chinese government has gradually cemented the basic agricultural status under the auspices of strategic adjustment of the agricultural structure and coordinated development of urban and rural areas. In response to the changing characteristics of arable land resources in China, the state has promulgated a series of policies and management requirements for the protection of cultivated land. In the latest major reports of the 19th National Congress of the Communist Party of China,[2] strictly protecting arable land and expanding the cropland rotation pilot program were both addressed, thus elevating the protection of arable land in China to the national strategic level.

Current research on arable land use change considers trends and simulation models, along with driving forces of arable land use change and policymaking. Many specific studies have been carried out at different scales (Deng et al. 2015). Many scholars believe that the current change of cultivated land in most parts of China is related to social and economic indicators such as urbanization rate (Cao et al. 2011), per capita GDP (Long et al. 2014), and rural workers (Cao et al. 2013). Furthermore, from a nationwide macro perspective, opinions regarding the quantity and quality of arable land are pessimistic (Xin et al. 2017). However, current research on the drivers of arable land use change is mostly confined to smaller areas. Cultivated land utilization in a certain area has been studied more with regard to its own region's arable land use change, neglecting the interaction between regions under the background of urban-rural integration and coordinated development (Song and Cao 2018). In the context of the implementation of China's unique policy of "a unified urban and rural land market" and poverty alleviation, the scope of the pattern of regional land use change will

[1] Data for the urbanization rate and GDP are obtained from the China Statistical Yearbook http://www.stats.gov.cn/tjsj/

[2] Xi Jinping's report at 19th CPC National Congress. http://www.spp.gov.cn/tt/201710/t20171018_202773.shtml

gradually expand (Fang et al. 2014). As such, the construction land index replacement between different regions has promoted a change in the arable land landscape pattern in different regions. Cultivated land changes brought by such policies may cause uneven quantitative changes in some areas. A change in cultivated land must be integrated to analyze the location conditions of different regions, the region's own economic development (Wen et al. 2016), and the driving influence of the economic development of surrounding cities. With the rapid promotion of urbanization, intercity economic development is trending. The metropolitan areas with large cities as their core play an increasingly significant role in economic integration. Perfecting the functional layout of the urban circle and understanding the regular pattern of land use change in the circle have both become hot research topics (Zeng and Yao 2013).

The gravity model used in this paper is derived from the law of universal gravitation in physics; this model has been widely used in social science fields. Many scholars have applied it to study the spatial structure of a city (Xu 2013) and its area of regional economic radiation (Stack 2009; Kabir et al. 2017). Since the gravity model can comprehensively consider the spatial and temporal factors that influence the change of arable land under the background of urban-rural integration, it can solve the limitations of past analyses of driving forces based on long time series (Liu et al. 2012). Research on introducing the gravity model into land use spatial coupling analysis has been gradually developing.

The Chengdu-Chongqing Economic Circle is the most densely populated, the most industrially dense, and the most urbanized developed area in Western China. "The one-hour economic circle of Chongqing"[3] is in the core area of the Chengdu-Chongqing economic circle. The urbanization rate of some cities in the economic circle, such as Yuzhong District, Dadukou District, and Jiangbei District, has reached more than 95%. In these areas, arable land has been inevitably occupied by rapid economic development and urban construction. Moreover, part of the research area, which belongs to the middle and upper reaches of the Three Gorges Reservoir area, is one of the areas with the most serious soil erosion in China (Cao et al. 2015). The cultivated land area has gradually been reduced by returning farmland to forest. Therefore, studying farmland utilization in this research area is both necessary and unique. In light of this, this study used the one-hour economic circle of Chongqing as an example to evaluate the regional difference of arable land use in the economic circle. On the basis of improving the method of calculating the driving force behind past changes in cultivated land use, this study introduced a gravity model to measure the economic linkages and the amount of spatial interaction between cities. Thus, there were three objectives to this study: (1) to calculate the coupling relationship between the change of arable land in different areas and the spatial interaction forces between cities within the scope of gravitation; (2) to divide different areas to analyze the driving mechanisms of arable land use change; and (3) to provide theoretical support for the formulation of future farmland protection policies in different regions to provide reference for other economic circles or other relevant policies in the study of regional arable land use.

[3] Covered area within 1 h of traffic near the core area of Chongqing

Study area and datasets

Study area

The study area is part of the one-hour economic zone in Chongqing in Chengdu-Chongqing Economic Circle (Fig. 1). Additionally, most districts belong to the middle and upper reaches of the Three Gorges Reservoir area (Chongqing section). Specifically, the area includes the core area of Chongqing City "(Yuzhong District, Dadukou, Jiangbei District, Shapingba, Jiulongpo District, and Nan'an District)," the urban function expansion area "(Beibei, Yubei District, and Banan District)," and a portion of the city development zone "(Fuling District, Changshou District, Jiangjin District, Hechuan, Nanchuan District, Yongchuan District, Qijiang District, Bishan District, and Tongliang District)" as part of a total of 18 districts. The economic circle is an important economic center in the western region, and urbanization is developing rapidly in the economic circle. It is also an ecological security guarantee area in the upper reaches of the Yangtze River and a demonstration area for coordinating the development between urban and rural zones. In addition, many special land policies are implemented here and have a great impact on urban development patterns and land use.

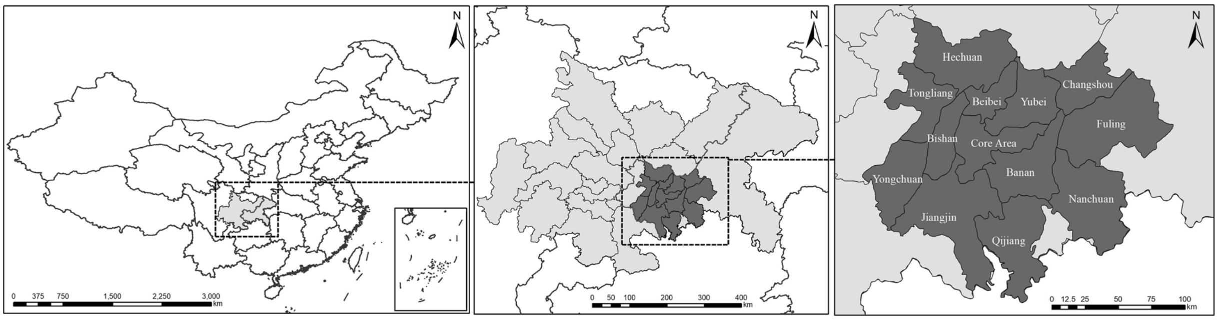

Fig. 1 Location of the study area (the shadow part of the first picture represents the Chengdu-Chongqing Economic Region)

According to the statistics of the Chongqing rural land exchange,[4] the implementation of the "land ticket" system accelerates the change of land use structure in different regions. First, rural areas far from the city center have accelerated land consolidation and some of the village collective construction land has been rebuilt into arable land to enable land ticket exchange with urban areas. This approach has somewhat increased the arable land area in the locality (Cao et al. 2010). Additionally, the land ticket system represents an increase in the scale of construction land in the downtown area. Chongqing implemented a pilot project of urban and rural construction sites linked to changes, and the special policy is conducive to the transfer of land value-added benefits from the vicinity of the main urban area to more remote areas (Lin and Zhu 2014). This also indicates that the drivers of change for arable land in Chongqing are more abundant and diversified than those in in other regions.

Datasets

Since 2005 is the base year for Chongqing's new round of overall land-use planning (2006–2020) and 2016 is the most recent year with available land use change data, we used these 2 years as the starting and end points for our research, respectively. Due to the Second Detailed Land Investigation Nationwide in China, the area of cultivated land across the country changed dramatically around 2010, and we regarded 2010 as a significant cut-off point for our research.

The nonspatial data for this study are as follows: (1) The social and economic indicators, such as the non-agricultural population and the total value of the first industry, are from the *Chongqing Statistical Yearbook (2006–2017)*, National Economic and Social Development for all districts in the research area (2006–2017). (2) The arable land area in all districts comes from Chongqing land utilization alteration data from 2006 to 2016.

The spatial data for this study are as follows: The distance between districts comes from the Chongqing Highway Mileage Map (2016).[5] Urban road vector data come from the Chongqing geographic information public service platform. In this paper, the spatial analysis function of the ArcGIS 10.2 platform is used to extract the geometric centers of each group and the spatial distance between cities within the study area is measured.

Methodology

Arable land use dynamics degree

This study used the model of arable land use dynamics degree (Zhu and Li 2003) to quantitatively analyze the status of arable land use in all districts during 2005–2016, as shown in Eq. (1):

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \qquad (1)$$

where U_a and U_b, respectively, represent the arable land use area in all districts of the research region at the beginning and end of the study period, T is the study period, and K is the arable land use dynamics degree in the research region during the study period. The model can reflect the change rate or amplitude of variation in arable land during a certain period of time.

[4] Data are obtained from Chongqing Country Land Exchange, http://www.ccle.cn/

[5] Data are obtained from Chongqing Transportation Network. http://cx.cqjt.gov.cn/main.html/

Gravity model

According to Newton's law of universal gravitation, gravity exists between any two objects. The magnitude of gravity is proportional to their mass and inversely proportional to the distance between them. An extension of the theory of spatial interaction suggests that the influence of urban development on the surrounding area is positively correlated with the size of urban development and inversely correlated with the distance between cities. A hypothesis is set for the study area, assuming that the system is closed. Chongqing is one of the four municipalities directly under the Central Government in China, and it is less affected by other cities. Based on this, to make the research results more prominent in the characteristics of the elements in the region, it is assumed that the city circle constitutes a closed system, and the influence of cities outside the region is ignored. Accordingly, this study used a gravity model to measure the impact of urban development on the change in cultivated land use in the surrounding areas. The model was established as follows.

First, we determined a central source of gravity. Chongqing's urban functional core area (including the whole area of Yuzhong District and Dadukou District, Jiangbei District, Shapingba District, Jiulongpo District, and Nan'an District within the inner ring, hereinafter referred to as the core area) is the central city, and this paper calculated that the core area's quality is far greater than the quality of other cities (Table 4). Moreover, its urban and rural construction, economic development level, transportation and communication, and industrial development are the most advanced in Chongqing. Based on the above analysis and reference to relevant literature (Gong et al. 2018), we selected the core area of Chongqing as the center of gravity model in this paper. We investigated the impact of urban development in the core area on arable land use in all districts of the one-hour economic circle in Chongqing (Fig. 2).

Second, we measured the quality of the cities. However, a standard of urban quality has not yet been determined. Since urbanization is a product of economic development, the traditional gravitational model generally uses population or GDP as the standard to measure the quality of a town (Gu and Pang 2007). However, urban development is a relatively comprehensive process, such that a single index cannot accurately measure the quality of a city. A literature analysis revealed that the non-agricultural population is often used as a significant factor to measure the level of urbanization, while the total value of the primary, secondary, and tertiary industries also corresponds to the urban development stage under different industrial structures (Delphin et al. 2016). Based on this analysis (Xu et al. 2003; Gong et al. 2018), factors that greatly impact the change in cultivated land were used to supplement the traditional gravitation model, including the non-agricultural population, the total value of the primary, secondary, and tertiary industries, and per capita GDP. According to the field investigation, residents in this economic circle generally choose highway transportation, so we also chose the highway mileage indicator for calculation. Then, the evaluation index system was constructed and the weight of each index was determined by the coefficient of variation method. After comprehensive measurement, the urban quality was obtained.

The above indexes were treated with the extreme value method to calculate standard values. In other words, the original data were linearly changed, and the minimum, maximum, and range of the calculated indexes were mapped to [0–1], as follows in Eqs. (2) and (3):

Positive indexes calculation formula:

$$A_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \quad (2)$$

Negative indexes calculation formula:

$$A_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \quad (3)$$

Next, the weight of each year's indexes in all districts was calculated by the coefficient of variation (CV) method (Xu 2013).

First, the average number of each index was calculated using $\left(X_i = \frac{1}{n}\sum_{j=1}^{m} X_{ij}\right)$. Then, the standard deviation of each index was calculated as $\left(S_i = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(X_{ij} - X_i\right)^2}\right)$. The weight of each index was computed as $\left(V_i = \frac{S_i}{X_i}\right)$. Using this method, we can determine the weight of each coefficient: $\left(W_i = \frac{V_i}{\sum_{j=1}^{m} V_i}\right)$. Finally, we calculated a comprehensive quality index (M) for each city in the study area using $\left(M_i = \sum_{i=1}^{n} X_i W_i\right)$, where X_i represents the standardized index value and W_i represents the weight.

Fig. 2 Gravity model role diagram

Second, in the process of evaluating the quality of cities, we considered not only these few indicators but also the scale and volume of the cities. The various elements of development in the urban area spontaneously flow under the action of the space between different cities to form a factor stream, which leads to the gathering of certain elements. This gathering process is also called urbanization. The agglomeration of factors in the development process is subject to different degrees of policy tilt, and policy implementation is strongly influenced by the level of urban development.

Some policy factors can directly affect the development of a city and thus indirectly affect the arable land area (Xu 2013). Unfortunately, these policies cannot be measured by quantitative indicators. Therefore, based on the classification of the urban population of the Chengdu-Chongqing urban agglomeration in the *China Urban Construction Statistical Yearbook (2006–2016)*, each district in the study area was divided into 5 grades, and the urban hierarchy correction coefficient P was assigned values of 1.1–1.5 to correct the city quality in each region (Table 1).

Table 1 Grade division of each city in the study area

Urban hierarchy	Permanent residents (people)	Administrative division	Urban hierarchy correction coefficient
Super megacity	> 3 million	Core area	1.5
Megacity	1–3 million	Yubei	1.4
Large city	0.5–1 million	Jiangjin	1.3
		Fuling	1.3
		Beibei	1.3
Medium city	0.2–0.5 million	Hechuan	1.2
		Yongchuan	1.2
		Banan	1.2
		Qijiang	1.2
		Changshou	1.2
Small city	0.1–0.2 million	Bishan	1.1
		Tongliang	1.1
		Nanchuan	1.1

Third, the distance was measured. The traditional gravitational model sets the distance to the gap of the geographical line to find the geometric center of several regional connections. Nevertheless, a linear distance cannot accurately express the spatial interaction of the region for a complicated urban synthesis. Thus, based on previous research (Xu 2013), we calculated a synthetic distance by adapting the previous method of giving weight to urban quality indicators, namely, the CV method, to assign weights to the time and space distances, respectively.

$$D = d_i \times \varphi_i + d_j \times \varphi_j \tag{4}$$

where D is the comprehensive distance between city A and city B, d_i and d_j represent spatial distance and time distance, respectively, and φ_i and φ_j are the corresponding weight values of spatial distance and time distance, respectively. Referring to the Chongqing Highway Mileage Map (2006–2016), we determined the spatial distance and time required by common modes of transport for residents to travel between two places (Table 2).

In summary, the gravity model can be constructed as follows: $F_{ab} = G\frac{M_a M_b}{D^C}p$, where F_{ab} represents the gravitational pull between city A and city B, M_a and M_b represent the different city's quality, respectively, D represents the comprehensive distance between two cities, p represents the urban hierarchy correction coefficient, G represents a gravitational coefficient or dimensionless constant, and C is a distance friction coefficient, which is generally valued in Fig. 2.

Finally, we analyzed the breaking point. When the gravitational force of a point to two cities is equal, that certain point is called the gravitational balance point or the breaking point. Suppose there is a point M that is located on the line between city A and city B. The distance from M to city A is D_a, and the distance between M and city B is D_b.M is the breaking point if the gravity between M and city A is equal to the gravity between M and city B. According to the gravity model formula, we can deduce the following results:

$$G\frac{M_a M}{D_a 2} = G\frac{M_b M}{D_b 2} \tag{5}$$

$$D_{ab} = D_a + D_b \tag{6}$$

$$D_a = \frac{D_{ab}}{1+\sqrt{M_b/M_a}} D_b = \frac{D_{ab}}{1+\sqrt{M_a/M_b}} \tag{7}$$

Results and discussion

Current situation analysis on arable land use in different regions

From 2005 to 2016, the arable land in Chongqing was reduced by 758,507.91 ha and the annual average reduction rate in cultivated land was as high as 5.04%. The rapidly shrinking arable land has become one of the most significant forms of land use change in the region over the past 11 years. According to the literature (Cao et al. 2006), the reduction mainly stems from the impoundment of the Three Gorges Reservoir, migration, and urban expansion. The scale of this study is based on the different districts in Chongqing. In the study period, the differences in cultivated land use in different districts were larger, showing different changing trends. According to the change in cultivated land area during 2005–2016, the variation trend in arable land in each district is divided into three types: reducing with fluctuation, first subtracting and then increasing, and continuously increasing (Table 3).

Compared with the initial stage of research, districts in the research area with reduced arable land include the following: core area, Changshou District, Fuling District, Banan District, Beibei District, and Yubei District. The general trend in arable land changes in these districts belongs to the reducing with fluctuation type, except for Changshou District. Furthermore, in the past 11 years, the districts where arable land area showed a reducing with fluctuation type trend were around the core area in Chongqing, except for Fuling District, which was far removed from the main urban area. Most of these districts are distributed in the urban function expansion areas or the new urban development areas of Chongqing. In the past 11 years, Banan District is the part of the study area with the largest reduction in arable land, and the arable land use dynamics degree of cultivated land is −25.74%. According to the requirements of the Chongqing "Eleventh Five-Year Plan" of Agricultural Development, the urban function expansion areas and the new urban development areas all focus on the development of modern agriculture and leisure agriculture. The expansion of urban areas and the adjustment of agricultural structures in these regions have considerably decreased the area of arable land over the past 11 years.

During the study period, more than half of the districts showed an upward trend in arable land, and most

Table 2 The comprehensive distance from each area to the core area

Study area	Distance (km)	Time (min)	Distance standard value	Time standard value	Comprehensive distance	Ranking
Banan	23.80	54.00	0.23	0.57	0.37	2
Changshou	76.10	68.00	0.74	0.72	0.73	7
Fuling	102.50	93.00	1.00	0.99	0.99	12
Jiangjin	58.10	75.00	0.56	0.80	0.66	5
Beibei	41.70	56.00	0.40	0.59	0.48	3
Yubei	23.30	32.00	0.22	0.33	0.27	1
Hechuan	69.70	81.00	0.68	0.86	0.76	8
Yongchuan	100.00	82.00	0.98	0.87	0.93	11
Nanchuan	89.00	94.00	0.87	1.00	0.92	10
Bishan	53.20	71.00	0.51	0.75	0.62	4
Tongliang	71.70	86.00	0.70	0.91	0.79	9
Qijiang	70.5	71.00	0.68	0.75	0.71	6

of them were distributed in the peripheral city, far from the core area. For example, Nanchuan District had the largest increase in arable land during the study period, with a dynamic degree of arable land of 2.97%. There are large grain-producing counties, including Hechuan and Jiangjin in these districts, where the arable land area belongs to the continuously increasing type. During the research period, the central government continued to increase the incentives for large grain-producing counties and steadily increased the financial resources of the major grain-producing areas. These large grain-producing counties enjoyed subsidies from the central government's incentive funds and further promoted the awareness of arable land protection, leading the area of arable land to steadily improve. The four regions that belong to the first subtracting and then increasing type are located in the Chongqing ecological conservation area. The tasks of farmland protection and ecological restoration in these areas should be synchronized. On the one hand, the implementation of the policy of returning farmland to forest has made the quantity of arable land fluctuate in these areas, and there have been many dynamic changes in arable land. A similar pattern is also seen in Fig. 3. In the past 10 years, the region with the largest change in arable land has always revolved around the core area. Furthermore, with the passage of

Table 3 Changes in arable land in different districts from 2005 to 2016 Unit: ha

The changing trend in arable land	Study area	2005	2010	2016
Reducing with fluctuation	Banan	77,679.72	58,987.28	57,681.81
	Beibei	26,624.86	24,478.58	21,783.47
	Fuling	119,170.24	103,115.51	103,226.91
	Yubei	48,099.97	46,666.30	41,919.22
	Core area	29,857.00	30,716.54	23,778.51
Continuously increasing	Nanchuan	57,939.73	70,079.43	70,667.64
	Yongchuan	65,698.53	67,674.77	67,527.93
	Jiangjin	112,131.67	114,967.55	114,019.79
	Hechuan	120,120.99	120,775.45	120,343.15
First subtracting and then increasing	Changshou	58,125.07	56,983.33	56,607.24
	Bishan	41,283.67	43,068.67	43,573.3
	Qijiang	81,682.64	91,986.44	92,734.72
	Tongliang	62,027.49	66,298.61	67,135.33

time, the dynamic change gradually widened radially from the center to the periphery, and the variation range gradually decreased. For example, during the study period, the study area with the smallest change of arable land was Hechuan District. The arable land use dynamics degree was only 0.028%, and the spatial distance between the district and the core area was large. Hechuan District also belongs to one of the outer ring cities in the economic circle.

As shown in Fig. 3, the dynamic change of the arable land in these 17 districts and counties was most drastic during 2009–2012. Afterward, the trend in cultivated land in some areas away from the core area became more stable, while the change in arable land in areas closer to the core of the economic circle remained dynamic. From the trend of dynamic change reflected in Fig. 3, there is a certain relationship between the change in arable land area and its geographic location in the one-hour economic circle of Chongqing and the extent of its change decreases from the core area to the surrounding regions. In addition, all six districts in the core area (Banan District, Beibei District, Fuling District, Yubei District, Jiangjin District, and Changshou District) are located in the Three Gorges Reservoir area. In the second water storage in the Three Gorges (2006–2010), the arable land area in these districts showed a decreasing trend. Compared with adjacent regions during the same period, these districts located in the Three Gorges area are in the core range, with the largest change in arable land throughout the study area. This indicates that the change in arable land is influenced by the Three Gorges Project. Due to the storage of water in

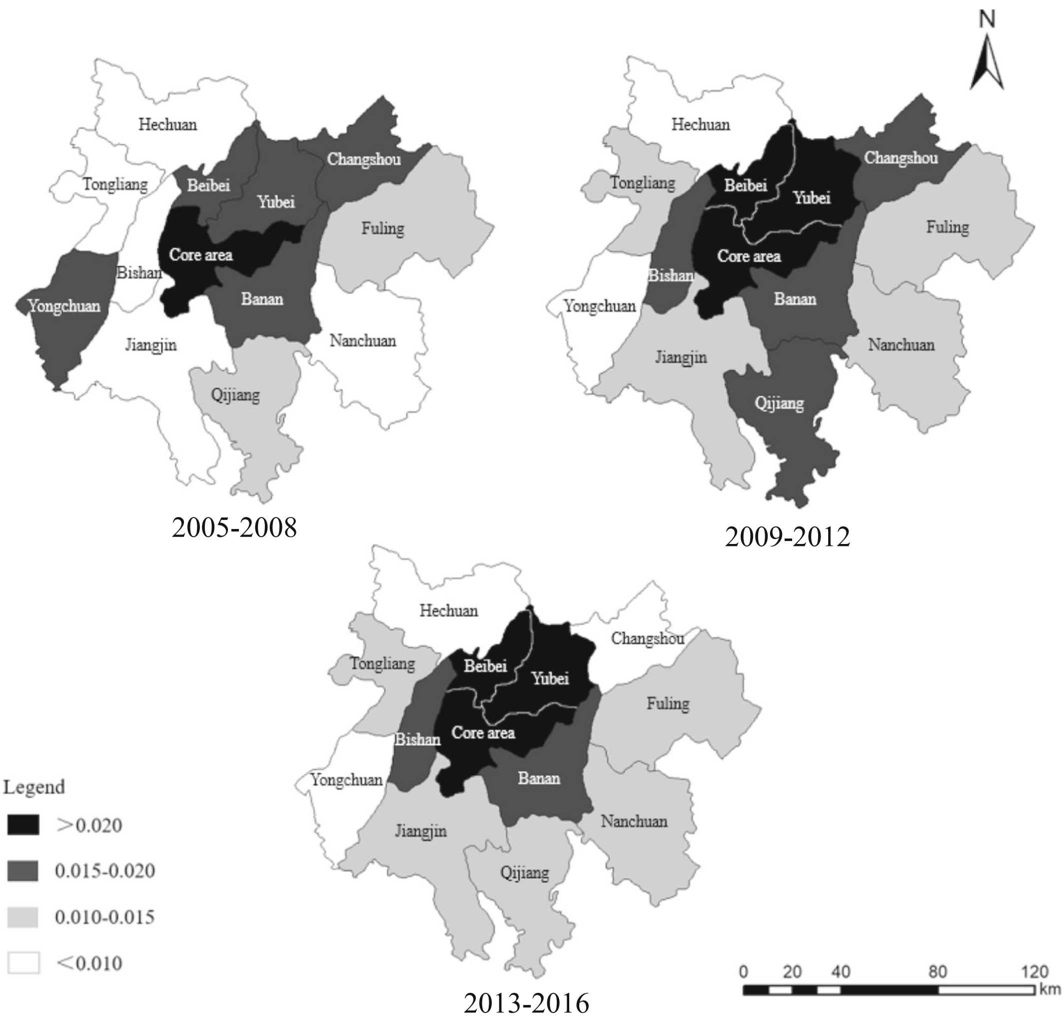

Fig. 3 Annual average dynamic variation index in Chongqing urban district in different time periods during 2005–2016

the reservoir area, the intensity of the arable land reduction in different regions varies.

Gravitation between different cities

Analysis of the trend in gravitational change in different cities

From the gravitational calculation between the 13 districts, we see the characteristics of the economic connection and the future development trend between different districts in the one-hour economic circle of Chongqing. According to the calculated city qualities in Table 4, the quality of the core area is far higher than that of the surrounding districts. This reflects that the core area has played a leading role in this economic circle as a "leading city." Furthermore, the gravity between the core area and the surrounding districts is much larger than the gravitational attraction between other districts. After calculation, the gravitational force between cities in the study area is less than 0.01, which is significant compared with the gravity of the core area to the surrounding cities. Therefore, this part of the gravitational force is temporarily ignored. The economic development of each district depends on the core area, while the gravitational effect generated by the economic development between other districts is weak. The economic interconnectedness in the entire city circle is low, so only the gravity values of the core area to other districts are listed in Table 4. Over time, the force of gravitational attraction between the core area and the surrounding districts showed an increasing trend annually. A pattern in which the economic development of surrounding districts is driven by the development of the core area is gradually formed. The interregional space force extends from the inside to the outside and gradually diminishes. The unbalanced development in urbanization and the interregional economy are the main reason for this phenomenon. In particular, the urbanization rate of Yuzhong District is as high as 100%, while in other distant areas, such as Qijiang area and Nanchuan District, the urbanization rate is only approximately 55%. Due to the uneven development of urbanization, the regional space interaction force showed significant differences.

Breaking point analysis

As illustrated in Table 5, the breaking point can be used to analyze the range of spatial interaction in the city circle. Over time, the changes in the location of all breaking points gradually weakened and the distance between each breaking point and the core area gradually enlarged. Consequently, the trend of the radiation range in the core area expanded, as shown in Fig. 4. Specifically, the distance from the breaking point to the core area in most areas of the study area increased and the change gradually slowed. This shows that the dependence of regional economic development on the core

Table 4 Calculation of a district's quality and the gravitation between districts and core area

Study area	Urban hierarchy correction coefficient	The comprehensive distance from each area to the core area	2005		2010		2015	
			Quality	Gravitation	Quality	Gravitation	Quality	Gravitation
Core area	1.500		1.364		1.227		1.246	
Banan	1.200	0.374	0.163	1.580	0.199	1.741	0.211	1.879
Changshou	1.300	0.731	0.120	0.306	0.177	0.405	0.197	0.459
Fuling	1.200	0.995	0.253	0.348	0.335	0.415	0.364	0.458
Jiangjin	1.300	0.664	0.364	1.126	0.412	1.149	0.416	1.176
Beibei	1.300	0.484	0.060	0.353	0.099	0.522	0.113	0.604
Yubei	1.400	0.269	0.233	4.398	0.379	6.422	0.420	7.235
Hechuan	1.200	0.756	0.227	0.542	0.283	0.606	0.292	0.636
Yongchuan	1.200	0.930	0.198	0.313	0.246	0.348	0.272	0.392
Nanchuan	1.100	0.925	0.089	0.141	0.131	0.188	0.116	0.169
Bishan	1.100	0.618	0.053	0.190	0.051	0.163	0.113	0.369
Tongliang	1.100	0.791	0.010	0.217	0.100	0.196	0.144	0.286
Qijiang	1.200	0.714	0.110	0.297	0.138	0.331	0.152	0.370

area has gradually increased, and the links between regions have gradually improved and stabilized.

The change in the location of breaking points not only represents an increase in the gravitational value between different regions but also highlights the leading role of economic development in the core region and reflects the accumulation of industries and trade. Judging from the overall changing trend, the impact radiating from the core area of Chongqing on the surrounding economic development has broadened over the past 10 years, extending the radiating circle. Close contact and cooperation among cities and the joint promotion of development are the inevitable results of rapid urbanization.

During the study period, the breaking points of Banan District, Changshou District, Beibei District, Yubei District, Laoshan District, Hechuan District, and Qijiang District all fell within the administrative scope of their respective divisions. The results show that these districts are greatly influenced by the economic development of the core area, which also echoes the analysis results of the gravitational value. Based on the comprehensive analysis of the relationship between the gravitational value of each district and the location of the breaking points (Table 6), the 12 districts were divided into strong gravitational areas, sub-strong gravitational areas, and weak gravitational areas.

Combined with the analysis of the "Current situation analysis on arable land use in different regions" and "Gravitation between different cities" sections, the arable land dynamic changes in the region with a strong relationship with the core area are all intense. As the core cities have a greater impact on the economic development of the surrounding cities, the arable land in these areas is affected by construction and urban expansion. For example, in Banan District and Yubei District, the arable land area has been in a fluctuation-decreasing trend over the past 10 years and the magnitude of change in these districts is the highest in the study area. In the weak gravitational zone, which is less affected by the core area, the changing trend in arable land is relatively gentle. Most of these regions (a great majority of which are major grain-producing districts) focus on the development of agriculture, and arable land area show an increasing trend. This illustrates that the farmland protection task in this city circle is gradually inclined to the weak gravitational areas that are less affected by the economic development of the core area. Priority should be given to the task of economic construction and development in the region affected by the gravity of the core area, which will strongly reduce the arable land area in the strong gravitational area. This will not only ensure that the total amount of cultivated land within the urban circle does not decrease but also enable the economy of the area to be fully developed.

Table 5 The distance between the breaking points of each area and the core area

Study area	Comprehensive distance	2005	2010	2015
Banan	0.37	0.28	0.27	0.27
Changshou	0.73	0.56	0.53	0.52
Fuling	0.99	0.70	0.65	0.65
Jiangjin	0.66	0.44	0.42	0.42
Beibei	0.48	0.40	0.38	0.37
Yubei	0.27	0.19	0.17	0.17
Hechuan	0.76	0.54	0.51	0.41
Yongchuan	0.93	0.67	0.64	0.63
Nanchuan	0.92	0.74	0.70	0.71
Bishan	0.62	0.52	0.51	0.47
Tongliang	0.79	0.73	0.62	0.59
Qijiang	0.71	0.56	0.53	0.53

The correlation between gravitational value and arable land area

According to the previous analysis, the study area is roughly divided into two ranges: one where the breaking point falls within the administrative scope of the zoning and another where the breaking point falls outside the administrative scope. That is, two regions are divided according to the influence of gravity. We used Spearman's correlation analysis to study the relationship between the variation of gravitational force in different regions and the changing trend in arable land area over time (Table 7). The correlation analysis between the change in arable land area and the gravitational value shows some special characteristics. The districts that passed bilateral inspection include Banan District, Hechuan District, Hanjiang District, Laoshan District, Beibei District, Jiangjin District, and Yongchuan District. Two of them fall in the strong gravitational area, four fall in the sub-strong gravitational area, and one falls in the weak gravitational area. In total, 83.33% of the city's gravitational change has a significant correlation with the change in arable land area in the scope of

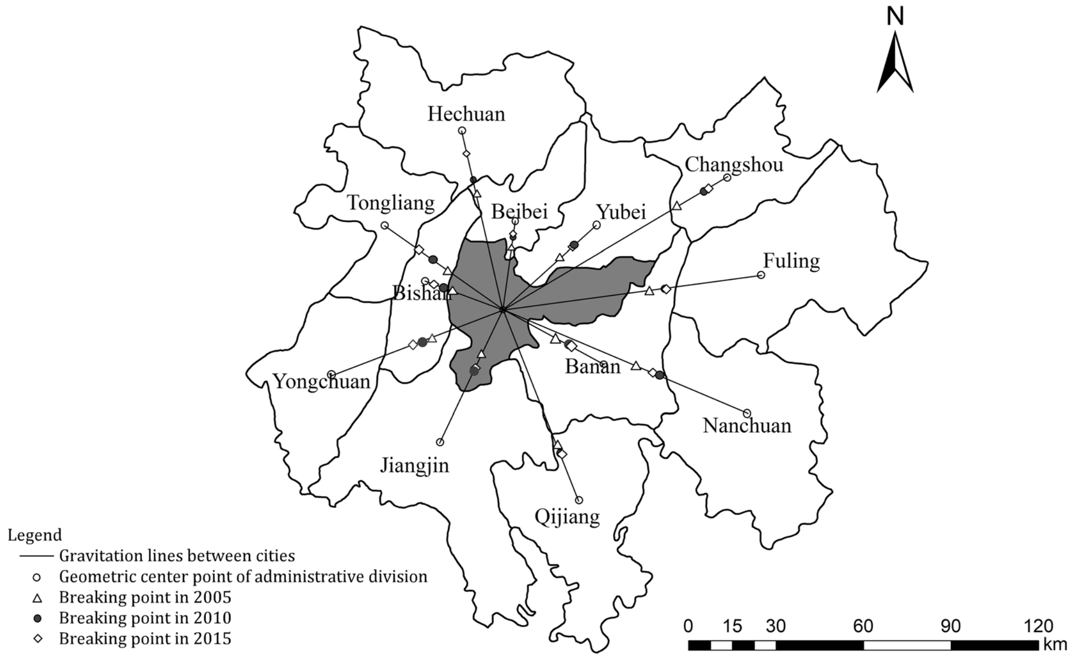

Fig. 4 The location of breaking points

gravitational force, while only 33.33% of districts where the breaking points are outside the administrative boundaries have a correlation between the gravitational value and the arable land area. Therefore, the gravitational value where the scope of the gravitational force falls within its own administrative division is more related to the change in arable land area, and the greater the gravitational attraction of the region, the easier it is to show this correlation.

Specifically, there are two kinds of correlation. There is a strong negative correlation between the area of arable land and the gravitational value in the strong gravitational areas. Most of the regions with sub-strong gravitation show a powerful positive correlation, while the weak gravitational areas show a feeble correlation with the gravitational field value. Owing to the high degree of dependence on the economic development of the core area in the area of strong attraction, these areas are also at the core of Chongqing's development. The three cities are easy to develop and have great economic ties with each other. Therefore, in the process of development, they are easily influenced by the relocation of core industries, they are vulnerable to industrial out-migration in the core area, and they alleviate the "urban land contradiction" in the core area. Urban quality is composed of some social and economic indicators. If the distance remains relatively constant, the increase in the value of the gravitation between districts represents, to some extent, an increase in the economic linkage between the two regions. With the continuous development of the core area, the regions affected by the core area are also constantly increasing their intensity of urban construction and rapidly increasing their economic aggregates, which has had a negative impact on the area of arable land between regions.

Table 6 Gravitational integrated partition

Types	Breaking points near the core region	Breaking points far from the core region
Strong gravitational	Strong gravitational areas (Yubei, Banan, Hechuan)	Sub-strong gravitational areas (Jiangjin, Changshou, Fuling)
Weak gravitational	Sub-strong gravitational areas (Beibei, Bishan, Qijiang)	Weak gravitational areas (Nanchuan, Tongliang, Yongchuan)

Table 7 Correlation between the area of cultivated land and the gravitational value

Study Area			Correlation coefficient[1]	Two-sided test (significance)
Breaking points outside the administrative scope	Weak gravitational areas	Nanchuan	0.427	0.190
		Tongliang	0.564	0.079
		Yongchuan	0.857*	0.014
	Sub-strong gravitational areas	Jiangjin	0.586*	0.043
		Changshou	0.522	0.098
		Fuling	0.607	0.108
Breaking points inside the administrative scope		Beibei	− 0.829*	0.042
		Bishan	0.786*	0.036
		Qijiang	0.791**	0.004
	Strong gravitational areas	Yubei	− 0.600	0.108
		Banan	− 0.786*	0.036
		Hechuan	− 0.886*	0.019

[1]When the confidence level (bi-lateral) is < 0.05, the correlation is marked as significant (*)

Nevertheless, most of the sub-strong gravitational areas show a strong positive correlation, except Beibei District. Although Beibei District is located in the sub-strong gravitational area, it is closer to the core area than other districts. It is relatively consistent with the area of strong gravitational areas in terms of the flow of elements, the interoperability of personnel in the core area, and the decommissioning of core area functions. Based on the overall land use plan of Chongqing (2006–2020), these areas are called suburban agricultural areas. The common feature of the remaining districts is that their agricultural functions are well positioned. They are the bases for leisure agriculture and rural tourism and act as urban service cities, and they are important modern agricultural demonstration zones. The control over the quantity and quality of arable land in these districts is relatively strict.

Considering the breaking points, these regions are less affected by the core area. Since the distance between some districts and the core area is greater, the land price is relatively inverse, the topography is more complex, and there are many hills that serve to limit the impact of the expansion of urban areas. In the context of the implementation of policies such as land tickets, the progress of land consolidation and reclamation in these districts has been accelerated, resulting in a relatively significant increase in the arable land area in these districts. In other words, with the development of the gravitational force between the core area and these four districts, the economic contact volume in these regions has increased. To realize an increase in farmer income, the overall urban-rural integration construction has been accelerated and the progress of land exchange for arable land after reclamation has been accelerated, which has had a positive effect on the arable land area in these areas.

Discussion

Comparison of research results

Despite the extensive literature on arable land use change and driving factors, relatively few studies have discussed the impact of the interaction between different cities on the change in arable land from a regional perspective. Among many model methods, the gravity model can better quantitatively characterize the spatial structure of the economic linkages between urban clusters, highlight the time-varying characteristics and changes in the spatial pattern of arable land resources under regional interactions, and consider regional economic forces in combination with time and space scales. The comprehensive effect of changes in arable land reveals the role of urban economic status, regional location, and economic development in changing the socioeconomic connections in an urban circle.

Although this study differs from prior data and methods, the conclusions in this paper are largely consistent with the findings of others (Table 8). The credibility of the conclusions of this paper is thus confirmed.

Table 8 Comparison with results of previous studies

Prior research result	Present study results
(1) Wu et al. (2011) found that the impoundment of the Three Gorges Project will result in a significant reduction in the amount of arable land during 2007–2008 and verified that the construction of the project caused changes in the amount of arable land.	The arable land area in the part of the research region that belongs to the Three Gorges Reservoir was reduced to various extents during the second impoundment of the reservoir area (2006–2010), and the amplitude of the variation in arable land area is far higher than that in other adjacent areas during the same period. This shows that the Three Gorges Project placed stress on the arable land area of the reservoir area and that different regions have different intensity.
(2) Cao et al. (2006) found that the changes in arable land in the Three Gorges Reservoir area are closely related to urbanization and the policy of returning farmland to forests.	In the Chongqing section of the Three Gorges Reservoir area, the tasks of arable land protection, ecological restoration, and returning farmland to forest in the ecological conservation development area need to be carried out simultaneously. Meanwhile, the change in arable land in the urban development new district is mainly affected by urban expansion, agricultural restructuring, etc.
(3) Lu et al. (2008) found that the economic development of the metropolitan area in Chongqing has a correlation with the changes in arable land in the city circle.	The division of gravitational values measured by various social and economic development indicators shows that the correlation between arable land area in gravitational zones with different intensity in the metropolitan area and comprehensive indicators of social and economic development is different.
(4) Wang et al. (2008) found that the extent of farmland change in the Beijing-Tianjin-Hebei metropolitan area first increased then decreased from the center to the surrounding cities. Different urban grades led to significant spatial differences in arable land changes.	The change in arable land in 17 districts within the study area is related to the location of geographic divisions. The extent of change gradually decreases from the core area to the surrounding areas. The changes in arable land in some areas far away from downtown are stable over time, while the changes in other districts that are closer to the core area remain relatively active.
(5) Qian et al. (2015) found that economic linkages between complex urban agglomerations are relatively large, and there is a certain dependence on the economic development between different cities and core area in urban agglomerations.	The economic development within the Chongqing urban agglomeration in the Chengdu-Chongqing economic circle is unbalanced. The pattern in which the core area drives the economic development of the surrounding cities has emerged, and the regional force extends from the inside to the outside and gradually weakens.
(6) Jiang and Pu (2017) found that there is an imbalance in development within Chengyu City.	As the "leading city," the attraction of the core area is far greater than that of other cities. The mutual connection within the entire city circle is insufficiently close. The inequality in urbanization and economic development has led to great differences in the spatial gravitational effects of the internal economic linkages within cities.
(7) Hou (2017) found that the gravity of the noncentral cities in the Beijing-Tianjin-Hebei region is increasing annually, affected by Beijing, and that the interaction between regions in the urban agglomeration is gradually increasing.	In the process of development, affected by the gravity of the regional center cities, the circle of influence of Chongqing's core area on the surrounding cities' economic development has broadened, the distance between the gravitational breaking points in most districts and the core area has broadened, and it now tends to be flat.
(8) Xu (2013) found that, in regions of strong gravitational relationships with central cities, there is a higher degree of coupling between the increase in cultivated land occupied by construction land and gravity.	Within the scope of gravitation, 83.33% of the city's gravitational change value and the change in arable land area show a significant correlation, in which the strong gravitational area shows a negative correlation, the sub-strong gravitational area shows a positive correlation, and the weak gravitational area has a weak correlation.

Compared with previous research, this paper combines spatial analysis in the study of arable land changes and highlights the guidance of different areas on the policy of arable land protection. A comparative analysis of arable land changes in the Chongqing section of the Three Gorges Reservoir area and some districts in the Chongqing one-hour economic circle during the past 10 years can more readily allow for the comparison of the differences in farmland changes between the reservoir area and the nonreservoir area. Furthermore, the results are more quantitative. For example, Wu et al. (2011) found that a significant reduction in the amount of cultivated land in the Three Gorges Project during 2007–2008 was due to the impoundment of water by the Three Gorges Project that drowned farmland. The present study made use of farmland change data from 13 districts (partly belonging to the Three Gorges Reservoir area, some of which belong to the economic circle) in the past 10 years for comparative analysis. With the policy and related variables unchanged, the arable land area of all districts in the Three Gorges Reservoir area was reduced to various extents during the second impoundment of the Three Gorges Project. In particular, the dynamic degree of arable land in Banan District during the impoundment period was as high as −24.06% and the area of cultivated land in the nonreservoir area remained relatively stable. This further demonstrates that the Three Gorges Project has a certain impact on the farmland in the reservoir area.

Research progress and prospects

Through analysis, we propose that the protection of arable land in the city circle should be accurately targeted according to the regional functions of different districts and counties. The regional key development types should be judged based on multiple resource endowments in different cities, such as geographic conditions and economic development. The purpose of this study was to ensure the dynamic balance of the total amount of arable land in the region and to implement indicators for construction land in regions with high economic development potential. This will not only protect the arable land resources within the urban circle but also play a role in promoting the coordinated development of the economy within the circle.

At present, the protection of arable land in China is eliminating the previous control of quantity and quality in small-scale areas, and the focus is turning to balancing the total amount of arable land from a regional perspective. As such, the management of the three aspects of quantity, quality, and ecology is emphasized. Therefore, research on arable land utilization should increase the interaction of the urban spatial forces in the overall scope and clarify the driving mechanisms and trends of cultivated land change under the influence of urban spatial interaction in different regions. It remains to be solved how to explore the quantitative relationship between the spatial forces of urban economic development and the changes in arable land resources from a regional perspective. Especially in the context of urban and rural coordination and rapid urbanization, the analysis of arable land use in larger urban economic circles and arable land protection-related policy reform should pay more attention to the differences and changes in arable land use under an overall regional effect. According to site-specific recommendations, the government should scientifically adjust the protection measures for the relevant arable land. Since the policy elements are difficult to quantitatively measure, this paper lists only some land use planning documents and agricultural economic plans that have obvious effects on the change in arable land quantity (Table 9). Different policies promulgated by various departments have different effects on the cultivated land area in Chongqing. This paper analyzes only the quantitative changes reflected in the cultivated land area. However, there are still some policies that may have a lagging effect on the change in cultivated land or that cannot directly affect the change in cultivated land. In the future, research on the mechanism of the policy of this type of hidden effect should be gradually strengthened.

A gravitational model can reflect the differences in the effect of spatial forces between regions on the change in arable land and can elicit a regional understanding of farmland changes within a certain spatial scope. However, there remain few studies on the impact of urban economic development interactions on arable land use and the indicators for measuring urban quality in gravitational models are still not unified. This study builds on previous research regarding the drivers of arable land changes to measure the quality of cities. However, there are many factors that influence spatial forces between cities. It is difficult to quantify the impact of special arable land protection policies on regional spatial forces, and the gravity model is still to be improved. Especially in the context of difficult policy quantification, the process of correcting the quality of different cities still needs to be

Table 9 Significant cultivated land-related policies in Chongqing (2006–2017)

Year	Issuance department	Laws/regulation policies	Policy orientation	Change in cultivated land area
2007	China's State Council	Notice on the Second National Land Survey	Strengthen Supervision and Inspection of Land Management Behavior	Decrease
2008	Chongqing Municipal Government	Interim Measures for the Management of Chongqing Rural Land Exchange	Gradually Establish a Unified Urban and Rural Land Exchange Market	Decrease
2012	Chongqing Planning and Natural Resources Bureau	"12th Five-Year Plan" for Construction of High Standard Basic Farmland in Chongqing	Improve the Quality of Cultivated Land and Ensure Food Security	Increase
2013	Chongqing Municipal Government	Planning of Chongqing's Main Functional Areas	Optimize Land Use and Urbanization	Decrease
2015	Chongqing Municipal Government	Administrative Measures for Land Tickets in Chongqing	Solve the Problem of Inefficient Use of Rural Housing Sites and Strengthen the Protection of Cultivated Land	Increase
2017	China's State Council	Opinions on Strengthening the Protection of Cultivated Land and Improving the Cultivated Land Requisition-compensation Balance	Realize the Strategy of Storing Grain on the Ground and with Technology and Improve the Land Preservation System	Increase

improved. The urban hierarchy correction coefficient in this paper only represents a trend of change rather than an accurate value. Future research should further measure the impact of different policies and convert them into quality correction factors. Since the scope of urban space represented by the gravity model is within a certain economic circle, when the scope of research is expanded, the number of variables may increase, potentially causing interference in the new core area within the study area. Therefore, the gravity model is not suitable for comparative analysis of economic development and arable land change over larger areas.

Countermeasures and suggestions

The rapid development of urbanization has placed pressure on the protection of arable land in the economic circle composed of various urban agglomerations.

In city circles with closely connected regional economic development, when formulating policies relating to the protection of arable land, government departments should establish a regional adjustment platform for supplemental arable land indicators to control the total amount of cultivated land in a region from the macro perspective and then transfer the focus of arable land protection to regions. The protection of arable land in terms of both quantity and quality from a regional perspective should be emphasized. In general, the distribution of indicators should take into account the needs of local economic development, the need for ecological protection, the need for grain production, and the advantages afforded by regional resources.

We should fully consider the main functional zoning of each city and carry out a functional orientation of different cities in the economic circle that is closely linked to the economy. Ensuring that the quantity, quality, and ecology of arable land are controlled in multiple directions, we should also consider promoting the stable development of the social economy in the urban circle such that the economic growth mode and rate can develop in a reasonable direction.

This point follows Sinclair's research findings (Sinclair 1967) on the "counter-Thunen circle" of land use around large cities in economic geography. That is, since agricultural land may be converted into urban land for residential or other uses at any time in urban areas where urbanization is rapidly developing, the farmers who live closer to the city may invest less in capital and labor in farmland and focus instead on economic development. Meanwhile, the farmers who live far away from the city invest more in agricultural land owing to the diminished opportunity for converting agricultural land into urban land, and they may engage in relatively high-intensity operations.

According to the gravitation partition and correlation analysis of the "Gravitation between different cities" and "The correlation between gravitational value and arable land area" sections, this study divided the urban circle in the study area into three parts. We calculated that the districts in the strong gravitational area should give priority to economic development. The area within the breaking point in the sub-strong gravitational area should focus on economic development, and areas outside the breaking point should focus on the development of featured agriculture. The weak gravitational area should give priority to the development of agriculture and bear an essential part of the protection of arable land within the urban circle. In view of the previous quantitative discussion of arable land management from a regional perspective, the following countermeasures are based on only the quantitative analysis of this article. Specific recommendations for the protection of arable land in the Chongqing section of the Chengyu Economic Circle and the regulatory rules are as follows.

1. The urbanization rate of the three districts in the strong gravitational area is extremely high (all higher than 63%). Furthermore, their economic development status and city functions are relatively high. Affected by the core area, population, capital, and technology are more concentrated in these areas. Therefore, as major urban development zones in the city circle, the strong gravitational area should be oriented toward finance, commerce, etc. to give full play to its economic radiation aggregation. The correlation between the gravitational value and arable land change in the strong gravitational area is negative. Therefore, these areas' economic development and urban construction have a destructive impact on the protection of cultivated land resources. For the arable land resource protection strategies in these areas, there should be a policy tilt. For example, under the premise of guaranteeing some basic indicators of arable land resources (i.e., basic farmland), these areas should transfer some arable land resources protection tasks to the surrounding districts to ensure their economic core role and drive regional economic development.
2. The sub-strong area of gravity is divided into two parts: the breaking points within the administrative division and the breaking points outside the administrative division. The locations of the breaking points in Changshou District, Beibei District, and Qijiang District all fall within the scope of their respective administrative divisions, indicating that these regions are greatly affected by the economic development of the core area. Arable land protection in these areas should be divided into two parts according to the calculation of the gravitational breaking points. Some areas are affected by the spatial forces of the development of the core area. They should focus on economic development according to the scientific pattern of urban economic development. Moreover, the local government should improve land use efficiency, reduce the unit GDP consumption rate, and develop urban boundaries in a high efficiency and intensive direction. The construction land planning index should fall in the area within the breaking point as much as possible, which is conducive to tapping the city's economic development potential, promoting the overall economic development of the city circle, and complementing other cities' strengths. The other part, which is outside the breaking point, should be used as a key protected area for arable land resources, focusing on promoting agricultural production conditions and improving the efficiency of agricultural land use. Based on the development of agriculture in the suitable farmland area, we should make full use of the advantages of the economic ties between their respective cities and core areas and explore ecotourism agriculture, such as leisure agriculture, and give full play to the characteristic agriculture and ecological maintenance of the city function.
3. The areas in the sub-strong gravitational area where the breaking points fall outside their respective administrative divisions (Bishan District, Jiangjin District, Fuling District) and the three districts in the weak gravitational area (Nanchuan District, Tongliang District, and Yongchuan District) are more suitable for agricultural development owing to their geographical divisions and topographic conditions.

Most of the districts (such as Jiangjin District and Fuling District) are major grain and economic crop production bases. Therefore, these regions should mainly undertake the task of protecting farmland resources within the entire city circle, thus offering more opportunities for urban development to other districts closer to the core region. These planning ideas provide space for landscape and ecological development for the entire city circle. In the future, these areas should improve the farming conditions by carrying out land consolidation and other projects to promote the continuous and stable

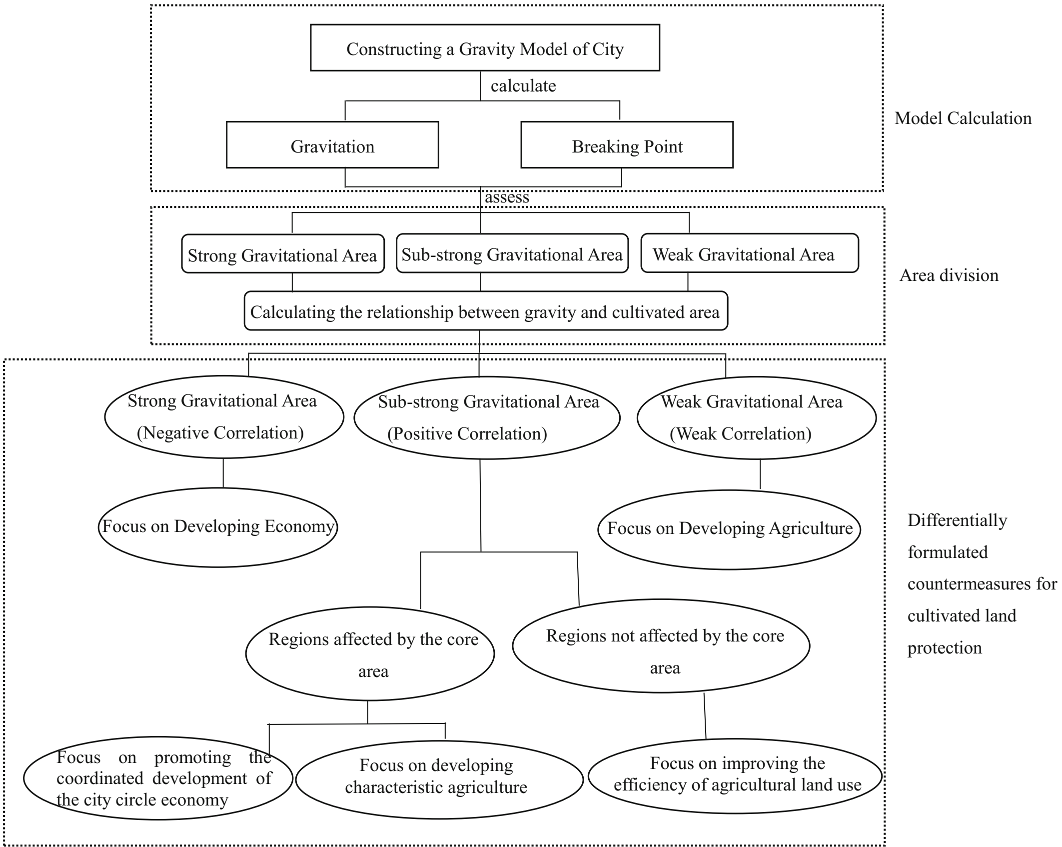

Fig. 5 Flow chart of countermeasures for the protection of arable land in a city circle

intensive use of arable land and improve the output efficiency. These areas should promote agricultural reforms, improve the optimization of grain varieties, change agricultural management concepts through the transfer of agricultural land, and promote the management of arable land industrialization. The government should also increase its support for agricultural development policies and science and technology in these regions, improve and adjust the agricultural subsidies policy, increase the enthusiasm for farming, and change the protection of arable land from "passive" to "active."

Therefore, we sketch a conceptual framework of how to draw up countermeasures for the utilization of arable land in a city circle (Fig. 5).

Conclusions

In this paper, a gravity model was used to measure the degree of economic closeness among different districts in Chongqing's one-hour economic circle. Furthermore, the research area was divided into zones and an urban group development plan was proposed. A correlation analysis between the change process in arable land use and the variation in gravitational values in different districts is concluded as follows.

1. During the study period, the changing trend in arable land in each district in the one-hour economic circle of Chongqing can be roughly divided into three types: reducing with fluctuation, first subtracting and then increasing, and continuously increasing. The areas with large dynamic changes in arable land are all distributed around the urban functional core areas in Chongqing. The area where the dynamic change of farmland is strong will gradually widen from the core area to the surrounding area over time, and the amplitude of change will decrease accordingly. The area with the largest reduction in arable land is Banan District, and the largest increase in arable land is in Nanchuan District.

2. From the perspective of urban quality, the quality of the core area far exceeds that of the surrounding districts. Areas affected by the core region often show strong dynamic changes in arable land. The arable land in this part of the district is influenced by economic construction and urban expansion. In areas of weak gravitational zones that are less affected by the core area, the changing trend of arable land is relatively flat, and most of the regions focus on agricultural development. There is a strong connection between the use of arable land and the impact scope of the core area.
3. According to an analysis of the breaking point of gravity, the overall changing trend in the radiation zone in the core area expanded during the study period. This proves that the dependence on regional socioeconomic development in the core area is increasing. The gravitational value of breaking points falling within their own administrative division is more related to the change in arable land area. Moreover, this paper shows that the greater the gravitational value in an area, the easier it is to show correlation. There is a strong negative correlation between the arable land area and the gravitational value in the strong gravitational area. Most regions in the sub-strong gravitational zone exhibited a strong positive correlation. As the gravitational value increased, the economic contact between the regions increased, and the arable land area increased. However, the change in the arable land area in the weak gravitational area has little correlation with the gravitational value.

Funding information The study was supported by the Humanities and Social Sciences Fund in the Ministry of Education of P. R. China (15YJC630005).

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