Chin. Geogra. Sci. 2013 Vol. 23 No. 3 pp. 365–377
doi: 10.1007/s11769-013-0600-2

Springer Science Press
www.springerlink.com/content/1002-0063

Modeling Patch Characteristics of Farmland Loss for Site Assessment in Urban Fringe of Beijing, China

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Abstract: Farmland protection and delimitation in the urban fringe considers not only natural factors but also the spatial characters and site factors. Taking Daxing District, Beijing in China as a case study, this paper used landscape ecology and power-law methods to analyze and evaluate farmland loss during the period of 2004–2007 based on the interpretation results of SPOT5 remote sensing images in 2004 and 2007. At the patch level, we selected four landscape indices, namely patch size, shape index, the nearest neighbor distance between farmland and construction land (including residential land and other construction land), and cropping type, to evaluate the risk of farmland loss and establish a farmland site analysis indicator system. The results showed that patch size and shape index have a significant positive correlation with farmland loss, whereas the distance to construction land has a clear negative correlation with farmland loss. As regards cropping type, fallow farmland is much easier for non-agricultural use than cultivated farmland. The relative transition ratio among vegetable land, fallow farmland and cultivated farmland is 1 ∶ 5.6 ∶ 1. The patch size of lost farmland follows a power-law distribution, indicating that not only small parcels but also large parcels can be lost. Patch size less than 4 ha or more than 15 ha is in high loss risk, between 4 ha and 10 ha in medium loss risk, and larger than 10 ha and less than 15 ha in low risk. Farmland with a more regular shape has a higher likelihood of loss. Patch shape index less than 2.0 is in high loss risk, between 2.0 and 3.0 in medium loss risk, and larger than 3.0 in low risk. Construction land has a varying impact on farmland loss, the residential land effected distance is 1000 m, and that of the other construction land is 2000 m. This analysis showed the relationships between site factors and farmland loss, and the analysis framework can provide support and reference for farmland protection and delimitation of prime farmland in China.

Keywords: farmland loss; loss risk; site analysis; logistic regression analysis; power-law distribution

Citation: Liu Xiaona, Zhang Weiwei, Li Hong, Sun Danfeng, 2013. Modeling patch characteristics of farmland loss for site assessment in urban fringe of Beijing, China. *Chinese Geographical Science*, 23(3): 365–377. doi: 10.1007/s11769-013-0600-2

1 Introduction

China implements the world′s strictest farmland protection system, and defends the red-line of 1.2×10^8 ha of farmland to ensure food security. The urban fringe, a special economic and geographical region located in the urban and rural transition belt, is an area of constant land use change with dramatic landscape heterogeneity (Li and Bai, 2003), and is an important region in which to protect farmland.

Designating prime farmland conservation zones is an important practice for China′s food security. However, the conditions and criteria for selecting prime farmland is an important and complex issue. Several scholars have conducted useful studies which mostly involve an indicator system for farmland quality and rely heavily on a qualitative analysis phase (Dumanski and Pieri, 2000; Lu *et al*., 2006; Mei *et al*., 2007; Cheng *et al*.,

Received date: 2012-06-19; accepted date: 2012-11-16
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 41130526), Beijing Municipal Natural Science Foundation (No. 8122020)
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2009; Liu *et al*., 2010). The United States of America established the Land Evaluation and Site Assessment (LESA) in the 1980s, to define prime farmland and protect farmland from the rapid urbanization process. LESA is a framework for combining multiple factors into an integrated assessment of the importance of a particular site for continued agricultural use. The system emphasizes the importance of farmland site (Steiner *et al*., 1987), which reflects the socio-economic environment of farmland and the environmental feasibility of maintaining agricultural use (Coughlin *et al*., 1994). Many states and counties achieved LESA patternization and systematization in the United States (Dunford *et al*., 1983; Hoobler *et al*., 2003; Dung and Sugumaran, 2005). Socio-economic factors are more active on farmland quality at a shorter time scale (Lambin and Geist, 2001). Especially, in the urban fringe, where land use change and landscape heterogeneity are the most dramatic, more attention should be given to the impact of socio-economic factors in farmland evaluation. Nowadays, many scholars began to study the LESA concept and attempted to use in China (Nie and Bao, 1999; Liu, 2004; Androkovic, 2013), but most concerning primarily statistical data can not express spatial differences in farmland patches (Nie *et al*., 2000; Liu and Quan, 2004; Quan *et al*., 2007; Li *et al*., 2010; Qian *et al*., 2011). Therefore, farmland site analysis is still in the exploratory and trial stages in China, and further research on methods and applications is needed. More attention should be paid to farmland site analysis using landscape ecology from a patch perspective, and applications in developing countries where socio-economic data at the patch level are lacking.

Landscape pattern analysis studies correlations between the patterns and processes at different scales (Lu *et al*., 2007; Buyantuyev *et al*., 2010). The appropriate landscape indices are heavily reliant on the purpose of the study (Tischendorf, 2001; Li and Wu, 2004). This study considers farmland loss at patch level. Thus, patch size, patch shape index, and distance to the nearest neighbor were chosen. Patch size is a basic characteristic of landscape structure, and affects the material and energy distribution in the landscape and the patch ecology function (Forman and Godron, 1986; Dung and Sugumaran, 2005). As well as size, patch shape has a significant impact on ecosystem, with different patch shapes being suited to different land use types. The interaction between patch shape and patch size may affect a large number of ecological process (Cousins and Aggemyr, 2008; Yu, 2008). Nearest neighbor distance is the most common indicator for site analysis, which usually use parameters such as the distance to roads, drainage channels or the center of town (Hoobler *et al*., 2003).

Many classes of object have a typical size or scale around which individual measurements are centered. However, not all items we measured cluster around a typical value. The majority of individuals are at small scale, while a few individuals have a large scale and have greater influence, and this phenomenon may obey a power-law distribution (Newman, 2005), among of which city size is a typical example. Whether farmland patches have a typical scale-free characteristic determines the threshold range of the evaluation classes. Therefore, the power-law distribution should be tested when calculating the complicated statistical correlations between farmland patch size and farmland loss.

In the urban fringe, farmland faces a constant threat of loss under the heavy development pressure of city sprawl. As the southern gateway to Beijing, Daxing District is located in the Beijing-Tianjin-Hebei growth region, as an important link between Beijing and the Bohai Gulf economic circle. Urbanization had obviously influences on the land use and land cover in this region. Many scholars have studied farmland protection and quality evaluation in the Daxing District. Zhang *et al*. (2004) mainly focused on the natural factors through an in-depth study of soil samples. Kong *et al*. (2008) based on the ′Pressure-Status-Effect-Response′ model including both natural and social factors to evaluate farmland quality at household level. Fan *et al*. (2009) identified the unstable farmland plots located in the northern part of the developed area and in belts alongside the roads. And Tang *et al*. (2010) found that farmland patch size steadily declined from 1993 to 2007, while patch number, density, average fractal dimension and separation degree increased. Using an interpreted remote sensing image in 2004 and 2007 in Daxing District, Liu *et al*. (2011) discovered that a higher density of farmland shelterbelt and agricultural irrigational land reduced the probability of farmland loss, and that a higher density of transport land increased the probability of farmland loss. The previous studies in the study area gave less attention to the site analysis and patch spatial characteristics.

Farmland protection and prime farmland delimitation should start at the patch scale, considering not only natural quality but also site features. With further urbanization and industrialization, farmland protection should focus more on the site features so as to provide a reference for national farmland protection and food security.

Therefore, this study is to reveal the general patterns of farmland loss in Daxing District, Beijing, China integrating the landscape pattern analysis, GIS spatial analysis, logistic regression analysis, complex network analysis and site analysis methods. Farmland patch size, shape index, distance to construction land (including residential land and other construction land) and farmland use status were chosen for analyzing the complex distribution characteristics, with an aim of establishing an indicator system for farmland site analysis.

2 Materials and Methods

2.1 Study area

Daxing District (39°26′–39°51′N, 116°13′–116°43′E) is located in the southern Beijing in China, with jurisdiction over 14 towns and two national farms covering 1036 km^2 (Fig. 1). The district lies on the east bank of the Yongding River. The prevailing topography is a slight slope from the northwest to the southeast, and the relative elevation ranges from 13 m to 56 m. The region is a warm-temperate and semi-humid zone with a continental monsoon climate, with an annual average temperature of 11.6℃ and an annual average precipitation of 556.4 mm. The river system includes the Yongding River, the Tiantang River, the Xinfeng River, the Dalong River and ten other rivers. With its modern three-dimensional traffic system, Daxing District is an important link for high-tech industries not only on the Beijing-Tianjin-Tangshan Expressway but also on the Beijing-Kowloon Railway, and will become a major connection for logistics centers. The district is also a major producer of grains, vegetables and fruits for Beijing. It has an agricultural land area of 64.94%, of which only 36.96% is farmland, and owns two new satellite cities of Beijing (Huangcun and Yizhuang) in the urban fringe.

Daxing District has experienced rapid development in construction, industry, transportation and other infrastructures from in 2004 to 2007. As a result, farmland area has shown a decreasing trend due to the expansion of non-agricultural land over these years (Fig. 2). Farmland decreased rapidly from 37.23% to 36.92% between 2004 and 2006, and then increased slightly to 36.96% from 2006 to 2007.

2.2 Data and processing

This study used land use classification maps in 2004 and 2007 as the basic data by using an object-oriented clas-

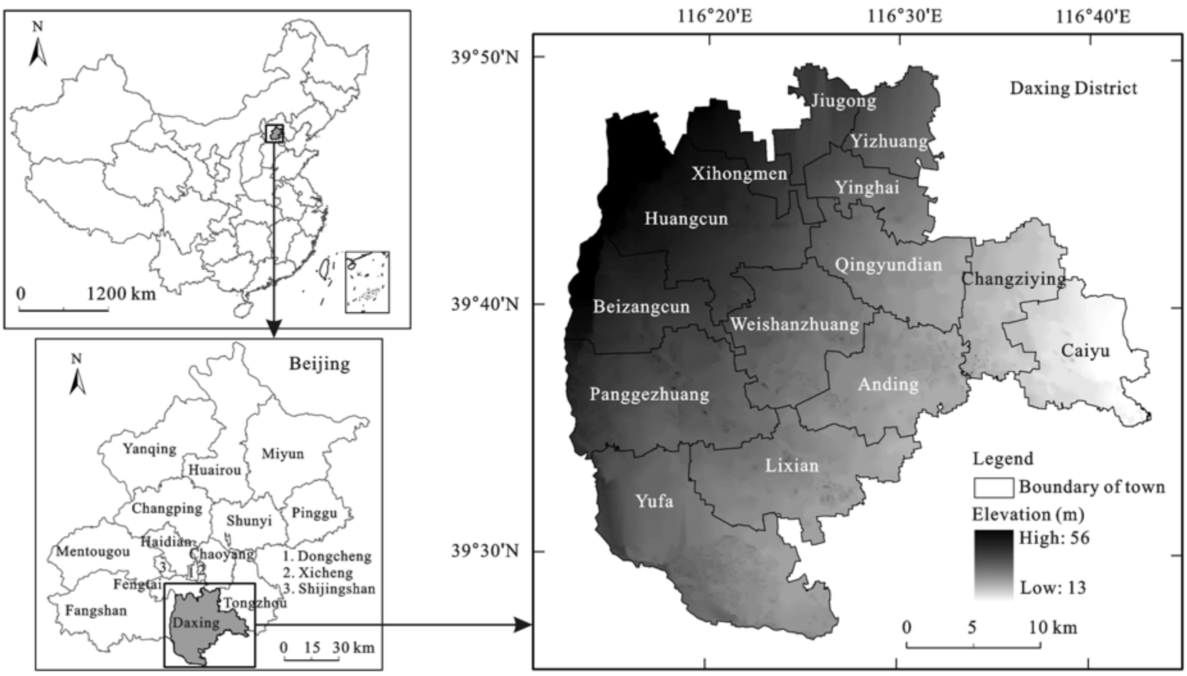

Fig. 1 Location of study area

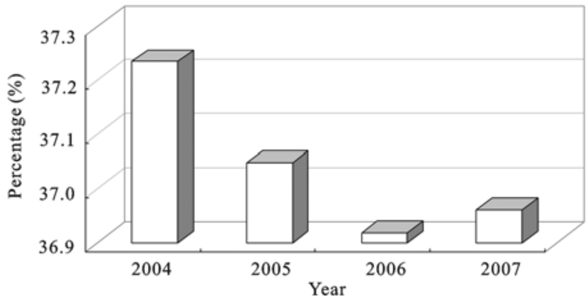

Fig. 2 Annual changes of farmland area in study area

sification method for SPOT5 remote sensing image interpretation (Liu *et al*., 2011). A three-class system with some appropriate changes on the basis of seasonal characteristics of the SPOT5 images was used, including three first class types, 11 second class types and 19 third class types, by consulting the national land use classification system (trial edition) issued by the Ministry of Land and Resources of the People′s Republic of China in 2002 (Table 1). Specifically, in order to analyze the influence of different types of farmland on loss risk, farmland was subdivided into vegetable land, fallow farmland and cultivated farmland.

The classification accuracy was evaluated based on the existing land use maps combining with visual interpretation and field survey. The results showed that overall accuracy in 2004 and 2007 were 0.945 and 0.955, respectively, and the Kappa coefficients were 0.933 and 0.945, respectively. So, the actual classification accuracy meets the needs for the further analyses. Since a part of the image for Yufa Town for 2004 is missing, the areas of land use map in 2004 and 2007 are both 98 825 ha uniformly (Fig. 3).

2.3 Methods

2.3.1 Landscape pattern analysis

Farmland patch, as the smallest unit in landscape, may reveal the impact of site factors on farmland loss more clearly. In this study, we examined patch size and patch shape index at the farmland patch scale. Patch size suggests management scale, and patch shape index refers to the shape of studied patch in comparison with a square or circular, and its value represents the patch shape deviating from the degree of square or circular. The more complicated the patch shape, the stronger the patch edge

Table 1 Classification system of land use

First class type	Second class type	Third class type	Remarks
Agricultural land	Farmland	Vegetable land	Grow vegetables, including greenhouse land
		Fallow farmland	Farmland texture without vegetation cover; close to non-agricultural land or farmland enclosed by construction land
		Cultivated farmland	Farmland texture with vegetation cover on basis of Normalized Difference Vegetation Index (NDVI); agricultural land surrounding mostly
	Garden plot	Garden plot	Grow fruits, tea, rubber, coffee, medicinal materials, *etc*., which belong to perennial woody vegetation and herb
	Forest land	Farmland shelterbelt	Line-shaped distribution; inside or outside of farmland to protect farmland; some presenting network structure
		Polygon-shaped forest land	Polygon-shaped distribution; high vegetation cover; relatively large area
		Other forest land	Forest land other than farmland shelterbelt and polygon-shaped forest land
	Other agricultural land	Pond land	Artificial excavation or natural water storage capacity less than 100 000 m^3
		Irrigational land	Farmland irrigation, drainage ditches and corresponding ancillary facilities belonging to farmers or agricultural companies
Construction land	Residential land	Residential land	Place for people to live and its ancillary facilities
	Other construction land	Other construction land	Artificial construction mainly for industry; high brightness; Independent distribution
	Transport land	First-class road	Highway, city circle road, relatively wide road and connection with large area
		Second-class road	Road between towns and villages without first-class road
	Irrigation facility land	Reservoir land	Reservoirs refer to artificial water storage capacity more than 100 000 m^3
		Hydraulic construction land	Hydraulic construction land without irrigational land
	Designated land	Designated land	Military facilities, foreign affairs, religion, prison education, funeral land
Unused area	Other land	River land	River from natural or artificial excavation with normal surface
		Shoaly land	Shoaly land between perennial water level and flood level of river and lake; shoaly land below flood level of seasonal lake and river
	Unused land	Unused land	Unused land, including hardly used land

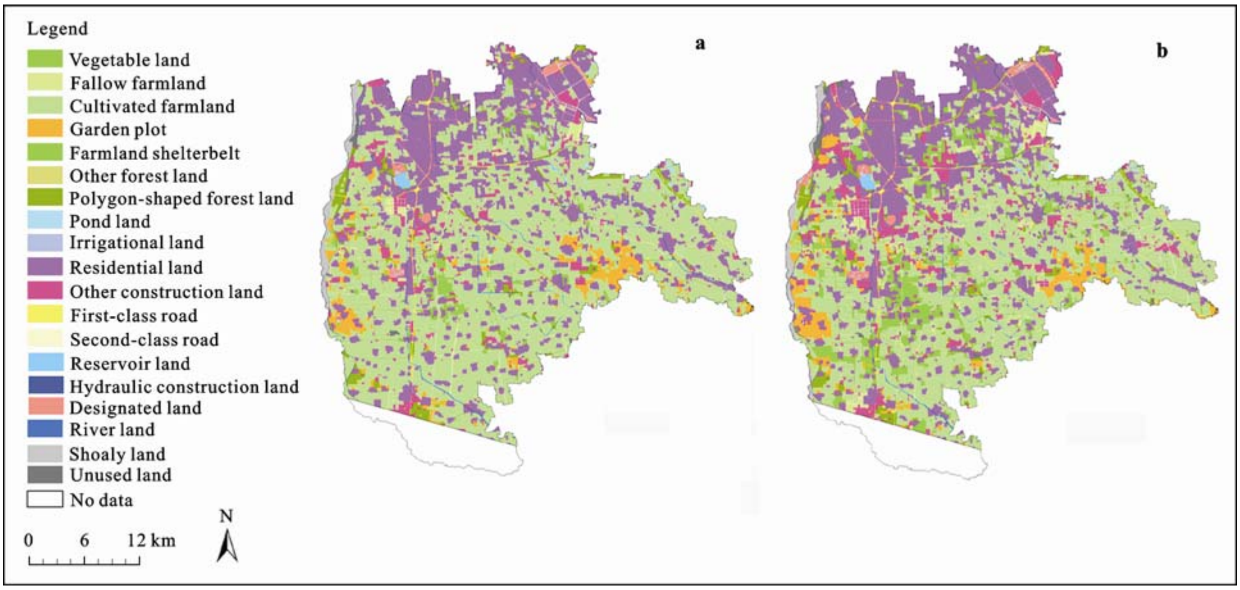

Fig. 3 Land use maps in third class in 2004 (a) and 2007 (b) in study area

effect. A patch shape index close to 1 means the patch shape is close to circular or square. All these indices were calculated by using the landscape pattern software of Fragstats 3.3.

2.3.2 Distance analysis

Nearest neighbor distance between farmland patches and construction land patches was calculated by using an expansion module from Hawths Analysis Tools which is used in space ecology and must be loaded in ArcGIS 9.3. Considering the different types of construction land that have different impacts on farmland, the distance index was divided into distance between farmland and residential land and distance between farmland and other construction land according to the land use and land cover change classification.

2.3.3 Power-law distribution

The power-law distribution, also called the scale-free distribution, is very common in nature and social life. At the individual scale, there are extremely large differences within the system resulting in no typical size. However, there is a similarity between the part and the whole across different scales. That is, we can reflect the characteristics of the whole from the part, and vice versa.

$$p(x) = \mathrm{C}x^{-\alpha} \tag{1}$$

Equation (1) follows a power-law distribution. The constant α is called the exponent of the power-law. The constant C is mostly uninteresting as it is determined when α is fixed. The exponent is the key to determine whether the distribution of a variable follows a power-law, and is usually found by plotting the data at logarithmic scale to see if the curve is a straight line. If so, then the slope of the straight line is –α (Mitzenmacher, 2001). In this study, we adopted a simpler and more convincing method proposed by Newman (2005).

$$\alpha = 1 + n \times [\sum_{i=1}^{n} \ln \frac{x_i}{x_{\min}}]^{-1} \tag{2}$$

where x_i (i = 1, 2, …, n) is the ith measured value, and $x_{\min}$ is the minimum value of x. As discussed in the following section, $x_{\min}$ usually does not correspond to the smallest value of x but to the smallest value for which the power-law distribution holds.

2.3.4 Logistic regression analysis

Farmland change types and land use status were non-continuous categorical variables, while farmland patch size, patch shape and distance to construction land were continuous independent variables. Therefore, logistic regression is used in this case to analyze the correlation between decreased farmland and independent variables. Assuming that four variables had impacts on farmland loss, the impacts of different variables on farmland loss could be obtained by using the following equation:

$$\ln(\frac{p}{1-p}) = \sum_{i=1}^{n} b_i x_i = \mathrm{a} + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n \tag{3}$$

where p is the probability of occurrence; x_i is the independent variable and a is a constant; b_i is the regression coefficient of x_i. The independent variable is positively correlated with the dependent variable when b_i is positive, and is negatively correlated when b_i is negative. The bigger the absolute value of b_i, the greater the influence of the independent variable on the dependent variable.

3 Results and Analyses

3.1 Farmland changes

Farmland layers were extracted by using GIS spatial analysis and changes of farmland were divided into unchanged farmland, decreased farmland and increased farmland through the overlay analysis method (Fig. 4a). For farmland in 2004, there were only unchanged and decreased conditions. The decreased farmland layer was the base map for the following analyses, extracted by using the overlay method from classification map in 2004 (Fig. 4b). As to the decreased farmland in Fig. 4b, if decrease occurred in one farmland patch no matter part or whole then the whole patch will be labeled as decreased farmland.

The area of changed farmland was assigned to each township (Table 2). The results showed that the farmland area decreased from 2004 to 2007 for nearly all

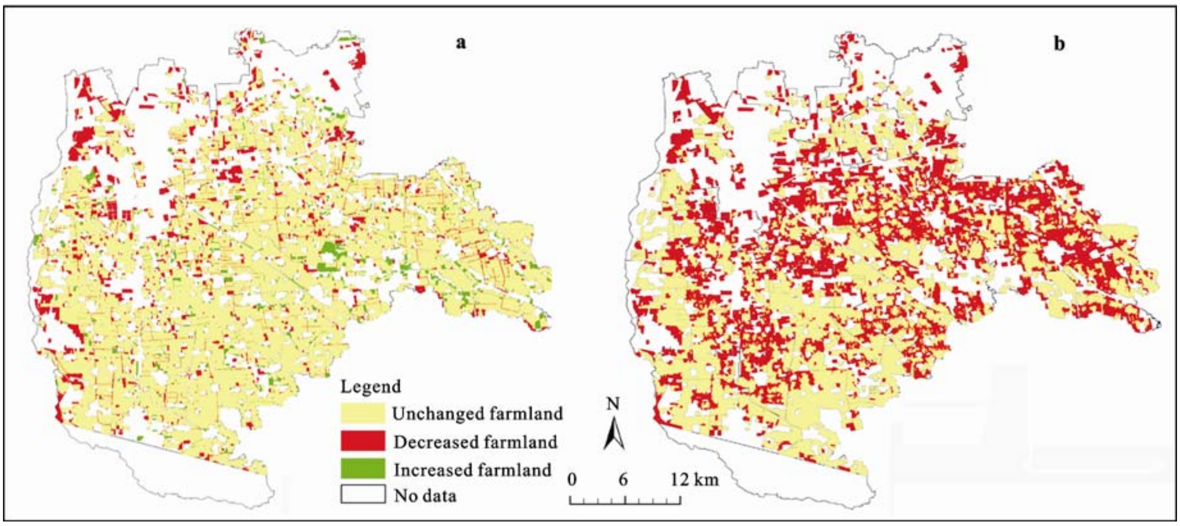

Fig. 4 Changes of farmland from 2004 to 2007 (a) and changes extracted in 2004 (b) at patch scale in study area. Decreased farmland in Fig. 4b refers to whole patch of which farmland decrease occurred no matter part or whole of this patch

Table 2 Change of farmland area from 2004 to 2007 at town scale in study area

Town	Increased area (ha)	Unchanged area (ha)	Decreased area (ha)	Changed area (ha)
Yizhuang	6.20	99.60	300.21	–294.01
Jiugong	30.09	304.22	383.14	–353.05
Yinghai	95.94	1654.31	467.79	–371.85
Huangcun	284.07	2916.44	1375.22	–1091.15
Xihongmen	48.98	474.21	363.81	–314.83
Beizangcun	220.42	2353.73	1116.53	–896.10
Qingyundian	258.98	4181.86	659.61	–400.63
Caiyu	314.07	4846.37	454.55	–140.48
Changziying	295.74	3409.04	359.49	–63.75
Panggezhuang	368.29	6308.62	585.39	–217.10
Anding	542.13	4497.87	457.23	84.89
Lixian	274.06	6913.37	456.20	–182.14
Weishanzhuang	299.15	5323.21	440.20	–141.05
Yufa	221.66	4880.52	629.46	–407.80

towns, except Anding Town with slightly growth. Construction, agricultural structure adjustment, policy effects and natural disaster may be the leading causes for farmland loss.

3.2 Farmland site factors weight

The logistic regression results showed that patch size had a more significant positive correlation with farmland loss than patch shape. Distance to construction land had a significant negative correlation with farmland loss, and the distance to residential land had a more obvious correlation than other construction land. Fallow farmland had a positive correlation with farmland loss while vegetable land and cultivated land were negative correlations (Table 3).

3.3 Farmland patch size

As mentioned above, patch size of farmland ranges across several orders of magnitude without a typical scale for describing the relationship with farmland loss. Therefore, this study analyzed the correlation based on a distribution test of farmland patch size. Patch number of decreased farmland was counted with an interval of 0.5 ha. Statistical analysis results showed that farmland patch size did not follow a normal distribution according to the Kolmogorov-Smirnov method in SPSS software (Fig. 5a). The curve showing the relationship between decreased farmland and patch size is skewed severely to the right, which indicates that decreased farmland in Daxing District corresponded mostly to small patch size. When plotted on logarithmic scales (Fig. 5b), the straight line suggests that the relationship between farmland patch size and patch number may follow a power-law distribution with the power exponent of 2.5. Therefore, patch size of decreased farmland followed a power-law distribution indicated that not only small patches were prone to loss but also larger patches.

The cumulative probability of patch size of decreased farmland was also plotted in Fig. 6. It is usual in probability theory to refer to incidents with probability less than 5% as small probability event. However, small probability events are likely to happen in a power-law distribution. The results showed that the cumulative probability of farmland patches size not more than 10 ha was 95.0%, and accounted for 82.2% of the decreased farmland area. The cumulative probability of farmland patches size larger than 10 ha was only 5.0%, while accounted for 17.8% of the total lost farmland, with the largest patch size of 45 ha. Comparatively speaking, larger patches had a higher loss risk and a gradually de-

Table 3 Variables weight in farmland loss risk

Variable	Area (x_1)	Shape index (x_2)	Land use			Distance	
			Vegetable land (x_3)	Fallow farmland (x_4)	Cultivated land (x_5)	Residential land (x_6)	Other construction land (x_7)
Exp(B)	1.076	1.055	0.361	1.273	0.566	0.989	0.998
Significance	0.000	0.057	0.000	0.000	0.002	0.000	0.000
Regression coefficient	0.073	0.053	–1.019	0.302	–0.569	–0.011	–0.008

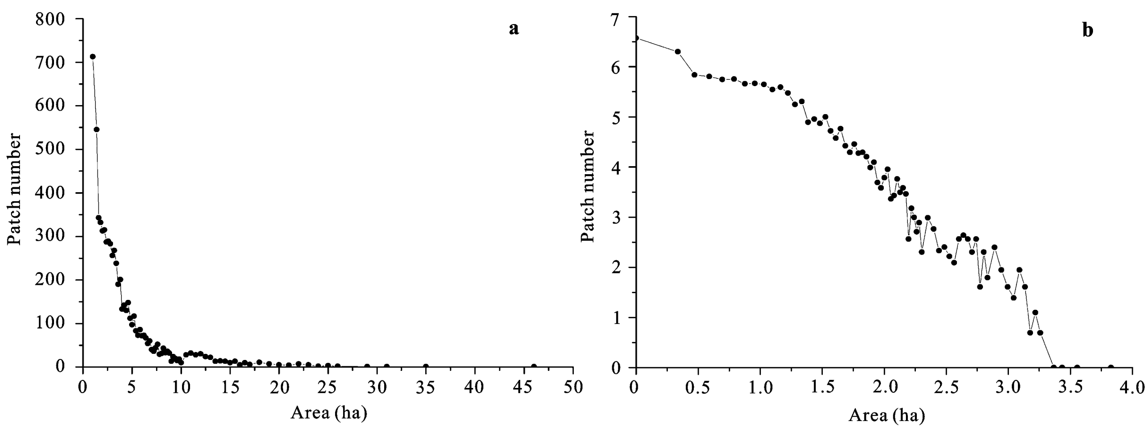

Fig. 5 Patch number of decreased farmland (a), and that plotted at logarithmic scale (b)

clining loss speed. Moreover, the derivative of the cumulative probability for decreased farmland patches smaller than 10 ha was calculated. Calculation results show that the derivative of cumulative probability of decreased farmland patches smaller than 4 ha was increased, which indicated that loss speed of farmland showed an increasing trend. When the patch size was 4 ha, the loss speed was maximized, then began to decrease while the number of decreased farmland patches continued to increase up to a size of 10 ha. When patch size of more than 15 ha, the number of decreased farmland patches reduced sharply with the proportion of patch number accounting for only 1.0% and total area accounting for 6.5%. The curve showed significant tailing phenomenon and a widely spread distribution.

A loss risk evaluation system between farmland loss and farmland patch size was initially established, in

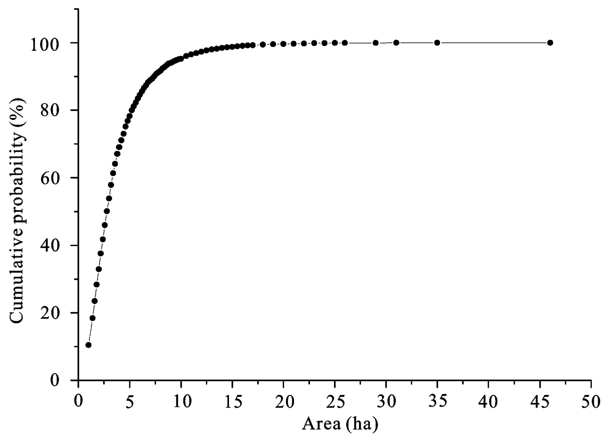

Fig. 6 Cumulative probability of patch size of decreased farmland

cluding high risk, medium risk and low risk. Farmland patches smaller than 4 ha or larger than 15 ha were grouped as high risk, those between 4 ha and 10 ha as medium risk, and those between 10 ha and 15 ha as low risk.

3.4 Farmland patch shape index

The logistic regression analysis results showed that farmland patch shape had a positive impact on farmland loss. Based on the statistical analysis for patch shape index of decreased farmland in 2004, we found that the correlation between patch shape and patch number had an obvious log-normal distribution (Fig. 7a). The patch shape index for decreased farmland ranged from 1.1 to 7.3. The proportion of patch number of decreased farmland with shape index in a range of 1.1 to 3.5 accounted for 95.3%, with a stable shape index of around 2.0. Therefore, the threshold characteristics of farmland loss based on farmland patch shape can be explored by using normal distribution statistics.

The cumulative probability of patch shape index of decreased farmland was calculated (Fig. 7b), which indicated that the loss speed of farmland increased when the index was less than 2.0. The loss speed was greatest when the patch index was 2.0, illustrating that the more drastic the impact of human activities, the easier the farmland reduced. The loss speed declined when the shape index was between 2.0 and 3.0. When shape index greater than 3.0, the cumulative probability was already 94.96% so the loss speed could be considered to be stable when shape index greater than 3.0. The loss risk for different farmland patch shape index was also divided into three grades, high risk (shape index between 1.0

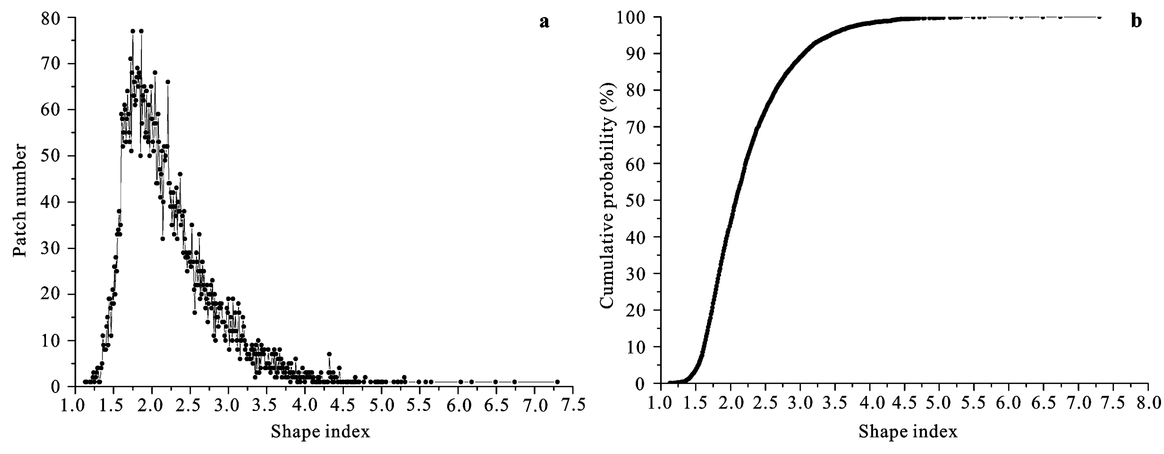

Fig. 7 Number statistics of different patch shape index of decreased farmland (a), and cumulative probability of patch shape index of decreased farmland (b)

and 2.0), medium risk (shape index between 2.0 and 3.0), low risk (shape index larger than 3.0).

3.5 Distance between farmland and construction land

Farmland loss mainly resulted from building occupation as discussed above. In general, building usage was driven by industrial land for the purposes of national economic development and residential land for urbanization. In fact, the distance between farmland and construction land was an important index in evaluating farmland loss. Based on logistic regression analysis, distance between them had a negative impact on farmland loss, and different construction land caused different levels of threat to farmland loss.

Different types of construction land had different impacts on farmland loss (Fig. 8a). Comparatively speaking, residential land had a more significant effect on farmland loss than other types of construction land. The statistical analysis results found that decreased farmland was not necessarily located in the places which were closest to or farthest from construction land, but that high loss risk occurred at some typical distance. The relationship between farmland loss and distance to construction land followed a log-normal distribution, which indicated that the threshold value could be found by using statistical analysis. The loss speed showed an increasing trend when the distance to residential land was not more than 400 m, with the risk being highest at a distance of 400 m. The cumulative probability of the distance between decreased farmland and construction land was calculated (Fig. 8b). The results showed that residential land had more severe influence on farmland loss than other construction land because of the different radius of influence. The cumulative probability of the distance to residential land being less than 1000 m was 96.67%, with 1000 m being the maximized distance of influence. At distances between 400 m and 1000 m, the loss risk gradually decreased with increasing distance. In this study, other construction land refers to industrial and warehouse land. The results show that farmland rarely reduced when the distance to other construction land was more than 2000 m. The loss risk first increased and then gradually decreased until to a distances of 2000 m. The loss risk was highest when the distance to other construction land was 1000 m, greatly different with a distance of 400 m to residential land.

The loss risk was the lowest when the distance to other construction land was 2000 m, which also differs from that for residential land. Thus, the risk grade for construction land should be separated by land use type (Table 4).

3.6 Farmland status

Farmland present situation can reflect its site characteristics. Different farmland types have different impacts on farmland loss. Vegetable land and cultivated farmland have a negative effect and fallow farmland has a positive impact. Based on vegetable land, fallow farmland and cultivated farmland in 2004, this study analyzed the transition probabilities between 2004 and 2007 (Fig. 9). There was 29.89% of vegetable land converted to other land use types, to non-farmland with transition probability of 13.37% which accounted for 44.76% of

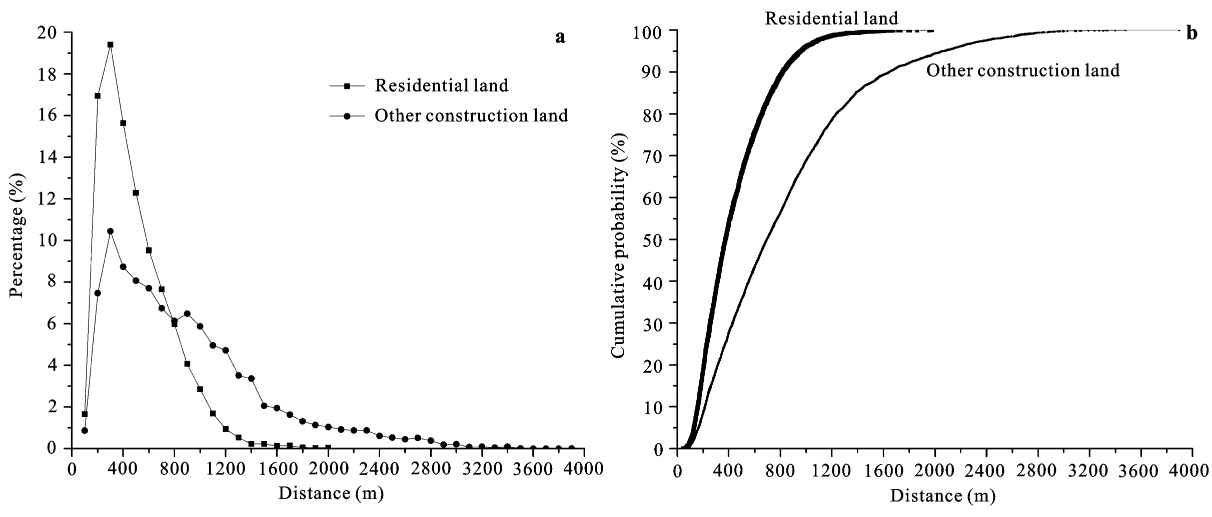

Fig. 8 Effect of distance to construction land on patch number percentage (a) and cumulative probability (b) of decreased farmland

Table 4 Rank partition of farmland loss risk

Residential land		Other construction land	
Distance (m)	Risk grade	Distance (m)	Risk grade
0–400	High	0–1000	High
400–1000	Medium	1000–2000	Medium
>1000	Low	>2000	Low

entire changes from 2004 to 2007. Specifically, vegetable land changed to cultivated farmland with 15.76% probability, and to construction land, especially residential land with 22% probability. Vegetable land was prone to be threatened by construction occupation because it was generally close to residential land. For the cultivated farmland, 77.04% remained unchanged, and probability transitioned to non-farmland was 13.43% which accounted for 58.49% of overall changes from 2004 to 2007. Changed cultivated farmland mostly transitioned to the construction land, with 3.75% changing to other construction land and 3.40% to the residential land. Cultivated farmland was the major type of farmland and its transition to construction land accounted for one third of all changes. Therefore, building occupation was the leading reason for the farmland loss. Inter-annual variability of fallow farmland is more significant than the other two types. There was only 11.37% fallow farmland without change. The transition probability of non-farmland from fallow farmland reached up to 75.35% which accounted for 85.02% of total change, while that to other construction land was 61.16%. Although seasonal differences of remote sensing image leading to classification error or confusion of fallow farmland with designated future construction land, this result indicated that fallow farmland was the most easily occupied by non-agricultural land.

As to the transition probabilities for the three farmland types, the ratio of vegetable land, fallow farmland, and cultivated farmland were 1∶5.6∶1. According to the logistic regression analysis, the risk grade of farmland loss of fallow farmland, cultivated farmland and vegetable land is high, medium and low, respectively.

4 Discussion

Farmland quality evaluation is an important foundation for farmland protection and the delimitation of basic farmland. Site assessment of farmland puts more emphasis on site characteristics as well as socio-economic attributes, and has more instructive meanings for farmland protection in the urban fringe. Based on the SPOT5 remote sensing image classification maps in 2004 and 2007, this study used logistic regression analysis to analyze the relationship between four site features and farmland loss from landscape ecology and complexity perspective. Then, the loss risk of farmland under different site indicators was evaluated by analyzing the relationship between farmland loss and characteristics of site factors.

This study shows that site characteristics of farmland patches have significant effects on the farmland loss. Patch size had a positive effect on farmland loss ($p <$ 0.05). Fan *et al.* (2009) found that farmland with small patch size and sporadic distribution was occupied by construction land easily. This study implied that not only farmland with small patches were prone to loss but also larger patches. Yue *et al.* (2008) indicated that homogeneous farmland was easily fragmented by other land

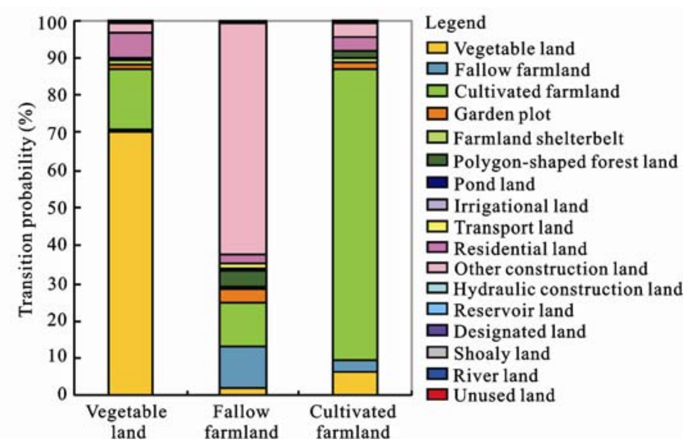

Fig. 9 Transition probability of sub-class of farmland from 2004 to 2007

types, which meant that farmland with large patch size was converted into small patches. Meanwhile, some farmland with large patch size was lost due to economic development and urban expansion. The results indicated that more attention should be paid to large patches as well when farmland protection.

Farmland with a more regular shape has a higher likelihood of loss risk, this result was similar with the findings of other researchers, e.g. Yue *et al.* (2008), Tang *et al.* (2010). Human activities not only consolidated farmland with more regular patch shape, but also created its potential loss risk. However, the internal mechanism between farmland patch shape and loss risk will be further investigated based on more evidence.

As we all known, construction occupation is the main way of farmland loss (Yang, 2001; Tan and Lu, 2005; Sun *et al.*, 2007). However, different types of construction land appeared to have a varying impact on farmland loss. In this study, residential land had a greater impact on farmland loss than other construction land with an effect extent of 1000 m, while that of the other construction land is 2000 m. The distance between construction land and farmland became closer because of urban sprawl, which will undoubtedly lead to increase the loss risk of farmland, especially in the context of accelerating the process of industrialization. In response to the phenomenon, we suggest the buffering zone such as green belt, agro-ecological garden, or leisure agriculture, can lie between the construction land and farmland to protect farmland. More attention should be paid to the ecological functions, landscape functions, culture functions and limitation functions of these zones in the urban fringe (Zhao and Zhang, 2008; Song and Ou, 2012).

Currently, most researches focused on soil and water loss, the physical chemistry characteristics of soil, and soil nutrient situation under different cultivated land use types (Yuan *et al.*, 2002; Li *et al.*, 2003; Zhao *et al.*, 2005), while rarely paid attention on the relation between farmland loss and different cultivated land use types. This study classified farmland into vegetable land, fallow farmland, and cultivated farmland, and analyzed the effects of three types to farmland loss. Fallow farmland had the highest risk of transition possibility because of the government policy and the lowest cost to occupy, while vegetable land had the lowest risk of transition. More studies should strengthen the effects of different farmland status on farmland loss, especially the process of fallow farmland loss.

5 Conclusions

This study attempted to explore a quantitative evaluation method for farmland quality evaluation at patch scale about site characteristics from landscape ecology perspectives. However, for the accessibility of high resolution remote sensing image data, this study did not use the latest remote sensing data, therefore, future studies should update farmland loss information to validate the findings. There are many reasons for farmland loss, while compared to the natural factors, social factors were more complicated. This study mainly analyzed the influence of the farmland site characteristics on farmland loss from farmland patch site. Meanwhile, some site factors can be refined to reflect more details about farmland loss process, such as the distance between farmland patch and construction land patch, including the distance between farmland patch and major town centers and roads. The main direction of future research about farmland loss in urban fringe will focus on the comprehensive research of the driving forces, the conversion process and the effects of farmland loss from qualitative and quantitative perspectives. This study involved preliminary use of the power-law distribution, which needs to be researched further in the future. Fractal theory will also be applied to the basic farmland site characteristics, and the process of quantifying variables needs to be made more rigorous. Future studies should strengthen farmland evaluation and site analysis in urban fringe so as to provide references for farmland evaluation and prime farmland delimitation.

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