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Interaction Between Construction Land Expansion and Cropland Expansion and Its Socioeconomic Determinants: Evidence From Urban Agglomeration in the Middle Reaches of the Yangtze River, China

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Nowadays, both urbanization and cropland expansion are hot issues. However, research related to the spatiotemporal interaction between urbanization and cropland expansion and their socioeconomic determinants remains scarce. Accordingly, this research takes the urban agglomeration in the middle reaches of the Yangtze River (MRUA) as the research area by combining spatial analysis, sensitivity analysis, and the spatial gravity model. To achieve this goal, we identified the area of the construction land expansion and cropland expansion, the sensitivity of cropland expansion to construction land expansion, and the shifting trajectory of gravity centers of construction land expansion and cropland expansion and their interaction during 2000–2020, respectively. Additionally, the geographically weighted regression model was utilized to explore the spatiotemporal heterogeneity of four socioeconomic determinants of the interaction between construction land expansion and cropland expansion. The results are as follows: 1) the area of the expanded construction land and the expanded cropland and the sensitivity of cropland expansion to construction land expansion show an overall increasing pattern; 2) the gravity center of the expanded construction land shifted toward the northeast, whereas that of the expanded cropland moved to the southeast but with similar moving distances (17.83 and 15.37 km, respectively); 3) the GDP has an increasing positive effect on the interaction of the construction land expansion and cropland expansion, whereas the investment in fixed assets shows an increasing negative effect during 2000–2020. The GDP in the agricultural sector and population displays a stable influence. This article offers a solution for decision makers to promote the interaction between construction land and cropland.

Keywords: gravity center, cropland protection, GWR, sensitivity analysis, urban agglomeration

INTRODUCTION

Globally, frequent human interactions with the natural environment have significantly changed Earth's surface (Song et al., 2018; Tesfaw et al., 2018). Only in the second half of the 20th century, human's efforts to develop the social economy have resulted in 24% of Earth's surface conversion into cropland and lost more than 55% of mangroves and coral reefs (Millennium Ecosystem Assessment, 2005). Therefore, land use/land cover change (LUCC) has been a hot issue in recent decades (Ariti et al., 2018; Folberth et al., 2020). Under human demands to attain economic progress, urbanization has unavoidably become one of the most active LUCCs, which then promoted the expansion of the impervious surface and loss of ecological land (Deng et al., 2009; Salerno et al., 2018; Qiu et al., 2019).

The urbanization level worldwide is estimated to reach over 80%, and in developing countries, the quantity of urban areas in 2050 will be far larger than that in 2000 with an increasing

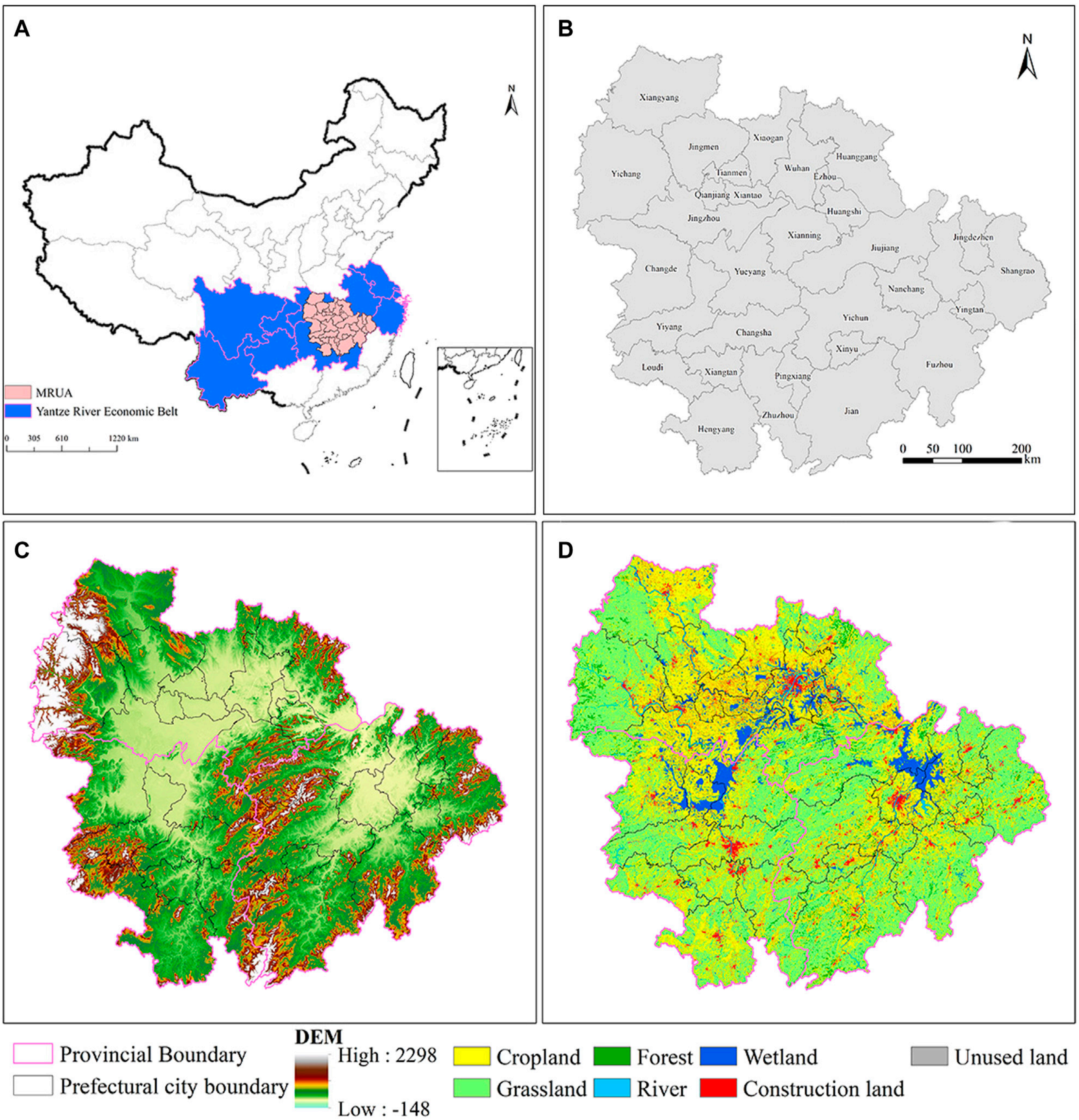

FIGURE 1 | Location **(A)**, names of prefectural cities **(B)**, DEM **(C)**, and land use in 2020 **(D)** of MRUA.

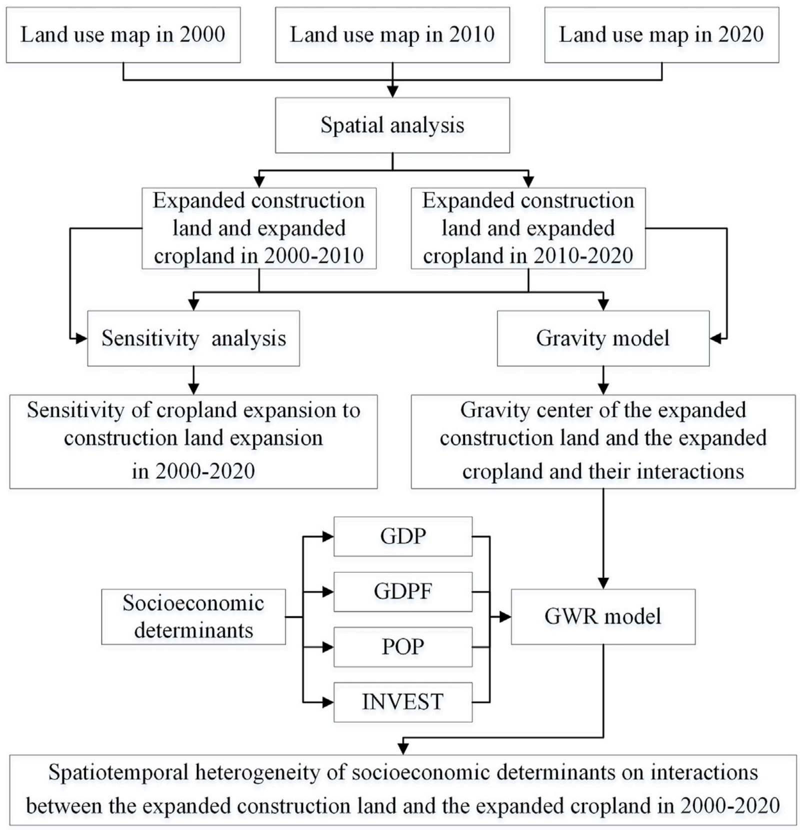

FIGURE 2 | Research framework.

expansion rate (Angel et al., 2011; United Nations, 2018). The increased urban area inevitably takes up a large number of cropland and occupies the space of ecological land (van Vliet et al., 2017; Wang et al., 2020; Wu et al., 2020). The high-quality lives brought by urbanization to the people also lead to the booming population (Shu et al., 2018; Boudet et al., 2019). Facing the pressure from two sides, that is, the reduction of cropland and population growth, the world is under severe food security problems (Foley et al., 2011; Asche et al., 2015).

Cropland, as a scarce resource, holds the key to maintaining food security for a country and the world (Egli et al., 2018; Yang et al., 2020a). To avoid cropland loss and ensure food security, many countries worldwide have promulgated several cropland protection policies in line with their national conditions (Monk et al., 2013). For example, in 1938, the United Kingdom promulgated the "Green Belt Policy" to restrict the growth of urban area and prevent cropland loss (Cullingworth et al., 2014); in 1996, China implemented a series of policies to ensure no net loss of cropland and increase the quality of cropland, such as the "Cropland Balance Policy" and the "Basic Cropland Policy" (Ke et al., 2018; Su et al., 2020; Wang et al., 2021). These policies are not only aimed at preventing cropland loss but can also promote cropland expansion (Ke et al., 2019; Tang et al., 2021). Song and Pijanowski (2014) pointed out that in 1999–2008, due to the "Cropland Balance Policy", 27,677 km^2 of cropland was reclaimed through land consolidation, exploitation, and rehabilitation in China. Additionally, the spontaneous agricultural activities of farmers can increase the area of cropland (He et al., 2021; Zhang et al., 2022). In the future, cropland expansion will play an increasingly important role in maintaining food security.

Both urbanization and cropland expansion are hot research topics at the regional and global scale. Researchers initially focused on the causes and effects of urbanization (Haase et al., 2012; He et al., 2014). At the regional scale, Souza et al. (2016) discussed the effects of urbanization on the microclimate of Manaus. Su et al. (2012) evaluated the urbanization impacts on ecosystem services at the eco-regional scale. Moreover, Liu et al. (2021) examined the characteristics of the urban expansion structure in a city scale. At a global scale, Lambin and Meyfroidt (2011) evaluated the relationships among urbanization, economic globalization, and land scarcity. Seto et al. (2012) projected the global urban area in 2030 and discussed its direct impact on carbon biomass. Li et al. (2022) analyzed the characteristics of global urbanization trend and its related population dynamics. As time goes on, the area of cropland expansion is continuously increasing (Zabel et al., 2019; Eigenbrod et al., 2020; Cheng et al., 2021), consequently gaining considerable attention on its effects. The effects of cropland expansion on ecosystem services (Ke et al., 2019; Tang et al., 2021) and cropland productivity (Song and

Pijanowski, 2014; Song and Liu, 2017), the causes of cropland expansion (Zelaya et al., 2016; He et al., 2021), and the relationships among cropland expansion, cropland intensification, and food security (Mauser et al., 2015; Zabel et al., 2019; Folberth et al., 2020) are all hot issues of the researchers. The interactions between urbanization and cropland change are also explored (Liu L. et al., 2014; van Vliet et al., 2017). For example, Tu et al. (2021) discussed the interactions of urbanization and cropland loss under different rates and patterns of urban expansion. Zhou et al. (2021) applied macro–micro comparative analysis to detect the urbanization-associated cropland loss at different scales. However, all of the aforementioned urban and cropland interaction research works are all based on the analysis of urbanization resulting cropland loss. Research scarcely focused on the interaction between urban expansion and cropland expansion.

Thus, this study attempts to explore the interaction between urban expansion and cropland expansion and its socioeconomic determinants. To this end, taking the urban agglomeration in the middle reaches of the Yangtze River (MRUA), China as the research area, we first identified the expanded construction land and the expanded cropland through spatial analysis during the periods of 2000–2010 and 2010–2020. Then, sensitivity analysis was utilized to detect the sensitivity of cropland expansion to construction land expansion. We also identified the gravity centers of the expanded construction land and expanded cropland, their shifting trajectories, and interaction. Last, the geographically weighted regression (GWR) model was applied to detect the socioeconomic determinants of the interaction between construction land expansion and cropland expansion.

STUDY AREA AND DATA SOURCES

MRUA is located within 110°15' – 118°30'E and 25°58' – 32°39'N, covering an area of 3,26,100 km^2, and lying in the middle of the Yangtze River Economic Belt (YREB) (**Figure 1**). YREB is the most complete urban system with the largest population and the largest industrial scale in the world (Pan et al., 2020). As one of the most important urban agglomerations in YREB, MRUA has a population of 125 million and a regional GDP of 7.90 trillion Yuan, creating 9.6% of the total economic output in China using 3.4% of the land area and 9.0% of the population according to the statistical yearbook in 2018. Moreover, MRUA has a large amount of cropland because of the large plains located in the middle and northeast (**Figures 1C,D**) and the abundant precipitation, making it an important rice production base in China. The agricultural activities are active. Therefore, given the pressure from both urbanization and agriculture, MRUA is a perfect area to study the interaction between construction land expansion and cropland expansion.

This research uses two types of data: spatial data and statistical data. The spatial data include the land use maps in 2000, 2010, and 2020 from the Data Center of Resources and Environment, Chinese Academy of Science (http://www.resdc.cn), and were reclassified into seven land use types based on the original land use reclassification system (Liu et al., 2010; Liu et al., 2014a). The statistical data come from the Statistical Yearbook of Hubei, Hunan, and Jiangxi Provinces in 2000–2020.

METHODS AND MATERIALS

Research Framework

In order to detect the interaction between construction land expansion and cropland expansion and explore its socioeconomic determinants, four steps were conducted (**Figure 2**). First, the area of the expanded construction land and cropland in the periods of 2000–2010 and 2010–2020 was evaluated using spatial analysis. Then, by integrating sensitivity analysis, we calculated the sensitivity of cropland expansion to construction land expansion to reflect the relationships between them. Third, the gravity model was chosen to estimate the spatial balance of construction land expansion and cropland expansion, changes of the gravity centers, and the interaction between construction land expansion and cropland expansion in 2000–2020. Finally, four socioeconomic determinants and the GWR model were applied to explore the spatial local effects of the variables on the interaction between construction land expansion and cropland expansion. The spatiotemporal heterogeneity of socioeconomic determinants can be identified by using these steps.

Identification of the Expanded Construction Land and the Expanded Cropland

This research defines the expanded construction land or the expanded cropland as follows: that a parcel is no construction land or no cropland at the beginning of the research period and it is transformed to construction land or cropland at the end of the research period. Therefore, the amount of the expanded construction land and the expanded cropland is calculated as follows:

$$Con_i = \sum\nolimits_{n1=1}^{m} L_{n1i}, \tag{1}$$

$$Crop_i = \sum\nolimits_{n2=1}^{m} L_{n2i}, \tag{2}$$

where Con_i and $Crop_i$ denote the amount of the expanded construction land and the expanded cropland in city i, respectively, m represents the number of land use types excluding construction land or cropland, which is six in these two equations, $n1$ and $n2$ represent the land use types, and L_{n1i} is the area of $n1$ land use type in city i. In detail, $n1$ indicates cropland, grassland, forest, river, wetland, and unused land and $n2$ denotes grassland, forest, river, wetland, unused land, and construction land.

Sensitivity Analysis

To evaluate the impact of the expanded construction land on the expanded cropland, the sensitivity analysis model was chosen to assess the sensitivity of cropland expansion to construction land expansion. The sensitivity analysis can reflect the effects of one

TABLE 1 | List of explanatory variables.

Variable	Description	Unit
GDP	Average gross domestic product in the research period	100 million Yuan
GDPF	Average gross domestic product in the agricultural sector in the research period	100 million Yuan
POP	Average population in the research period	10 thousand people
INVEST	Average investment in fixed assets in the research period	10 thousand Yuan

TABLE 2 | Area of the expanded construction land and the expanded cropland in 2000–2020 (km^2).

	2000–2010	2010–2020
Construction land	3,410.92	5103.82
Cropland	1,785.92	7809.46

changing element on another or a group of elements through quantitative analysis (Han et al., 2016; Chai et al., 2019). The sensitivity of cropland expansion to construction land expansion is calculated as follows:

$$\theta_i = \frac{\left(Crop_{t_{2i}} - Crop_{t_{1i}}\right)/Crop_{t_{1i}}}{\left(Con_{t_{2i}} - Con_{t_{1i}}\right)/Con_{t_{1i}}}, \tag{3}$$

where θ_i is the sensitivity of cropland expansion to construction land expansion in city i, $Crop_{t_{1i}}$ and $Crop_{t_{2i}}$ refer to the area of the expanded cropland at the beginning and end of the research period, respectively, and $Con_{t_{1i}}$ and $Con_{t_{2i}}$ denote the area of the expanded construction land at the beginning and end of the research period, respectively.

The sensitivity analysis denotes the reflection of cropland change to construction land expansion, where a positive score indicates that cropland expansion is affected by construction land expansion; whereas a negative score represents that cropland expansion has an inverse relationship with construction land expansion. Notably, this study focuses on the sensitivity of the expanded cropland area to the area of expanded construction land. Thus, the score of sensitivity is positive. A higher value of sensitivity indicates a higher sensitivity of cropland expansion to construction land expansion.

Spatial Gravity Model

In the development process of an element, its quantity, quality, and location continue to change in space, leading to the change in spatial force magnitude (Li et al., 2018; Chai et al., 2019). The concept of gravity center is from physics, which refers to a space point whose forces are relatively balanced in all directions (Zhang et al., 2012; Wang et al., 2018). Therefore, the spatial gravity model can be utilized to analyze the spatial balance of some elements by analyzing the direction and distance changes, such as energy (Zhang et al., 2012), grain production (Chai et al., 2019), and ecological capacity (Cheng et al., 2019). The gravity model can also calculate the interaction or flow between at least two locations (Zeng et al., 2019; Yang et al., 2020b). In this article, the gravity model is first used to calculate the coordinate of the center of the expanded construction land and the expanded cropland. Then, it estimates the interaction between the expanded construction land and the expanded cropland. The coordinates of the gravity center can be calculated according to **Eqs 4**, **5**:

$$\bar{X} = \frac{\sum_{i=1}^{n}(X_i \times V_i)}{\sum_{i=1}^{n} V_i}, \tag{4}$$

$$\bar{Y} = \frac{\sum_{i=1}^{n}(Y_i \times V_i)}{\sum_{i=1}^{n} V_i}, \tag{5}$$

where $(\bar{X}, \bar{Y})$ is the coordinate of the element's gravity center, (X_i, Y_i) represents the coordinate of the element and V_i denotes the attribute value in location (X_i, Y_i). This research calculates two types of gravity center, one is the gravity center in the subresearch area and the other is the gravity center in the entire research area. In the former calculation process, (X_i, Y_i) denotes the coordinate of the location of the focused attribute in city i. For the latter, (X_i, Y_i) is the coordinate of the gravity center of the focused attribute in city i.

The changing direction and distance of the gravity center is evaluated according to the following equations, respectively:

$$\alpha = \left(\frac{k \times \pi}{2} + \left(\arctan\left(\frac{\bar{Y}_{t_2} - \bar{Y}_{t_1}}{\bar{X}_{t_2} - \bar{X}_{t_1}}\right)\right)\right) \times \frac{180°}{\pi}, \tag{6}$$

$$D = \sqrt{\left(\bar{X}_{t_2} - \bar{X}_{t_1}\right)^2 + \left(\bar{Y}_{t_2} - \bar{Y}_{t_1}\right)^2}, \tag{7}$$

where α and D represent the changing direction and distance of the gravity center, respectively, $(\bar{X}_{t_1}, \bar{Y}_{t_1})$ and $(\bar{X}_{t_2}, \bar{Y}_{t_2})$ refer to the gravity center's coordinate at the beginning and end of the research period t, respectively, and k is the coefficient that makes sure α belongs to $[-180°, 180°]$, which equals 0, 1, and 2. We defined east as 0°, and the anticlockwise direction was defined as the positive direction. Owing to the changing distance calculation, all the coordinates in this article are defined as projected coordinates.

The interaction calculated by the gravity model exhibits a positive relationship with the focused elements' attributes and a negative relationship with their spatial distances. The equation is as follows:

$$I_i = \frac{V_{1i} \times V_{2i}}{D_{12i}^2}, \tag{8}$$

where I_i denotes the interaction between the two elements in city i, V_{1i} and V_{2i} represent the attribute values of two elements, and D_{12i} is the spatial distance between the two elements.

Geographically Weighted Regression Model

The GWR model was conducted to investigate the socioeconomic determinants of the interaction between construction land expansion and cropland expansion in MRUA. Regression models are widely used in the driving mechanism analysis (Zhong et al., 2011; Ariti et al., 2015; Mohmmed et al., 2019).

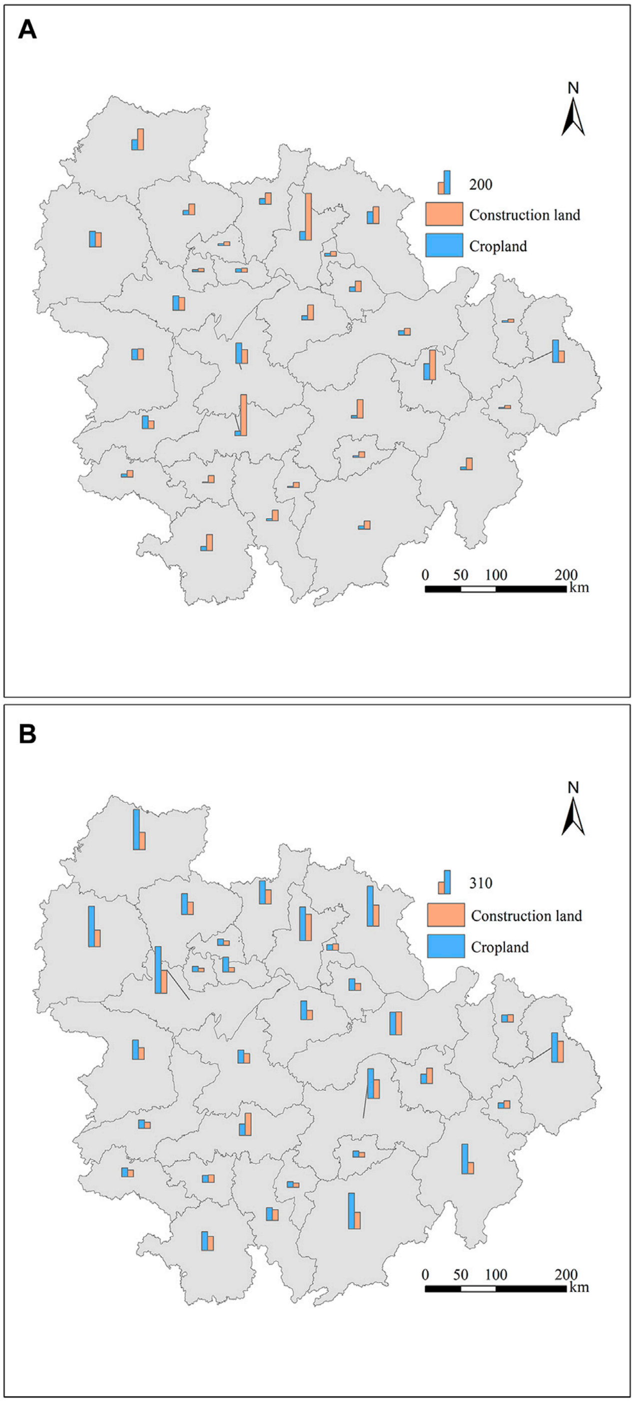

FIGURE 3 | Area of the expanded construction land and the expanded cropland in the subresearch area in the periods of **(A)** 2000–2010 and **(B)** 2010–2020 (km^2).

The GWR model is an extension of the traditional regression model, which considers the spatial effect by integrating the coordinates of the variables into the calculation (Fotheringham et al., 1996; Punzo et al., 2022). Therefore, the GWR model can estimate the coefficients as many as the local research units, thereby better reflecting the local spatial effects of the explanatory variables on dependent variables (Su et al., 2014; Guo et al., 2021). To obtain a better view of the spatially varying relationships between the interaction of construction land expansion and cropland expansion and socioeconomic determinants, the GWR model was used to visualize the spatial heterogeneity. The GWR model is described as follows:

$$y_{it} = \gamma_t (X_i, Y_i) + \sum_k^q \gamma_{kt} (X_i, Y_i) x_{ikt} + \varepsilon_{it} \quad i \in \{1, 2, \ldots, n\}, \tag{9}$$

where y_{it} is the dependent variable at research unit i in period t, γ_t is the intercept, (X_i, Y_i) is the spatial coordinate of the explanatory variable of x_{ikt}, γ_{kt} is the coefficient of the variables, ε_{it} is the error, n and q represent the number of research units and explanatory variables. The dependent variable in this article is the value of the interaction between construction land expansion and cropland expansion at two time periods 2000–2010 and 2010–2020, and the explanatory variables are the socioeconomic determinants selected in **section 3.6**. To avoid the multicollinearity between the selected variables, we transferred all variables into their LN format.

Variable Selection

The interaction between the construction land expansion and cropland expansion is a result of the development of social economy, and its calculations are based on two sides the expanded construction land and the expanded cropland. Thus, it is influenced by the joint effects of socioeconomic factors affecting the construction land and cropland. **Table 1** displays the explanatory variables selected in this study. The GDP and INVEST have been regarded as the factors influencing construction land expansion (Zhang et al., 2020; Wu et al., 2021), while GDPF is the factor affecting the change of cropland (Cheng et al., 2020; Eigenbrod et al., 2020; Tian et al., 2021). In addition, POP can be considered as the socioeconomic factor that influences both construction land and cropland (Sarparast et al., 2020; Uisso and Tanrıvermiş, 2021).

RESULTS

Characteristics of Construction Land Expansion and Cropland Expansion

In the last 20 years, MRUA has experienced massive changes of construction land and cropland expansions. As time goes by, both construction land expansion and cropland expansion display an increasing trend (**Table 2**). In 2000–2010, MRUA experienced the expansion of 3,410.92 km^2 of construction land and 1785.92 km^2 of cropland. Meanwhile, these figures increased to 5,103.82 and 7,809.46 km^2, respectively, in the period of 2010–2020. **Figure 3** provides a detailed view on the amount of the expanded construction land and cropland in each subresearch area. From this figure, we can see that in 2000–2010, as capital cities in their provinces, Wuhan, Changsha, and Nanchang experienced the largest amount of construction land expansion

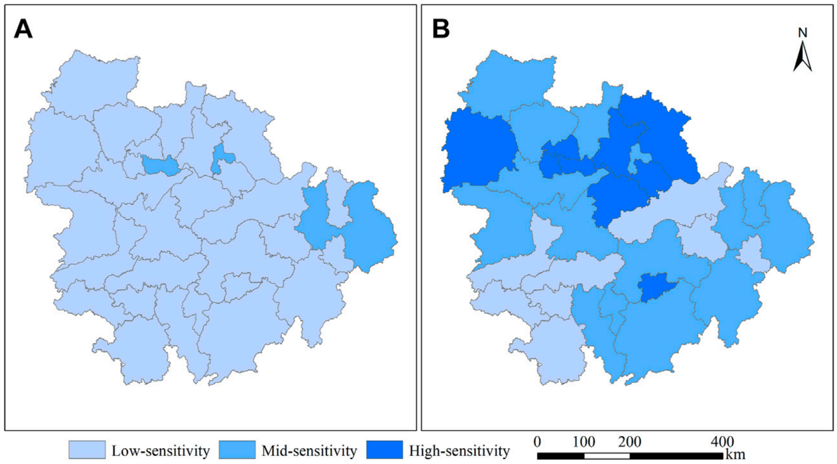

FIGURE 4 | Sensitivity of cropland expansion to construction land expansion in the periods of **(A)** 2000–2010 and **(B)** 2010–2020.

with a number of 407.02, 357.68, and 257.21 km^2, respectively. In 2010–2020, Wuhan was still the city that experienced the largest number of construction land expansion with a number of 351.38 km^2. Meanwhile, the other top two cities with the largest areas of construction land expansion have been changed to Jiujiang and Jingzhou with the area of 305.29 and 302.75 km^2, respectively. As for the area of the expanded cropland, Shangrao, Yueyang, and Nanchang are the top three cities experiencing cropland expansion (194.41, 176.32, and 139.42 km^2, respectively) in 2000–2010; while in 2010–2020, the top three cities with the largest cropland expansion have been changed to Jingzhou, Yichang, and Xiangyang and the areas of the expanded cropland have been increased to 621.41, 537.73, and 531.73 km^2, respectively.

Figure 3 also shows that the difference between the expanded construction land and the expanded cropland indicates a shrinking trend. In 2000–2010, only five cities, namely, Yichang, Jingzhou, Shangrao, Yueyang, and Yiyang showed that the area of the expanded cropland was larger than that of the expanded construction land. The other cities experience more construction land expansion than cropland expansion, especially in fast developing cities, such as Wuhan and Changsha. In 2010–2020, the area of the expanded cropland showed an increasing pattern, and that of the expanded construction land displays a decreasing trend compared with that in 2000–2010. The phenomenon of the area of the expanded cropland which is larger than that of the expanded construction land happens in nearly all the subresearch area and meets the requirement of cropland protection policies.

Sensitivity of Cropland Expansion to Construction Land Expansion

By integrating the area of the expanded construction land and the expanded cropland, the sensitivity of cropland expansion to construction land expansion of each city in MRUA was estimated (**Figure 4**). To gain a clear view of the results, the sensitivity was divided into three levels as follows: low sensitivity ($0 < \theta \leq 0.1$), mid sensitivity ($0.1 < \theta \leq 0.2$), and high sensitivity ($\theta > 0.2$).

Overall, the number of cities denoting the sensitivity of mid and high continuously increased and those with low sensitivity kept decreasing over time. During 2000–2010, only three cities were with mid sensitivity and the other cities in MRUA were all at the level of low sensitivity (**Figure 4A**). In comparison, the number of cities with low sensitivity decreased to eight, whereas the quantity of cities with mid and high sensitivity increased to 14 and nine during 2010–2020, respectively (**Figure 4B**). Additionally, cities with high sensitivity were mainly located in the north of MRUA. The results of sensitivity analysis in MRUA demonstrate that the area of cropland expansion is becoming increasingly related to the area of construction land expansion over time.

Changes of the Gravity Center of the Expanded Construction Land and the Expanded Cropland and Their Interaction

Figure 5 displays the changes of the gravity centers of the expanded construction land and the expanded cropland in 2000–2020, and the change directions and distances of the gravity centers are listed in **Table 3**. Although the gravity centers were all in Xianning during 2000–2020, the gravity center of the expanded construction land has moved toward the northeast, whereas that of the expanded cropland has continuously changed toward the southeast of the research area. Both the gravity centers of the expanded construction land and expanded cropland show a moving trend toward the east. The moving distances of the gravity centers of the expanded construction land and the expanded cropland experienced little difference with distances of 17.83 and 15.37 km, respectively. With respect to the moving directions, the difference between the expanded construction land and the expanded cropland showed substantial changes. During 2000–2020, the change direction of

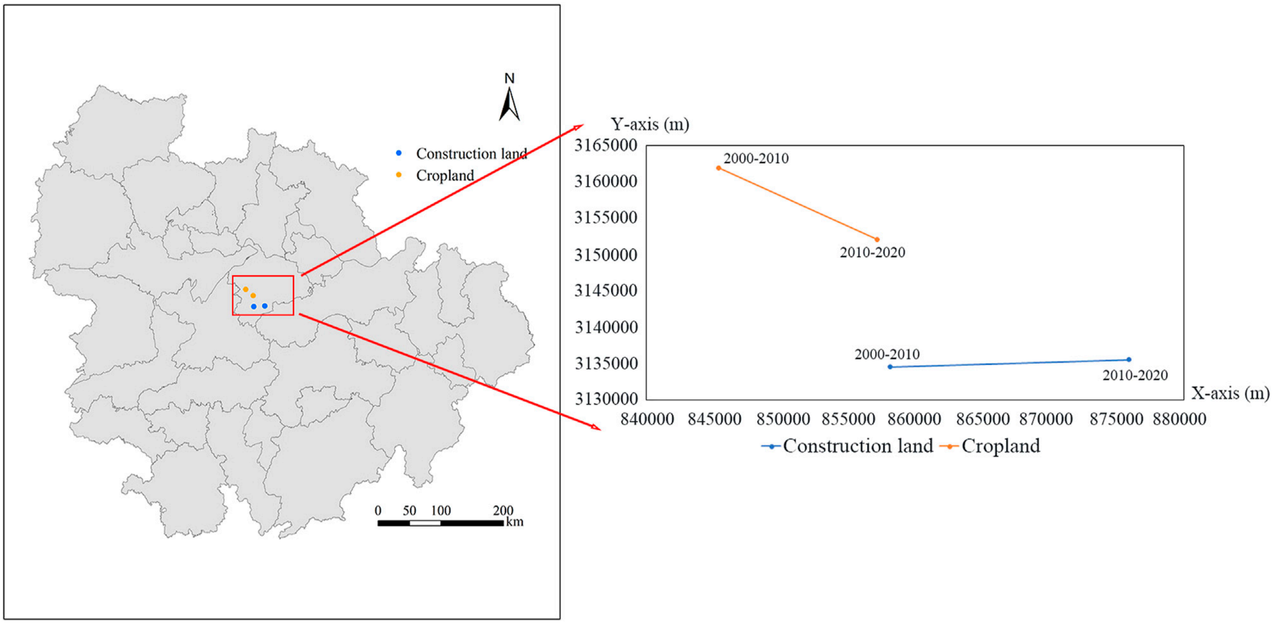

FIGURE 5 | Changes of the gravity center of the expanded construction land and the expanded cropland in 2000–2020.

TABLE 3 | Moving directions and distances of the gravity centers of the expanded construction land and cropland.

Period	Center of the expanded construction land		Center of the expanded cropland	
	Direction (°)	Distance (km)	Direction (°)	Distance (km)
2000–2020	3.24	17.83	−39.74	15.37

the gravity center of the expanded construction land was 3.24°, while that of the expanded cropland changed to −39.74°. In other words, the gravity center of the expanded construction land moved 3.24° and 17.83 km toward the northeast, whereas the gravity center of the expanded cropland shifted −39.74° and 15.37 km toward the southeast.

Figure 6 presents the spatiotemporal characteristics of the spatial interaction between the construction land expansion and cropland expansion in each subresearch area from 2000 to 2020. For a clear view, **Figure 6** presents the LN format of the values of the interactions. From an overall perspective, the values of the interaction show an increasing trend as follows: the minimum and maximum values of the interaction have increased from 5.65 and 8.72 in 2000–2010 to 7.15 and 9.89 in 2010–2020. For a spatial perspective, in 2000–2010, cities with high values mainly locate in the central and north of the research area; meanwhile, the highest values distribute in the central of the research area. Wuhan, Changsha, Xianning, and Jingzhou were the cities with the highest values of interactions. The lowest values distribute in the south of the research areas, such as Zhuzhou, Xiangtan, and Jingdezhen. For the period of 2010–2020, only three cities showed the lowest values, namely, Yichang, Xiangtan, and Zhuzhou. The highest values occured in Tianmen and Wuhan. Most of the cities with the lowest values in 2000–2010 have increased their interaction values, indicating a good phenomenon for balancing the tradeoffs between construction land expansion and cropland expansion.

Spatiotemporal Heterogeneity of Socioeconomic Determinants

The GWR model was utilized to analyze the spatiotemporal heterogeneity of socioeconomic determinants on the interaction between construction land expansion and cropland expansion both in 2000–2010 and 2010–2020. **Table 4** shows the performance of the GWR model in 2000–2010 and 2010–2020. The values of AICc in 2000–2010 and 2010–2020 are 580.84 and 219.26, respectively, and the adjusted R^2 values are 0.92 and 0.6, respectively, indicating that the GWR model can be used to reveal the spatial and temporal differentiations of socioeconomic determinants. From the summary table of the estimated coefficients (**Table 5**), we can see considerable variations in the coefficient of each explanatory variable with different positive and negative effects. The standard deviation of GDP and INVEST shows a decreasing trend over time, changing from 5.15 and 4.66 in 2000–2010 to 3.87 and 3.89 in 2010–2020, respectively, whereas that of GDPF and POP displays an increasing pattern (2.7 and 4.76 in 2000–2010 and 4.28 and 5.25 in 2010–2020, respectively).

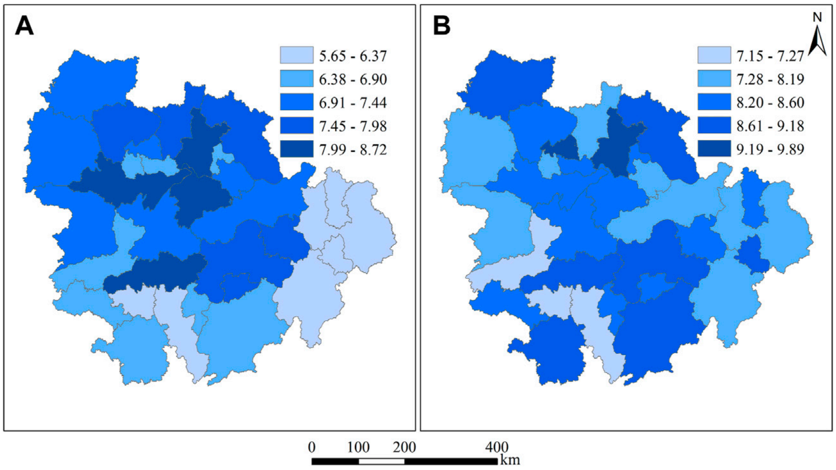

FIGURE 6 | LN format of the interaction between the expanded construction land and the expanded cropland in the periods of **(A)** 2000–2010 and **(B)** 2010–2020.

TABLE 4 | Performance of the GWR model in the periods of 2000–2010 and 2010–2020.

Indicator	2000–2010	2010–2020
AICc	580.84	219.26
Adjusted R^2	0.92	0.6

TABLE 5 | Summary of the estimated coefficients detected by the GWR model.

	2000–2010				2010–2020			
	Min	Mean	Max	SD	Min	Mean	Max	SD
GDP	−11.19	−0.23	11.12	5.15	−2.14	2.21	17.14	3.87
GDPF	−5.93	0.02	6.31	2.7	−12.37	−1.94	3.68	4.28
POP	−6.93	1.48	12.06	4.76	−3.95	2.89	16.82	5.25
INVEST	−11.54	0.09	9.72	4.66	−18.56	−2.49	0.123	3.89

Min, Mean, Max, and SD represent the minimum, mean, maximum, and standard deviation of the estimated coefficients.

Based on the local coefficients estimated by the GWR model and the Natural Breaks Jenks method in ArcGIS 10.2, the coefficients with similar values have been divided in to the same classification level (**Figure 7**). In addition, to distinguish the positive and negative effects, the authors separated the positive and negative coefficients as follows: blue represents the positive values, and yellow denotes the negative values.

The spatiotemporal effects of GDP on the interaction between the construction land expansion and cropland expansion in 2000–2010 and 2010–2020 are shown in **Figure 7A**. Overall, the positive effects of GDP displayed an increasing trend, whereas the absolute values of coefficients showed a shrinking pattern. In 2000–2010, the positive coefficients distributed in the south of the research area, and the negative coefficients were located in the northwest and northeast. In 2010–2020, nearly all the subresearch areas displayed with the positive coefficients whereas negative coefficients could only be seen in northwest and were scattered in the middle. The proportions of positive coefficients increased overtime with a proportion of 45.16% in 2000–2010 to 77.42% in 2010–2020 (**Table 6**).

According to **Figure 7B**, the influence of GDPF on the interaction between construction land expansion and cropland expansion slowly follows the trend of negative effects distributed in the west and positive effects located in the east both in 2000–2010 and 2010–2020. Moreover, the proportions of the positive and negative coefficients are stable in these two time periods (**Table 6**).

The spatiotemporal effects of POP in 2000–2020 are displayed in **Figure 7C**, showing an overall pattern of the positive coefficients located in the west and the negative coefficients distributed in the east. The distribution pattern of the POP's different types of coefficients is nearly reversed with that of the GDPF. Meanwhile, the proportions of the positive and negative coefficients of POP are similar to that of GDPF, with proportions of 58.06 and 41.94% both in 2000–2010 and 2010–2020 (**Table 6**).

Figure 7D presents the spatiotemporal influences of INVEST on the interaction between construction land expansion and cropland expansion, which shows that the overall pattern of the cities with negative coefficients are continuously increasing over time. In 2000–2010, the positive coefficients could be detected in the northwest and southeast of the research area; whereas in 2010–2020, only two cities had positive coefficients. Therefore, the proportion of the negative coefficients showed a sharp increase, with a proportion of 41.94% in 2000–2010 to 93.55% in 2010–2020 (**Table 6**).

DISCUSSION

Taking 31 prefectural cities in MRUA as the case area, this study analyzed the spatiotemporal patterns of the interaction between construction land expansion and cropland expansion and detected their socioeconomic determinants' effects from 2000 to 2020 by integrating the spatial gravity model and the GWR

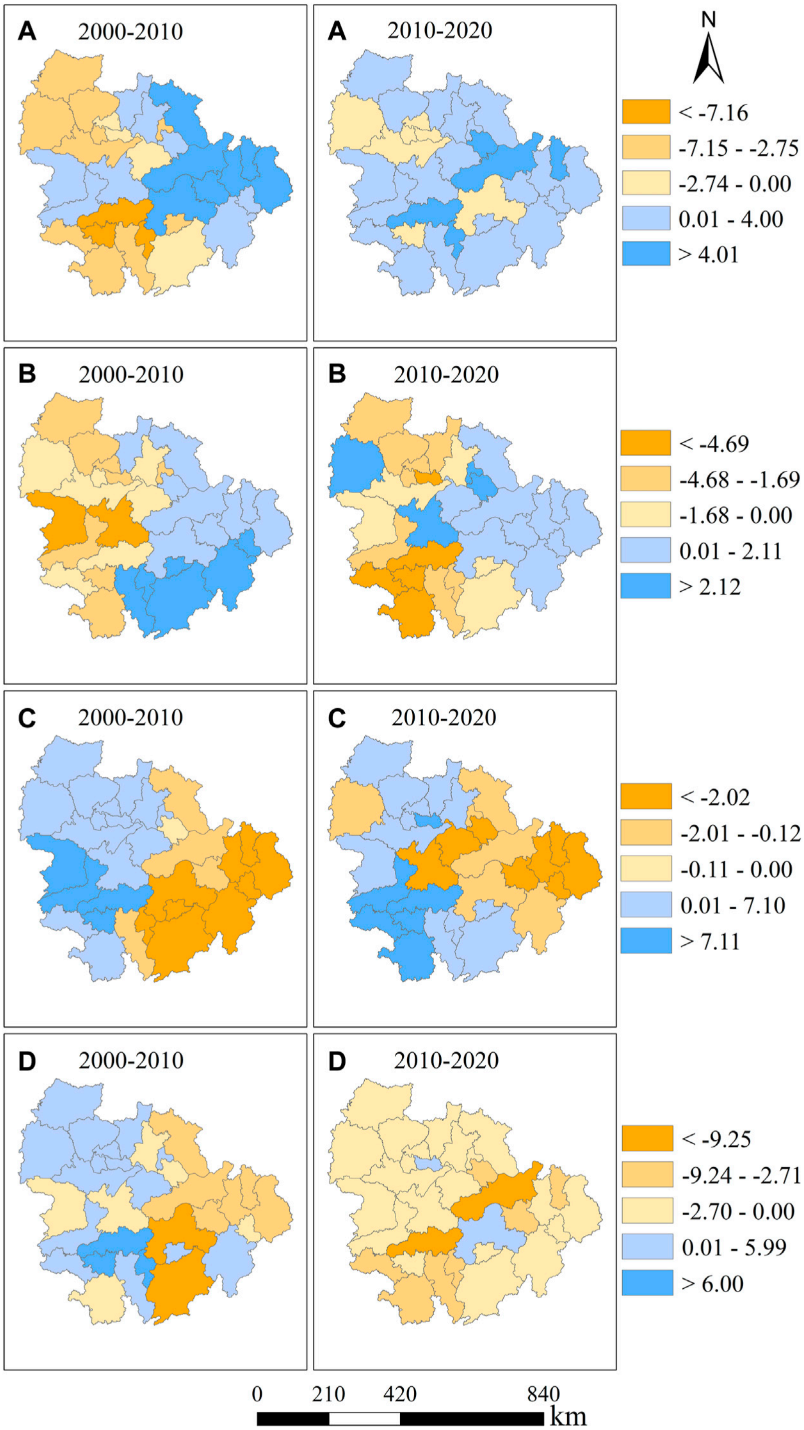

FIGURE 7 | Spatiotemporal distributions of the GWR coefficients of socioeconomic determinants in MRUA from 2000 to 2020: **(A)** GDP, **(B)** GDPF, **(C)** POP, and **(D)** INVEST.

model. The urbanization and cropland expansion are both hot issues for researchers (Badreldin et al., 2019; Zhou et al., 2021; Wang et al., 2022). Since the implication of cropland protection policies, it is important to assess the implication effect and its consequences (Liu et al., 2017; Ke et al., 2018; Ke et al., 2019; Wang et al., 2020). The interaction analysis of construction land expansion and cropland expansion can directly reflect the requirements of cropland protection policies on the cropland area. Owing to one of the cropland protection policies, Cropland Balance Policy, requests that if the development of construction

TABLE 6 | Proportions of the cities with different types of coefficients (%).

	2000–2010		2010–2020	
	Positive	**Negative**	**Positive**	**Negative**
GDP	45.16	54.84	77.42	22.58
GDPF	45.16	54.84	41.94	58.06
POP	58.06	41.94	58.06	41.94
INVEST	58.06	41.94	6.45	93.55

land takes in cropland, the construction land developer must reclaim the same area of cropland as the loss of cropland due to construction land development through land consolidation, exploitation, or rehabilitation (Lichtenberg and Ding, 2008; Song and Pijanowski, 2014; Liu et al., 2017). The results of the characteristics of the expanded construction land and the expanded cropland showed that during 2000–2020 both construction land and cropland expansions displayed an increasing trend. Additionally, the area of the expanded cropland exceeded those of the expanded construction land in 2010–2020. In the subresearch areas, during 2000–2010, only five cities showed that the area of cropland expansion exceeded that of construction land expansion. This phenomenon nearly happened in all subresearch areas. The value of the interaction of construction land expansion and cropland expansion also showed an overall increasing pattern with the minimum and maximum values increased from 5.65 and 8.72 to 7.15 and 9.89, respectively. All of the aforementioned results have proven that the implementation results of the cropland protection policies are progressively improving over time, which is in line with the conclusions of Yu et al. (2018) and Yang et al. (2020a).

We also identified the spatial and temporal sensitivity of cropland expansion to construction land expansion through sensitivity analysis and drew the shifting map of the gravity centers of the expanded construction land and the expanded cropland. The decrease in the sensitivity of cropland expansion to construction land expansion may cause many problems, such as imbalance of regional land use structures and insufficiency of grain production (Xu et al., 2013; Chai et al., 2019). The sensitivity analysis also demonstrated an increasing pattern of sensitivity of cropland expansion to construction land expansion. Moreover, the proportion of high sensitivity cities is progressively expanding over time, showing that cropland expansion is becoming increasingly sensitive to construction land expansion. The results of the gravity center showed that during 2000–2020, the gravity centers of the expanded construction land and the expanded cropland were all located in one prefectural city, but their shifting patterns were different. Both the gravity centers of the expanded construction land and the expanded cropland shifted to the east in the X-axis direction in 2000–2020, which supported the research of Chai et al. (2019) conducted in Hubei Province. In the Y-axis direction, distinct from the research carried out by Wang et al. (2018), the gravity center of the expanded construction land shifted toward the north and that of the expanded cropland moved toward the south. This phenomenon decided by the DEM of the research area (**Figure 1B**). The research area presents a pattern of high in the southeast and low in the northwest. People prefer to use the land with low DEM for developing construction land because of the low cost and high repay (Liu et al., 2005; Su et al., 2020), pushing the expanded cropland to the locations with relatively high DEM. Therefore, the gravity center of the expanded cropland moved to the southeast of the research area.

Existing studies have separately discussed the influence factors of construction land and cropland transitions (Ariti et al., 2015; Zelaya et al., 2016; Zhou et al., 2020). However, these studies did not explore the spatiotemporal impacts of socioeconomic determinants on the interaction between construction land expansion and cropland expansion. Thus, this study explored the spatiotemporal heterogeneity of the socioeconomic determinants of the interaction between construction land expansion and cropland expansion for 2000–2010 and 2010–2020 using the GWR model. Four socioeconomic determinants were chosen, namely, GDP, GDPF, POP, and INVEST. The positive impact of GDP showed an increasing pattern over time. The GDP reflects the overall economic level of a region (Xie and Wang, 2015; Gollin et al., 2016). With the improvement of socio economy, the government began to pay extra attention to the implementation of cropland protection (Liu et al., 2017; Piquer-Rodríguez et al., 2018). Therefore, the more construction land expansion, the larger the area of cropland expansion. Then, it promotes the interaction between them. The impacts of GDPF and POP nearly show an inversed distribution pattern. This finding is due to the fact that the economic development of the west of the research area is better than the east. The high GDPF is more attractive for the people in the east for agricultural activities. Thus, the positive impact of GDPF located in the east. By contrast, people in the economically underdeveloped areas prefers to live in the urban areas and the construction land expansion rate brought by population increase in economic developed areas is higher than that in underdeveloped areas (Li et al., 2019; Li et al., 2022). Therefore, the negative effect of POP distributed in the east. The negative influence of INVEST is continuously increasing during 2000–2020 because the investment in fixed assets concentrates on the urban areas and ignores the development in the agricultural areas. This situation leads the unilateral expansion of construction land instead of the joint expansion of construction land and cropland, thus negatively affecting their interaction.

This research contains some limitations. First, only two time periods of construction land expansion and cropland expansion were identified with a time interval of 10 y. Several LUCC-related studies have chosen the time interval of 5 y to better reveal the detailed change in land use changes (Lang et al., 2018; Wu et al., 2021). The time interval in this article can be improved. Second, construction land expansion can also bring the loss of cropland. Future research could explore the relationships among construction land expansion, cropland expansion, and cropland loss. Last, this article identified the spatiotemporal heterogeneity of four socioeconomic determinants on the interaction between construction land expansion and cropland expansion. Several other socioeconomic determinants may also affect the interaction between construction land expansion and cropland expansion. Other determinants should be explored in the future.

CONCLUSION

This study first detected the spatial and temporal characteristics of construction land expansion and cropland expansion. Then, the sensitivity analysis was applied to identify the sensitivity of cropland expansion to construction land expansion. Next, the gravity center of the expanded construction land and the expanded cropland and their shifting trajectories were detected by the spatial gravity model. Finally, four socioeconomic determinants were chosen, namely, GDP, GDPF, POP, and INVEST, and their impacts on the interaction between construction land expansion and cropland expansion were explored by the GWR model. The results show that the areas of the expanded construction land and expanded cropland and the sensitivity of cropland expansion to construction land expansion demonstrated an overall increasing trend over time in MRUA. The shift trajectories of the expanded construction land and cropland displayed different patterns, where the gravity center of the expanded construction land moved toward the northeast, whereas that of the expanded cropland shifted toward the southeast. The spatiotemporal heterogeneity of socioeconomic determinants of the interaction between construction land expansion and cropland expansion obviously exists in MRUA. The GDP has an increasing positive effect, whereas the investment in fixed assets displays an increasing negative influence during 2000–2020. The GDP in the agricultural sector and the population show a stable effect with half the proportion of the cities having a negative or positive influence. However, the distribution of the negative or positive influence of these two determinants are almost reversed. This study is not only helpful to understand the regional spatiotemporal interaction of construction land and cropland expansions and their socioeconomic determinants but can also offer solutions for the decision makers to promote this interaction and continue the pursuit of sustainable development.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

LW: writing—original draft preparation, methodology, and writing—reviewing and editing. SZ: writing—reviewing editing and methodology. YL (3rd author): writing—reviewing and editing and methodology. YL (4th author): writing—editing and supervision.

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