Driving Force Analysis of Cropland Loss in a Rapid Urbanizing Area—The Case of Beijing

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Abstract. Understanding the driving forces of cropland loss is important for land resource management and sustainable development. This paper aimed to identify the effects of physical and socioeconomic factors of cropland loss in a rapid urbanizing area–Beijing. Geographical detector was used to analyze the importance of drivers and the cropland loss intensity in space. Our results showed that physical factors were generally more influential than socioeconomic factors and their effects changed over time. Urban land was the most important factor during the late 1980s–2000, while woodland became the most influential one in 2000–2010 due to the Sloping Land Conversion Program. Also, the rural settlement in the surrounding area got more influential than urban land in the later period. At last, the cropland loss intensity showed clear but different relationships with most factors. These findings can offer government useful information to protect the cropland and thus maintain sustainable development.

Keywords: Geographical detector · Cropland loss · Driving force · Beijing · Rapid urbanizing

1 Introduction

Stable agricultural production, which relies on sufficient cropland maintenance, is the guarantee of food security and sustainable socioeconomic development [1]. Cropland change is an important issue for China, since the nation supplies food to 22 % of the world population with only 7 % of the world's cropland base [2]. Although the area of cropland is stable from the late 1980s in China, the area of traditional cropland with higher production actually decreases [3]. Cropland loss in China is especially serious in big cities where built-up land construction occupies large amounts of cropland. At the same time, with the implement of some environmental protection policies in China, the area of cropland also decreases in some ecologically fragile areas. Under such situations, it is essential to understand the driving forces of cropland loss deeply, which may provide important implications on cropland conservation of the nation.

Beijing, as the capital city of China, is experiencing rapid urban expansion along with serious cropland loss. More than 80 % of the expansion area of built-up land was converted from cropland between the late 1980s and 2010 [3]. Also, Beijing's cropland

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loss was influenced by environmental protection policies. Beijing began to implement Sloping Land Conversion Program and Beijing and Tianjin Sandstorm Source Control Project in 2000 and 2002, respectively, which promoted the conversation of cropland to woodland in Beijing evidently. So Beijing was an optimal area to study the driving force of cropland loss in rapid urbanizing areas, whose cropland loss was affected by both urbanization and environmental protection policies.

Several studies have examined the spatial patterns and driving forces of cropland loss in rapid urbanization areas, for example, in Su-Xi-Chang region in Jiangsu [1], Shanghai [4, 5] and the delta of the Pearl River [6]. Current studies mostly get the driving forces using temporal statistical analysis such as bivariate regression and multiple linear regression. But relatively less attention has been paid to the temporal variation of the driving forces. The analysis of physical and socioeconomic factors as a whole in rapid urbanizing areas is also worth further exploration. In this study, we used a relatively new spatial statistical method called geographical detector to identify the spatial relationships and their changes between cropland loss and its drivers, which could help better understand the questions mentioned above.

This paper aims to examine the effects of physical and socioeconomic factors that leading to cropland loss and their changes during the late 1980s–2000 and 2000–2010 in Beijing, China. We would deal with the following questions: (1) What factors had dominant influence on cropland loss in Beijing during the late 1980s–2000 and 2000–2010, respectively? (2) How the effects of different factors changed over time? (3) Where did cropland lose more seriously?

2 Study Area, Drivers and Data

Beijing, the capital of the People's Republic of China, is located between 115.7°E-117.4°E and 39.4°N-41.6°N at the northern tip of the North China Plain, with a total area of about 16410 km^2. The average elevation of Beijing is 43.5 m, with Taihang Mountain and Yanshan Mountain surrounded in the west and north. Beijing has fourteen districts and two counties. The city has a monsoon-influenced humid continental climate with hot, humid summers and cold, dry winters. As the nation's political, cultural and educational center, Beijing has experienced rapid urbanization since the market reform initiated in 1978. Its population increased from 11.08 million in 2000 to 19.61 million in 2010, and the proportion of the urban population grew from 77.54 % to 85.96 % [7]. Along with the rapid urban expansion and population growth, the area of cropland in Beijing decreased by 27.4 % from 3704.85 km^2 at the end of 1980s to 2689.53 km^2 in 2010 [3]. The cropland is mainly located in the southeast of Beijing around the city center and in the plain area of the outer suburbs. The cropland loss process from the late 1980s to 2010 is shown in Fig. 1.

Factors leading to cropland loss are complicated. After a comprehensive literature review, we found three types of drivers have been typically considered in similar studies: physical factors, socioeconomic factors and policy factors. Physical factors included topography [8–12], climate [8] and neighborhood factors (e.g. urban land in the surrounding area or undeveloped land in the surrounding area) [8–13]. Socioeconomic

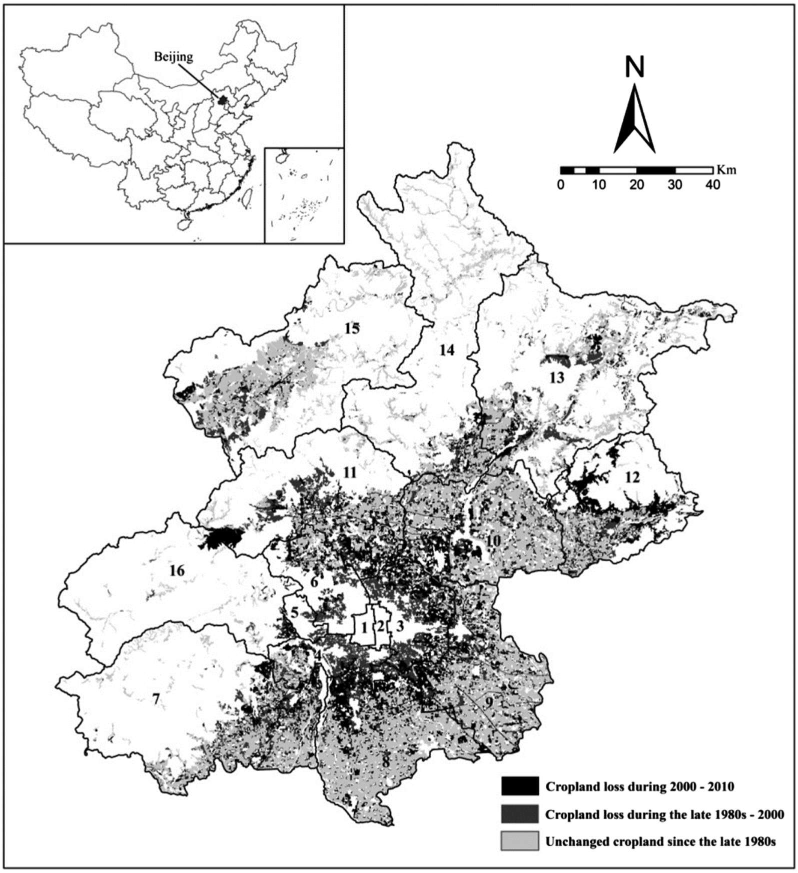

Fig. 1. The study area and its cropland loss process from the late 1980s to 2010. (1: Xicheng, 2: Dongcheng, 3: Chaoyang, 4: Fengtai, 5: Shijingshan, 6: Haidian, 7: Fangshan, 8: Daxing, 9: Tongzhou, 10: Shunyi, 11: Changping, 12: Pinggu, 13: Miyun, 14: Huairou, 15: Yanqing, 16: Mentougou).

factors included population [8–10, 12, 14, 15], economy [8, 14, 15], access to roads [8–12, 14], agricultural input intensity (e.g. tractor density and fertilizer use) [10, 11, 15] and so on. At the same time, policy factors such as cropland protection legislations and urban land policy were also considered in some research [8, 14]. Based on these studies, we selected eleven physical and socioeconomic factors that may influence the cropland loss during the two periods (Table 1). Policy factors were not included for the difficulty to express its spatial heterogeneity in this area. For period of the late 1980s–2000, factors of GDP and Prm_Indu were not included because of the lack of data in late 1980s.

Data used in this study include: (i) land use raster of Beijing of the late 1980s, 2000 and 2010 with six first level types (cropland, woodland, grassland, water bodies, built-up land and unused land). Cropland comprises two second level types: Paddy and dry land, while built-up land comprises three second level types: urban land, rural settlement

Table 1. List of selected factors in this study.

Category	Factors	Abbreviation
Physical factors	Elevation	–
	Slope	–
	Woodland in the surrounding area	Woodland
	Urban land in the surrounding area	Urban
	Rural settlement in the surrounding area	Rural_St
	Industry-traffic land in the surrounding area	Indu_Trf
Socioeconomic factors	Permanent population	Per_Pop
	Rural population	Rural_Pop
	Gross domestic product	GDP
	Proportion of primary industry in GDP	Prm_Indu
	Per capita income of rural residents	Rural_Icm

and industry-traffic land. The data are from national land use/cover database of China, which are mapping by digit human-computer interaction method based on multiple sources of remote sensing data (the Landsat Thematic Mapper, the China-Brazil Earth Resources Satellite and HJ-1A) [16]; (ii) digital elevation model (DEM) of 1980s from 1:250000 topographic database produced by National Fundamental Geographical Information System of China. Land use and DEM data are both raster files with a 100 m resolution; (iii) socioeconomic data of 16 districts and counties of Beijing including GDP, permanent population, rural population, per capita income of rural residents, proportion of primary industry in GDP [7, 17–19].

3 Method–Geographical Detector

Geographical detector is a spatial statistical method to test the consistency of spatial distribution between study objects and their potential driving factors. When the method is applied to cropland loss, we assume that the spatial distribution of cropland loss is similar to that of its potential factors. It consists of four factors: factor detector, risk detector, ecological detector and interaction detector. In order to answer the questions mentioned above, factor detectors is used to explore which factors are more important during each time period and their changes, while risk detector is used to answer where the cropland lost more seriously.

Figure 2 demonstrates the mechanism of geographical detector [20]. First, the study region A is divided with a grid system $G = \{g_i;\ i = 1, 2, \ldots, \mathrm{n}\}$ and the area of cropland loss in every grid is calculated: $y_1, y_{1...}y_n$. $D = \{D_i; i = 1, 2, 3\}$ is the geographical stratum of potential factors that can be both continuous and categorical variables. Then the distribution of cropland loss is overlaid with the geographical stratum *D*. Every grid in system *G* will record the value of cropland loss area and the attribute of potential factors according to where it located. For factors of elevation and slope, the value of the grid is equal to the type with the largest proportion. The mean value and the dispersion variances over sub-regions D_i are denoted as $\bar{y}_{D,i}$ and $\sigma^2_{D,i}$ (i = 1, 2, 3), respectively. Let n be the total number of samples over the entire region *A* and let $n_{D,i}$ be the number of samples in sub-region D_i. The global variance of cropland loss in the region *A* is σ^2.

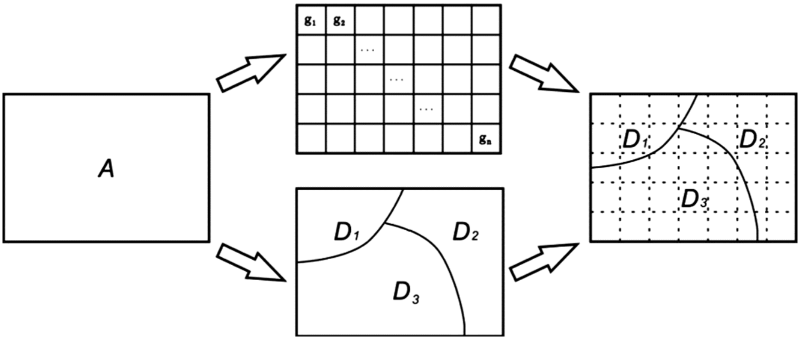

Fig. 2. Mechanism of geographical detector

The factor detector can quantitatively indicate the relative influence of different factors. In this study, the power determinant (PD) is defined as the difference between one and the ratio of accumulated dispersion variance of cropland loss area over each sub-region to that over the entire study region:

$$\mathrm{PD} = 1 - \frac{1}{n\sigma^2}\sum\nolimits_{i=1}^{3} n_{D,i}\sigma^2_{D,i} \tag{1}$$

It means that if factor D is one determinant of cropland loss, the dispersion variance of cropland loss area of each sub-region is small, whereas the variance between sub-regions is large. The value of PD lies between 0 and 1. The larger the PD value is, the more influential the factor is. In this study, PD value represents the consistency of the spatial distribution between cropland loss and its factors.

The risk detector uses a t-test to compare the difference in average values between sub-regions of factor *D*. In this study, we only use the average value ($\bar{y}_{D,i}$) to calculate cropland loss intensity (I_d) which is the average percentage of cropland loss area of the grids in a sub-region D_i:

$$\mathrm{I}_d = \frac{1}{\mathrm{S}\cdot \mathrm{n}_{D,i}}\sum\nolimits_{1}^{\mathrm{n}_{D,i}} \mathrm{y}_{D,i} \tag{2}$$

where $y_{D,i}$ denotes the cropland loss area of a grid in sub-region D_i, $n_{D,i}$ denotes the number of grids in the sub-region and S denotes the area of a grid of GD. With I_d values, it is more convenient to compare the effects of different sub-regions. The greater the I_d value is, the more dramatically the cropland loss in space.

4 Results and Discussion

The relative importance of each driver was listed in order of decreasing PD values, while the cropland loss intensities of each driver at different levels were shown in Figs. 3 and 4.

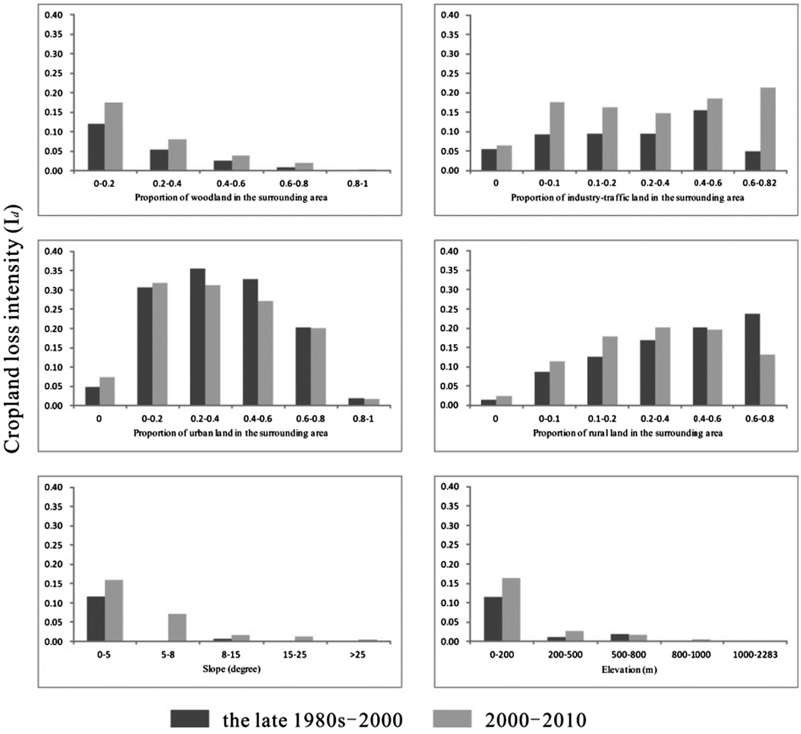

Fig. 3. Cropland loss intensity of physical factors for the two periods.

Period of late 1980s–2000: Slope (0.2071), Urban (0.2038), Woodland (0.1888), Elevation (0.1729), Rural_Icm (0.1693), Rural_St (0.1648), Per_Pop (0.1315), Rural_Pop (0.1048), Indu_Trf (0.0106).

Period of 2000–2010: Woodland (0.2683), Elevation (0.2396), Slope (0.2363), Rural_St (0.2031), Prm_Indu (0.1664), Urban (0.1372), P_Pop (0.1318), Rural_Pop (0.1198), GDP (0.1101), Indu_Trf (0.0837), Rural_Icm (0.0597).

The most influential factors during the late 1980s–2000 were slope and urban land in the surrounding area, while during 2000–2010, woodland in the surrounding area

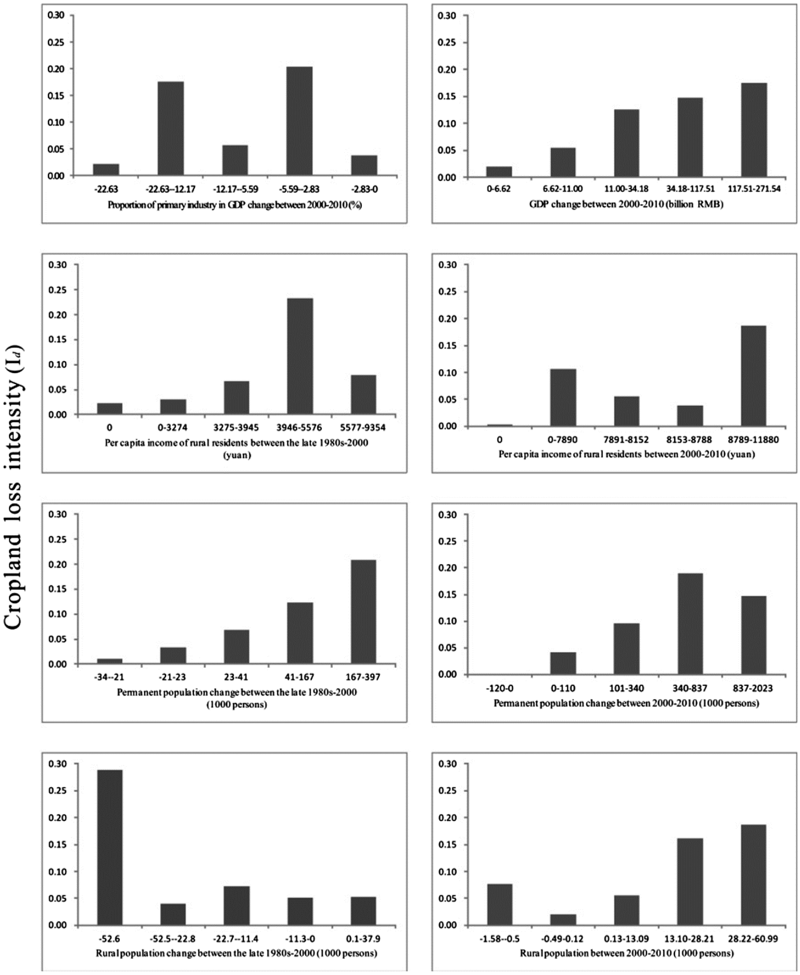

Fig. 4. Cropland loss intensity of socioeconomic factors for the two periods.

became the most important factor. The importance of different factors as well as their spatial effects on cropland loss also varied during these two periods.

4.1 Physical Factors

Physical factors showed significant effects on cropland loss in Beijing during the whole period.

The most obvious changed factor was woodland in the surrounding area which increased greatly as the most influential factor during the later period. It meant that the spatial distribution of cropland loss was more consistent with that of woodland after 2000. Similarly, the I_d value at different levels of woodland surrounding was larger during 2000–2010. This phenomenon was primarily due to the fact that Beijing began to implement the policy of China’s Sloping Land Conversion Program in 2000. The program covered four districts and two counties in Beijing: Pinggu, Huairou, Changping, Mentougou, Fangshan, Miyun and Yanqing. Beijing completed the task of the program in 2004 and afforested 306.67 km^2 cropland [21]. The afforested farm land were mainly distributed in ecological fragile areas, low food production areas, desertified and sloping land and sides of main roads. It may be due to this policy, the PD and I_d value of woodland in the surrounding area, elevation and slope all increased (Fig. 4). Elevation and slope became more influential because the afforested cropland was mainly located in lower and less sloping area. Investigation showed that 69.37 % of the afforested cropland was located in places with slope less than 15° (the desertified cropland accounted for 78.45 %) [21]. At the same time, it was shown that cropland lost more dramatically where the woodland was sparse. This might be caused by two reasons. First, the returned cropland was mainly located in flat area where the woodland was sparse. Second, the land use types in Beijing mainly consisted of built-up land, cropland and woodland. So the less woodland might indicate a larger proportion of built-up land in the surrounding area which usually caused the cropland loss seriously.

As for other surrounding land use types, urban land and rural settlement also showed significantly effects during both periods. In the first period, urban land in the surrounding area was more influential than woodland and rural settlement, while its relative influence decreased during the later ten years. Its I_d value was generally higher than all the other factors reflecting its great effects on cropland loss intensity. It was interesting to find that rural settlement contributed more than urban land in causing cropland loss during 2000–2010. Also, the I_d value of urban land in the surrounding area at some levels decreased, while that of different levels of rural settlement surrounding was basically larger in 2000–2010. It indicated that the urban growth in Beijing was more sustainable in terms of the intensity of cropland loss and consistency of spatial distribution between urban land and cropland, but the rural settlement which was fragmented in space actually occupied the cropland more seriously than before. There was another phenomenon that worth noting. The largest I_d value of both the urban land and rural settlement in the surrounding showed a trend of moving to less developed areas. For example, the largest intensity point of rural settlement moved from 0.6–0.8 level to 0.2–0.4 level during the two periods. It reflected a trend that the less developed area might occupy cropland in its surrounding more seriously in future. Industry-traffic land in the surrounding area was the least influential physical factor. Its PD and I_d value both increased during the two periods. The I_d value did not show large difference between different proportions of industry-traffic land in the surrounding area.

Elevation and slope were also important factors in causing cropland loss and they both influenced the I_d value negatively. The I_d value was much higher where elevation was below 200 m and slope was less than 5°. The reason might be that the cropland in Beijing was mainly distributed in plain areas in the southeast. In addition, built-up land expansion which occupied most cropland mainly concentrated in these regions, for the lower development cost in flatter areas [22].

4.2 Socioeconomic Factors

Compared with physical factors, socioeconomic factors had a relatively low influence.

Per capita income of rural residents (Rural_Icm) was the most important socioeconomic factor during the late 1980s–2000. It indicated the well spatial distribution consistency between Rural_Icm and cropland loss. But during 2000–2010, the spatial distribution consistency between Rural_Icm and cropland loss decreased greatly. The cropland loss intensity did not show a clear relationship with this factor. During 2000–2010, proportion of primary industry in GDP was influential but its I_d value did not show a regular pattern with in space. By contrast, GDP had a positive effect on I_d value. Places with more GDP growth tended to lose cropland more dramatically. It indicated that economy growth in Beijing was at the cost of cropland loss to some extent.

The influence of permanent population remained generally unchanged during the two periods. From the late 1980s to 2000, the I_d value was well positively correlated with the permanent population change, indicating the more the population grew, the more dramatically the cropland lost. It was because population in Beijing increased, but they required more urban land instead of cropland. This phenomenon was similar in the later ten years, however, when the population increased dramatically of 837–2023 thousand persons, the I_d value decreased. Further analyzing these high population increased area, they were Chaoyang, Haidian, Fengtai and Changping Districts where urban land was concentrated. This was consistent with the finding that the large intensity occurred where there were less proportion of urban land surrounding in 2000–2010.

Factor of rural population became a bit more influential within these years. It was interesting to find that the rural population change showed different relationships with the I_d value during the two decades. During the first decade when rural population decreased in Beijing, the largest loss intensity happened where the rural population dropped most, while in the later decade, the I_d value showed positive relationship with rural population growth. This might be explained by the fact that people living in the rural area depended less than agriculture to earn a living in Beijing. The rural population increased by 32.07 % from 3.798 million in 1996 to 5.016 million in 2006 and the structure of rural population also changed a lot in Beijing. Nearly one third of the rural population in Beijing was from other cities and this figure reached 58.7 % in the city functional expansion area (Chaoyang, Haidian and Fengtai Districts). However, rural population employed in the primary industry decreased from 855,000 in 1996 to 657,000 in 2006. There were 79.3 % of the employed rural population being involved in the secondary and tertiary industry in 2006, while only 61 % in 1996 [23]. These phenomena indicated that increased rural population in the later period had a higher requirement of rural settlements instead of cropland. It also explained the rural settlement in the surrounding area becoming a more important factor than urban land during 2000–2010.

It should be noted that the relative importance of different factors obtained by factor detector only reflected the spatial consistency between cropland loss and potential factors. So the higher relative importance was not equal to a large amount area of lost cropland. Although woodland and rural settlement in the surrounding area outweighed the influence of urban land in the later period, cropland in Beijing was still primarily converted into urban land in terms of area.

5 Conclusion

Based on multi-temporal LUCC data getten from satellite images, we observed a serious loss of cropland in Beijing from the late 1980s to 2010. Physical and socioeconomic factors significantly affected the cropland loss in Beijing. Based on the spatial statistic results of geographical detector, we could draw the following conclusions:

(1) During the late 1980s–2000, slope and urban land in the surrounding area are the dominant factors in causing cropland loss in Beijing with the relative importance of 0.2071 and 0.2038, respectively. By contrast, in period 2000–2010, woodland in the surrounding area was the most influential factor with the relative importance of 0.2683.
(2) The relative importance of different factors varied over time. Woodland in the surrounding area became the most influential factor after 2000, reflecting the great interference of the policy of China's Sloping Land Conversion Program. Moreover, we found that the influence of rural settlement outweighed urban land in the surrounding area during the later period, indicating a relative sustainable development of the urban land but less controlled rural settlement expansion in Beijing.
(3) The cropland loss intensity was influenced by various factors combined. Places with urban land and rural settlement concentrated were more likely to experience serious cropland losing, but less developed area tended to lose cropland more dramatically in the future. Also, the cropland loss intensity was much higher where the elevation was lower than 200 m and the slope was less than 5°. As for socioeconomic factors, GDP and population both showed a positive relationship with cropland loss intensity. However, rural population showed different relationships with cropland loss intensity during the two periods, indicating a changed land requirement and working structure of rural residents in Beijing.

Based on the findings of this study, it was evident that the urbanization and environmental policy had a significant influence on the cropland loss in Beijing. So we suggested that effective cropland protection management combined with urban planning should be implemented to control the cropland loss in Beijing. Moreover, government should take action to control the rural settlement expansion to protect the cropland in rural areas in the future.

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