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Article

Factors Influencing the Conversion of Arable Land to Urban Use and Policy Implications in Beijing, China

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Abstract: Rapid urban land expansion and the resulting arable land loss have put food security in China at risk. This paper investigates the characteristics and mechanism of arable land conversion in Beijing using a logistic model based on land-use data for 2001 and 2010. The results suggest that (1) arable land conversion tends to occur near built-up areas, city centers and major roads; (2) arable land that lies closer to irrigation canals and country roads is less likely to be converted to urban use; (3) arable land that is bigger in size and has a more regular shape has a lower probability of conversion to urban use; and (4) the Prime Farmland Protection policy and related land-use plan have played a positive role in preserving arable land, demonstrated by the probability for arable land conversion inside a prime farmland boundary is 63.9 percent less than for land outside the boundary. Based on these findings and on sustainable-development principles, we suggest that, rather than an exclusive focus on controlling the quantity of arable land, the location and characteristics of the arable land should be a primary consideration when designing urban policies and plans.

Keywords: arable land conversion; sustainable development; logistic regression; Beijing China; planning policy

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1. Introduction

With rapid economic development and population growth, urbanization is taking place at an unprecedented pace around the world [1]. As a result of rapid urbanization, many countries are experiencing a drastic loss of arable land [2]. The disappearance of arable land is especially pronounced in developing countries where urbanization has lagged behind developed countries. Industrialization and urbanization in these countries have left a lasting imprint on rural land use and profoundly altered the sustainability of arable land [3]. It is, therefore, critical to understand the characteristics and mechanisms of arable land conversion.

China, as a developing country, is experiencing drastic urban land expansion and the consequent loss of arable land. Arable land is a fundamental resource and is therefore critical to food security [4]. Given that China's per capita arable land was more than 40% below the world average in 2006, but that the country has one-fifth of the world's population [5], food security and arable land preservation are a vital concern of the Chinese government [6,7]. Since the early 1980s, arable land protection has been one of the basic state policies and the country has applied a series of land-protection policies. Based on China's land administration law, the Prime Farmland Protection Regulation was passed in 1994 and revised in 1998, with the fundamental objective of protecting arable land. According to this regulation, prime farmland protection must be incorporated into each level of a comprehensive land-use plan, and the boundary of prime farmland must be clearly defined in county- and town-level comprehensive land-use plans. Prime farmland is to account for no less than 80% of arable land within an administrative area, and each level of local government often requires a higher rate than this in order to establish a favorable administrative record [8]. Compared with ordinary arable land, prime farmland protection is more stringent. As required in the law and the regulation, only the state council can approve the conversion of more than 35 hectares of arable land, and approval from the state council must be obtained for the conversion of any amount of prime farmland. Nevertheless, although the government has boasted on many occasions that the country is applying "the most strict farmland protection policies in the world", the amount of arable land in China has been consistently dropping over the past thirteen years, going from 130.04 million hectares in 1996 to 121.72 million in 2008, which is close to the red line of 120 million hectares, as defined by the *China Statistical Yearbook.* An understanding of the characteristics and causes of arable land loss is therefore critical to improving government policies and measures.

In the past two decades, a number of studies have focused on the causes of arable land conversion and have provided important insights [9–12]. The research has attributed the conversion to urbanization, population growth, economic booms and the construction of transportation infrastructure [13–16]. A variety of methods have been used in these analyses. Some of the studies have focused on a quantitative analysis and used time series data [17,18], while some have studied arable land conversion from the perspective of landscape, analyzing the distribution, area, shape, center of gravity and other landscape characteristics [19–21]. These studies have introduced a series of useful parcel characteristics that add to an understanding of arable land characteristics and that describe changes in arable land for particular regions. Yet other studies have applied a market-based theory and an urban economic model, attempting to identify the causes of arable land conversion more qualitatively [22]. Most of the studies that have focused on China, however, have relied on qualitative methods and concluded that arable land loss should be attributed to urbanization, rural settlement development, industrialization, transportation infrastructure and other factors [16,23,24]. The location factors and the influence of policies have been investigated less often and few have done so quantitatively, with all other factors controlled. This is one focus of this study.

Another focus is the sustainable preservation of arable land. The definition of sustainable arable land protection has also been discussed widely and has been approached from different perspectives [25]. Some of the common views are that sustainable arable land utilization and preservation serve three functions: first, to increase crop production efficiency so as to meet the world's future food security needs [26,27]; second, to provide a barrier to protect the environment and ecological systems in suburban areas [28]; and third, to coexist harmoniously with patches of urban activities [29]. This paper will consider policy implications based on these three functions.

The paper aims to investigate influences on arable land conversion and assess the policy implications of planning and land management on sustainable development. The method we use is a spatial logistic regression model. We selected Beijing as the study area because it is a typical and important metropolitan area in China, with rapid growth in urban land and rapid reductions in arable land. The city also maintains good land-use data relative to other cities. In addition, finally, as the capital city, Beijing sets an example for China, so the study's policy implications will have a wider potential application.

The rest of the paper is organized as follows. Section 2 provides general information on the study area and describes the data and methods. Section 3 presents the results and discussion. Section 4 concludes and draws policy implications.

2. Study Area and Methods

2.1. Study Area

Beijing is located in the northwest region of the North China plain, with an area of 16,410 km^2, including two districts in the central city, four districts in its suburbs and eight districts and two counties in its outer suburbs. Hilly terrain accounts for 62% of the area and the other 38% is plain. Arable land is mainly distributed in the southeast of Beijing, which belongs to the plains and contains Daxing, Tongzhou, Shunyi and Pinggu districts, as shown in Figure 1. In 2011, per capita GDP for Beijing was 80.4 thousand yuan, close to the average for developed regions in the world. According to the sixth population census of China, the total population of Beijing in 2010 was approximately 19.61 million, with around 2.57 million people (14% of the total population) living in rural areas, some of whom still make their living on arable land.

As China's capital, Beijing is the country's political center and is home to the central Chinese and Beijing government ministries and several dozen representative offices of international organizations. There are far more scientific research institutions and universities in Beijing than in other cities, contributing to its position as China's cultural center. The city also has the largest number of headquarters for the top five hundred enterprises in the world, and it is a transportation hub connecting domestic travel with a railroad and highway network that extends in all directions. The result has been a swelling population and concentration of activities that have led to an increasing demand for urban land development and expansion [30]. From the 1980s to the 2000s, the 3rd to 6th ring roads in Beijing were built and began use, in succession.

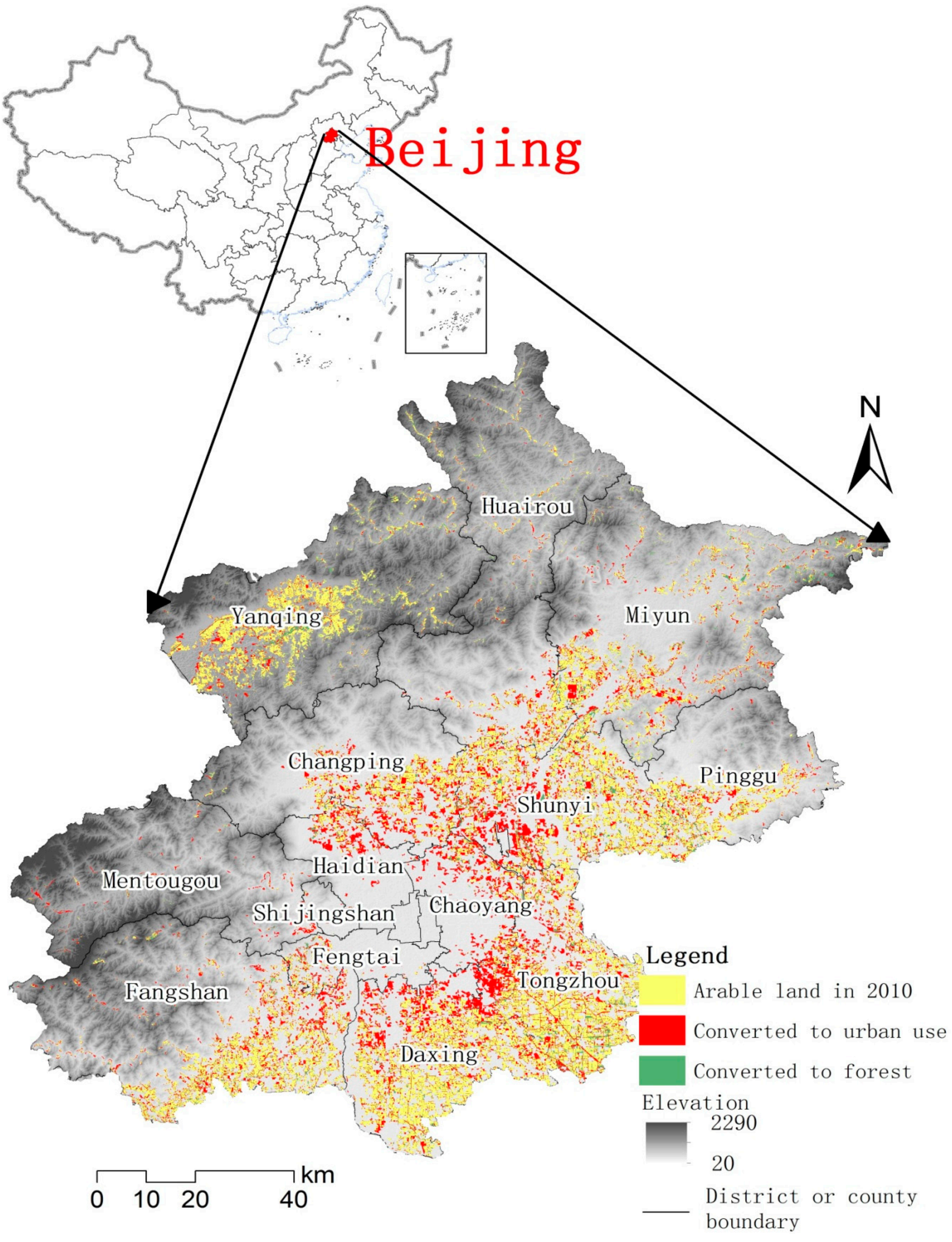

Figure 1. The distribution of arable land in 2001 and its conversion.

Despite all of this, Beijing has sufficient natural conditions for agricultural development and the potential to expand wheat and corn crops. Its location in the North Temperate Zone, a semi-humid continental climate area with high temperature and rainfall that both occur during summer, makes it conducive to crop growth. Its annual non-frost period is 190 days and annual rainfall is 483.9 mm, which constitutes the highest rainfall rate in the north China region. Per-unit area yield in Beijing is 12.4% higher than it is nationwide [31].

There is thus a sharp contradiction between Beijing's urban land development needs and the protection of its arable land. Comparing arable land-use data in 2001 and 2010, 61.13% of arable land in 2001 remained arable in 2010 and 30.96% had been converted to urban use, with the rest converted to forest land due to a policy for returning cropland to forest. Urban land sprawl played the most important role in arable land loss and much of the converted arable land was close to an existing built-up area. As urban land continues to expand in the future, arable land will inevitably be further encroached upon [32,33]. This paper therefore focuses on the conversion of arable land to urban use, (we consider the 7.91% of land that was converted to forest as being maintained for agricultural use). By looking at the mechanism for arable land conversion to urban use, we hope to contribute to the better preservation of arable land in Beijing and to provide a model for other countries.

2.2. Data Sources and Processing

We collected 2001 and 2010 land-use data for Beijing, and land-use planning data from 2001 to 2010 from the Bureau of Land and Resources of Beijing, which is Beijing's land administrator. The data on arable land and on the conversion of arable land were extracted from these two digital maps. The digital elevation model data, which provided elevation information, were obtained from the computer-network center website of CAS [34]. We then calculated the slope and aspect data using Arcgis 10.2. The distribution of built-up areas, irrigation canals, rivers, rural roads and highways was extracted from the 2010 land map. The points of *Tiananmen* and district governments were digitized according to their coordinates. Population data were obtained from the sixth demographic census at the unit of street (or township). We divided the whole study area into 200 m × 200 m grids. Every grid contained the information described above as well as the distances to *Tiananmen* (representing the city center), the nearest river, road and district government.

2.3. Method

We used a logistic regression model to investigate the characteristics and mechanism of arable land conversion. The advantage of using a logistic regression model is that it can measure the relationship between the categorical dependent variable and many independent variables. In addition, by dividing land into grids, the model can analyze the grid data and study the effect of the influencing factors on land use. The factors include spatial information, policy, and socioeconomic conditions.

2.3.1. Logistic Regression Model

We calculated the probability that a given grid of arable land would be converted to urban use between 2001 and 2010. This would help in understanding the rules of arable land encroachment and of which parcel of arable land has a higher probability of conversion to urban use. If arable land was converted to urban use during this period, we assigned a value of "1" to this grid and if not, we assigned a value of "0". The logistic regression model is of the form:

$$P_i(y_i = 1 | \beta_0, \beta) = \frac{\exp(\beta_0 + \beta_1 x_{1,i} + \cdots + \beta_n x_{n,i})}{1 + \exp(\beta_0 + \beta_1 x_{1,i} + \cdots + \beta_n x_{n,i})} \tag{1}$$

where p (y_i = 1/X) is the probability that y takes the value 1. Given the vector of independent variables X, β_s are model coefficients to be estimated.

In line with formula 1, Odds can be defined as:

$$Odds = \frac{p_i}{1 - p_i} = \exp(\beta_0 + \beta_1 x_{1,i} + \cdots + \beta_n x_{n,i}) \quad (2)$$

The relationship between dependent and independent variables could be reflected by the regression coefficient (e^{β_i}). When $e^{\beta_i} > 1$, the possibility that arable land will be converted to other uses increases as the independent variable increases, and Odds increases e^{β_i} times as the independent variable increases 1 unit, and vice versa. If $e^{\beta_i} = 1$, the possibility of arable land conversion is changeless as the independent variable changes. The quality of the fit of the models is measured by the relative operating characteristics (ROCs), which make comparisons between predicted values and true values. The value of the ROC ranges from 0.5 to 1 or from random distribution to perfect assignment of the probability of arable land change.

2.3.2. Variable

According to land-use classification standards, we divided land into arable, urban and other uses. Arable land contained vegetable, irrigable and arid types. We selected arable land in 2001 as the object of study. If arable land was converted to urban use, we assigned it "1", if not it was assigned "0".

Based on previous studies and on our understanding of Beijing, we chose five types of associated factors, such as location and accessibility, policy, parcel characteristics, socioeconomic condition and terrain [35–37]. Among them, we are more concerned with the first three factor types. The interpretation of dependent and independent variables is shown in Table 1.

Location and accessibility: Location, which refers to the position of arable land in a particular area, is a key factor influencing land-use change. Because the location of the site relative to different levels of government and construction can help to determine the position of arable land, we chose the distance from the nearest built-up area (x_1), the district governments (x_2) and Tiananmen (as the center of Beijing) (x_3) as the indicators (Figure 2). A water source is an important practical consideration required for arable land development. We chose the distance from irrigation canals (x_4) and rivers (x_5) as the indicators of water sources. To show the accessibility of arable land, we chose the distance from rural roads and highways (x_6, x_7) as indexes.

Prime Farmland Protection Policy: Although policy is hard to quantify, we cannot ignore its impact on arable land protection. In China, the Prime Farmland Protection boundary (x_8) is an important measure that helps government protect arable land so that developers are restricted from legally using the land for other uses. In fact, according to a simple comparison, 41.4% of land in the Prime Farmland Protection zone was converted between 2001 and 2010, primarily near built-up areas. Nevertheless, whether the Prime Farmland Protection policy has an effect will be investigated statistically in the logistic model.

Table 1. Definitions and descriptive statistics of variables.

Variable Name	Variable	Interpretation	Unit	Expected Signs	Mean	Standard Deviation	Minimum	Maximum
Dependent Variable								
Conversion of arable land	Y	If the grid is converted to urban use from arable land, assign it 1, if not, assign it 0	−		0.31	0.45	0.00	1.00
Independent Variable								
BA	X_1	Distance from nearest built-up area	km	−	0.89	1.66	0.00	23.07
DG	X_2	Distance from district governments	km	−	16.13	9.75	0.05	72.41
CG	X_3	Distance from Tiananmen	km	−	44.72	20.05	5.29	123.37
IC	X_4	Distance from irrigation canals	km	+	0.82	2.79	0.00	34.00
River	X_5	Distance from river	km	+	1.61	1.46	0.00	17.11
RR	X_6	Distance from rural road	km	+	0.95	3.66	0.00	42.84
Road	X_7	Shortest distance from highway	km	−	0.50	0.56	0.00	9.62
PFP	X_8	If parcel is in prime farmland protection zone, assign “1”; “0” otherwise	−	−	0.59	0.49	0.00	1.00
Area	X_9	Area of parcels	km^2	−	301.66	351.40	0.04	850
Shape Index	X_{10}	The ratio between area and perimeter of parcels, from which the grids are created	−	−	0.22	0.25	0.04	1.00
Pop	X_{11}	Population (streets as a unit)	10000 people	+	5.99	7.33	0.25	47.47
Elevation	X_{12}	Perpendicular distance from sea level	km	−	0.10	0.18	0.02	1.18
Slope	X_{13}	Degree of steepness	°	−	3.24	3.33	0.00	61.00
Aspect	X_{14}	Aspect of earth surface	°	+	166.41	106.04	−1.00	359.46

Grid number = 72028. In this table, several independent variables of location and accessibility were coded according to the abbreviations of nearest land features as: BA: built-up area, DG: district governments, CG: city government (represented by Tiananmen), IC: irrigation canals, RR: rural road. PFP was short for prime farmland protection zone.

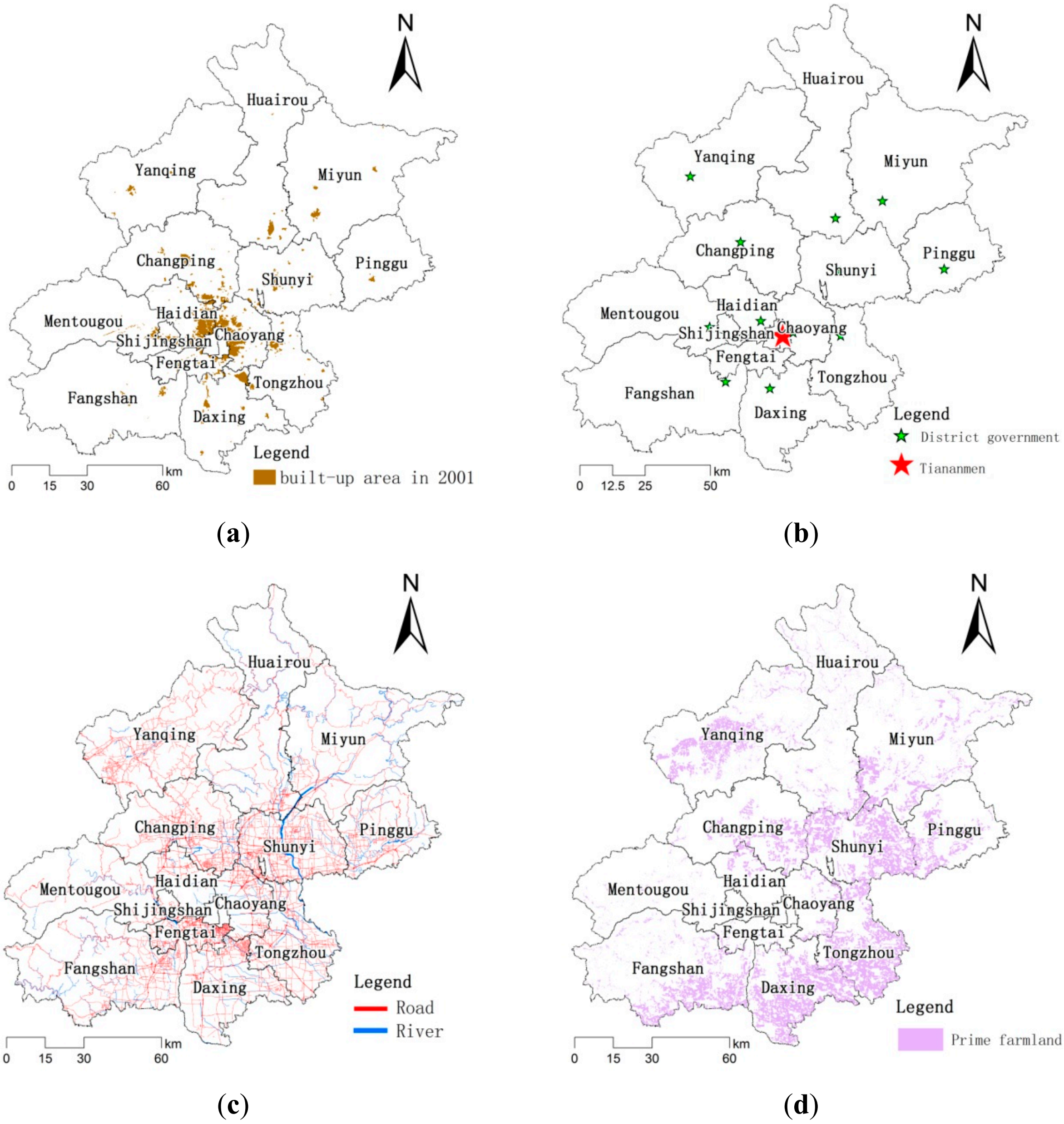

Figure 2. Spatial distribution of influential factors. (**a**) Distribution of built-up areas in 2001; (**b**) Locations of district governments and Tiananmen; (**c**) Map of roads and rivers; (**d**) Distribution of prime farmland.

Parcel characteristics: To reflect the natural evolution of landscape ecology and man-made intervention, many studies have analyzed the spatial pattern of land with indices such as number, average area and density of parcels [38,39]. In this paper, parcel area (x_9) and shape index (x_{10}) are introduced as indicators that reflect landscape characteristics. A parcel is the basic unit of the Land Survey of China, irregular in shape, and usually defined according to its land use type, ownership, and natural and administrative boundaries [40]. The area of each parcel was computed directly and the shape index was defined as: $Shape\ Index = \frac{4\sqrt{A}}{L}$. A is the area and L is the perimeter of the parcel. Shape index reflects the deviation degree of a parcel from a square with the same area. The larger the shape index, the more regular the parcel's shape, and vice versa.

Socioeconomic conditions: To live and work, humans need space, so population growth can lead to urban land development. This will often occur on arable land, and so we chose local population (x_{11}) as a measurable indicator.

Terrain: In areas with complex topography, elevation, slope and aspect are also important factors influencing land use. For example, the high altitudes in the western mountain area, which can be as high as 800 m, may significantly limit interest in developing arable land. Arable land in south-facing areas benefits from more sun, leading to higher crop productivity and the probability of the land being cultivated. We thus chose altitude (x_{12}), slope (x_{13}) and aspect (x_{14}) to reflect the terrain.

We checked the correlation between independent variables and found the correlation coefficients were generally low and acceptable (most are under 0.2 and the highest is 0.6). We added a short description of the correlation between independent variables in the manuscript.

3. Results and Discussion

The coefficients and significance level of model variables are presented in Table 2. β is the coefficient of every independent variable as shown in Equation (1). The estimated equation performs satisfactorily in terms of goodness of fit. The likelihood-ratio chi-squared value for the model is 75,598.1 and the estimated model is highly significant with a *p*-value of less than 1%. More importantly, most coefficients are statistically significant at the 1% level and their signs are mostly consistent with expectations. The ROC value was calculated to assess the simulating effects of the regression model and its value was 0.724, which suggests that the model was statistically credible. The estimated results suggest that several factors influenced the probability of arable land encroachment. The influencing factors included a plot's location, parcel characteristics, protection policy, accessibility and physical elements.

Based on the estimated equations, location has a significant influence on whether arable land is converted to urban use. The coefficients of the independent variable CG and BA are of statistical significance in the model. The results suggest that for every kilometer increase in distance to city center and built-up area in 2001, the risk of being converted to urban use decreases by 2.5% and 12.4%, respectively. This suggests that the conversion of arable land to urban use tends to occur close to existing built-up areas and the city center. This phenomenon could be explained by the lower cost of development there, since these parcels of land are usually located in flat areas with a smooth surface and have the innate advantage of utilizing existing infrastructure. In other words, economic development has increased the need for spaces where people can work and live, so a large amount of arable land around built-up areas has borne the brunt of being converted into urban use. Metropolitan areas may play an important role in social development as well, and corresponding policy is needed. These cities need to both comply with the arable land quota from their appropriate level of government and to weigh the need for land development associated with urban development. Smart growth theory holds that urban development should be relatively concentrated and should reduce the distance from workplace to home, making good use of the infrastructure and restraining unreasonable urban sprawl [41–43]. In other words, the area near a central city should reserve some space for future development, considering the urbanization process is ongoing and will continue in the near future. However, the variable of DG is not significant. This suggests that the distance from district governments does not have a strong influence on the conversion of arable land to urban use.

Table 2. Results of logistic regression model.

	β	Coefficient (e^β)	Standard Error	Significance Level
Location and Accessibility				
BA	−0.132	0.876	0.010	0.000
DG	−0.002	0.998	0.001	0.124
CG	−0.025	0.975	0.001	0.000
IC	0.054	1.056	0.007	0.000
River	0.002	1.002	0.007	0.777
RR	0.057	1.059	0.005	0.000
Road	−0.265	0.767	0.019	0.000
Policy				
PFP	−1.018	0.361	0.018	0.000
Parcel Characteristics				
Area	−0.015	0.985	0.001	0.000
Shape Index	−0.113	0.893	0.021	0.000
Socioeconomic Condition				
Pop	0.011	1.011	0.001	0.000
Terrain				
Elevation	−0.067	0.935	0.089	0.454
Slope	−0.017	0.983	0.003	0.000
Aspect	0.000	1.000	0.000	0.295

The estimated coefficient IC is positive and statistically significant. This indicates that if other variables remain constant, the risk of arable land being converted to urban use increases by 5.6% for every kilometer increase in distance to irrigation canals. This makes sense because canals are important for irrigating arid land, which occupies a large proportion of Beijing, so parcels close to the canals have a lower probability of conversion. It is also worth noting that the variable River is not significant. The difference may be because most arid land was irrigated by canals instead of rivers, so the distance from a river does not significantly influence arable land change. The variables RR and Road are both significant with opposite coefficients signs. The use of arable land occurs close to rural roads because of the convenient commuting possibilities, while land near a highway would be more likely to be developed as industrial or residential land.

The estimated coefficient could also be used to evaluate the implementation of Prime Farmland Protection policy, which is carried out through a comprehensive land-use plan at each government level. If the estimated coefficients of PFP are significantly positive, Prime Farmland Protection policy could be considered effective in saving arable land from development for nonagricultural uses. As shown in Table 2, the PFP coefficient is negative and statistically significant, demonstrating that in fact it has a positive effect on arable land protection.

Parcel characteristics also influence arable land conversion. The estimated coefficients for area and shape index are both significantly negative. This suggests that the risk of being converted is lower for parcels with larger size and a more regular shape. The odds of being converted decrease by 1.5% for each increase of 1 km^2, and decrease by 10.7% for each unit increase in the shape index between area and perimeter. This suggests that parcels with different characteristics share different land-use trends, meaning that if the parcels are divided into several parts, they are more prone to conversion to other uses. This supports a proposal for the future protection of arable land that provides that we should plan arable land so that it is contiguous and thereby reduce the probability of conversion and improve its utilization. To meet the requirements for the sustainable development of arable land, its spatial distribution should be attended to and should have a contiguous and regular shape.

The estimated coefficient for slope is significant and negative, while the coefficients of elevation and aspect are insignificant. The negative sign of slope confirms that the slope of a parcel has a negative influence on arable land conversion. The value for the coefficient of slope in the model is −0.017 and the estimated odds ratio for a unit increase of slope is 0.983, which means that for an increase of 1 unit in slope, the risk of being converted to other uses decreases by 1.7%. However, the elevation or aspect has a negligible influence on the probability of arable land conversion.

4. Conclusions

Rapid urbanization and the consequent arable land loss have created a dilemma for many countries, especially those less developed countries with large population. Therefore, understanding of the causes of arable land conversion is critical to improving government policies on arable land protection and making better plans to accommodate development. In this paper, we took Beijing as a case and investigated the influence of location factors, parcel characteristics and policies quantitatively, so as to draw implications for decision makers and policy makers. The experiences of Beijing may be useful for the other cities in the process of fast urbanization in China, as well as other cities of developing countries. Our key findings are as follows.

The conversion of arable land to urban use was influenced by many factors. The location of arable land has a significant effect on its conversion. Arable land near existing built-up areas and the city center has a higher probability of being converted to urban use due to the flat terrain and the convenience of utilizing the existing infrastructure there. This reflects the influence of the market. The characteristic of a parcel is also an important influencing factor. Larger and more regularly shaped parcels tend to be preserved. Arable land close to irrigation canals and rural roads is also more likely to be preserved because it is convenient to cultivate. The variables of highway, population and terrain are also significant in a logistic model with different effects on arable land conversion.

The Prime Farmland Protection policy, as an essential part of land planning, does have a significant positive effect on arable land preservation. According to the logistic regression model we developed, arable land within the range of a prime farmland protection zone has a 63.9 percent lower probability of conversion. Thus, although the plan did not protect arable land completely, it did reduce the occurrence of arable land being converted to urban use, which demonstrates the feasibility of managing land use by spatial policy. These findings have several policy implications, particularly from the perspective of land-use planning.

First, more attention should be paid to the market. According to our findings, arable land that is close to an existing built-up area or city center tends to have a higher probability of being converted to other uses. This conforms to urban economic theories and is a more efficient system of development due to its better use of existing infrastructure and shorter commuting distances. Given China's rapid urbanization and the likelihood that it will last for another ten to twenty years, urban areas will continue to grow and expand to accommodate increasing urban populations and economic activities. The conversion of arable land to urban use around cities is therefore, to a certain degree, inevitable. A more important question then is how to manage and control the amount of arable land to achieve a more efficient urban growth pattern that can ensure that the converted land is balanced by healthy urban development.

Second, there should be a focus on preserving large and contiguous parcels of arable land. On the one hand, according to our findings, arable land of a smaller size or irregular shape has a higher probability of being converted to urban use, while on the other hand, fragmented and irregularly shaped arable land incurs higher farming costs due the limitations of mechanized farming.

Third, the land-use plan, which plays a key role in regulating land development, should focus more on properly guiding land development around existing built-up areas rather than blindly limiting the area of land development. In our model, prime farmland protection policy has a significant, positive influence on the preservation of arable land. However, comparing the 2010 land-use map to the land-use plan, 41.4% of planned arable land has been converted, especially near existing built-up areas. This suggests there is a strong market demand for arable land surrounding existing built-up areas because the urbanization process is ongoing and will continue into the near future. Therefore, when designing policies and plans, market rules should be given consideration and more attention should be paid to the location and characteristics of arable land rather than to the quantity alone.

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Author Contributions

Daquan Huang developed the original idea and contributed to the research design. Haoran Jin was responsible for data collection and processing. Xingshuo Zhao contributed to the research design and provided guidance. Shenghe Liu provided additional guidance and advice. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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