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Study on Ecological Risk of Land Use in Urbanization Watershed Based on RS and GIS: A Case Study of Songhua River Watershed in Harbin Section

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Abstract By using RS and GIS technology, the ecological risk index (ERI) was constructed based on the analysis of land use change and structural characteristics in urbanization watershed of Songhua River in Harbin section. Afterwards, the spatial distribution and change characteristics maps of ERI obtained by using block Kriging were analyzed to reveal the spatial and temporal evolution characteristics, change rules and formation mechanisms of ecological risk based on land use under the background of urbanization, and to minimize land use risk during urbanization process. The results showed that during the past 18 years, moderate ecological risk level was major, while proportion of high ecological risk was the lowest, and the area of higher and lower ecological risk region changed most greatly; high and higher ecological risk were focused on urban region and the transition zone from urban to suburban region, while low and lower ecological risk mainly distributed in forestland with higher vegetation coverage, water bodies, grassland, shrub land and so on. Meanwhile, the transition zone from high to low ecological risk was very obvious. In addition, ecological risk became slightly worse in some region due to the transformation from cropland to residential and urban land, while it became slightly better in other regions because of the transformation from cropland to forestland; the center of gravity in lower ecological risk region shifted most greatly, while the shift was the smallest in high ecological risk region, namely 12.31 and 0.57 km respectively.

Key words Land use, Urbanization, Ecological risk, Spatial and temporal evolution, Distribution characteristics

At present, Land Use/Cover Change (LUCC) has become a front and hot topic in the study on global change, and it has changed the pattern and structure of global ecosystem[1-2], determining regional ecological risk. Studying regional ecological risk means assessing production capacity of resources and service value decrease of ecosystem as well as adverse effects (losses) of eco-environmental pollution and deterioration on society and production[3-4]. As the increase in the degree and complexity of land use development[5], the evolution process of land use pattern and functions has become more complex[6], such as soil properties[7-8], surface runoff, soil erosion and so forth[9-10], thereby affecting ecological security of regional land use pattern. Therefore, studying ecological risk based on land use pattern is important to the maintenance and protection of regional ecological security[4], has become one of hot spot issues at home and abroad[11-14]. Presently, there have been many studies of ecological risk based on land use[15-18], but there are few relative studies about big cities, especially urbanization watersheds in Northeast China.

Located in the middle reaches of Songhua River, Harbin City, an important old industrial city, has an important strategic position, and its urbanization process is rapider compared with other cities in Northeast China. Hence, based on the analysis of land use change and structural characteristics in urbanization watershed of Songhua River in Harbin section, by using RS and GIS technology, the ecological risk index (ERI)[19] was constructed to analyze the spatial and temporal evolution characteristics, change rules and formation mechanisms of ecological risk based on land use, further reveal the influences of spatial and temporal evolution of land use on ecological risk, and minimize the adverse effects of urbanization eco-environment[20], aiming at providing scientific references for eco-environment management, rational plan of land use, and establishment of economic development decisions during urbanization process and realizing coordinated development of land use and eco-environment.

1 Methods

1.1 General situation of the area studied Harbin City (125°42′ – 130°10′ E, 44°04′ – 46°40′ N) is located in the middle reaches of Songhua River, and the river flows through the city from southwest to northeast. Meanwhile, it is an important industrial city whose area is the largest and population is in the second place among provincially administered cities in China, as well as a comprehensive city taking industry as its main body and fully developing diverse industries. The terrain is high in north, east and south, and it is shaped like a crescent inclining westward. It borders on the branch of Zhangguangcai Ridge to the southeast and

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Xiaoxing'an Mountains to the north, while the land is flat and low in the west, and there are many mountains and hills in the east. Besides, it has vast plains, rich plant resources, all kinds of soil and many rivers, belonging to Songhua River system that mainly includes Songhua River, Hulan River and Ashihe River.

1.2 Data sources Landsat, American earth resources satellite, can monitor earth resources and the environment by using satellite-borne remote sensors to obtain surface image data, and it had been widely used to obtain remote sensing data about earth resources and the environment in the late 1980s, so it has become an important tool to quantitative study regional land use/cover change at present[21]. In this research, we chose Landsat TM remote sensing images in July 1989 and September 2007 (Track No. 118/28) as major data, and 1:50 000 topographic map, land use planning and administrative division maps or tables of Harbin City as secondary data.

1.3 Specific methods

1.3.1 *Processing of remote sensing data*. Referring to 1:50 000 topographic map, RGB false color composite and geometric correction of Landsat TM remote sensing images in 1989 and 2007 were carried out by using ERDAS IMAGINE 9.2. Afterwards, according to status quo and characteristics of land use, land use can be divided into six types, including farmland (dry land and paddy field), forestland (woodland, shrub land and other woodland), grassland (natural and constructed grassland), water (river, reservoir, pond and so on), residential and urban land as well as unused land (sand marsh and mudflat). Land use classification interpretation of remote sensing images was finished by using supervised classification and man-machine interactive interpretation, and its precision was verified according to the sampling points surveyed, finally it was saved in the form of GRID, which is easy to calculate.

1.3.2 *Spatial analysis of ecological risk index*. Here, we adopted grid sampling method to divide the area studied into many grid units with the size of 3 km × 3 km, and then evaluation unit of ecological risk based on LUCC was established after equidistant partition. Ecological risk index values were as ecological risk values of sampling grid points[22].

1.3.3 *Construction of ecological risk index and its weight*. To quantitatively analyze the relationship between land use and regional ecological risk, according to the area proportions of various land use types, regional ecological risk index (ERI)[23] was constructed to determine the comprehensive ecological risk of a sampling plot. Its formular is as follows:

$$ERI = \sum_{i=1}^{n} \frac{A_i \times W_i}{A}$$

where ERI is ecological risk index; i is land use type; A_i is area of land i; A is total area of sample plots; W_i is ecological risk intensity reflected by i land, namely weight. Here, we adopted analytic hierarchy process (AHP) to determine the weight of each land, namely farmland 0.21, forestland 0.09, grassland 0.11, water 0.14, residential and urban land 0.30, unused land 0.15.

1.3.4 *Analysis on the spatial variation of ecological risk*. Land cover center of gravity migration model can describe the spatial and temporal evolution process of major land use types well[24-25]. Here, by using the center of gravity model of land use, we studied the spatial distribution and spatial and temporal evolution of ecological risk in the region. Areal coordinates (longitude and latitude) can be calculated based on the follow-up formulas:

$$X_t = \frac{\sum_{i=1}^{n} (C_{ti} \times X_i)}{\sum_{i=1}^{n} C_{ti}} \quad (2)$$

$$Y_t = \frac{\sum_{i=1}^{n} (C_{ti} \times X_i)}{\sum_{i=1}^{n} C_{ti}} \quad (3)$$

where X_t and Y_t refer are longitude and latitude of center of gravity in an ecological risk region in year t; C_{ti} is area of ecological risk region i, while X_i and Y_i are longitude and latitude of its geometric center; n means number of small regions in the area studied.

2 Results and analyses

2.1 Land use structure and its changes According to Table 1, farmland area in both 1989 and 2007 was the largest among these land use types, followed by forestland, while the area proportion of grassland, unused land and water was small; the sum of area proportions of farmland and forestland reached 80.88% in 1989 and 79.36% in 2007. It shows that agricultural and forestry production is its dominant industry in the area studied, in accordance with the characteristics of regional economic and social development. In recent 18 years, the areas of forestland, grassland, water as well as residential and urban land showed increasing trends, especially residential and urban land which increased most greatly (218.04 km^2), and annual variation of water area was the largest (3.093 8%). The increase of residential and urban land in area is closely related to the continuous expanding of urban scale caused by population increase, economic development and acceleration of the urbanization process. Moreover, affected by economic policy for promoting the old industrial bases in Northeast China, the urbanization process has been speed up after 2001. Besides, the residential and urban land increased was mainly from farmland; due to the implementation of "returning farmland to forestland and grassland" project, the area of forestland and grassland also went up; the increase in water area was mainly attributed to natural factors and human activities like the construction of the dam in Dadingzi Mountain. On the contrary, the areas of farmland and unused land showed decreasing trends, especially unused land, decreasing by 236.86 km^2. The farmland increased was mainly from unused land (mudflat), followed by grassland, while the grassland increased was mainly from water and unused land.

2.2 Analysis of ecological risk Based on the geostatistical analysis module of ArcGIS 9.2, Kriging interpolation of ecological risk index in 1989 and 2007 was carried out. Afterwards, by using Natural Breaks classification method, ecological risk could be grouped into five grades according to ecological risk index, namely high ecological risk, higher ecological risk, moderate ecological risk, lower ecological risk and low ecological risk. As shown in Fig. 1, the high and higher ecological risk were focused on the urban region and the transition zone from urban to suburban region, while the low and lower ecological risk mainly distributed in forestland with higher vegetation coverage, water bodies, grassland and shrub land. In addition, the plain region with farmland suffered moderate ecological risk. Moreover, the farther the distance to the central city, the smaller the ecological risk index, showing that the spatial distribution of ecological risk had been affected by rapid urbanization process. Meanwhile, the transition zone from high to low ecological risk was very obvious, and there were great changes in the spatial distribution and intensity of each ecological risk region from 1989 to 2007.

Table 1 Areas of various land use types and their proportions in the region studied during 1989 – 2007

Land use type	1989		2007		1989 – 2007	
	Area//km^2	Proportion//%	Area//km^2	Proportion//%	Variation//km^2	Annual change//%
Farmland	4 591.86	65.58	4 386.91	62.65	–204.95	–0.248 0
Forestland	1 071.15	15.30	1 170.14	16.71	98.99	0.513 4
Grassland	295.41	4.22	321.08	4.58	25.67	0.482 8
Water	177.97	2.54	277.08	3.96	99.11	3.093 8
Residential and urban land	540.00	7.71	758.04	10.83	218.04	2.243 2
Unused land	325.44	4.65	88.58	1.27	–236.86	–4.043 4

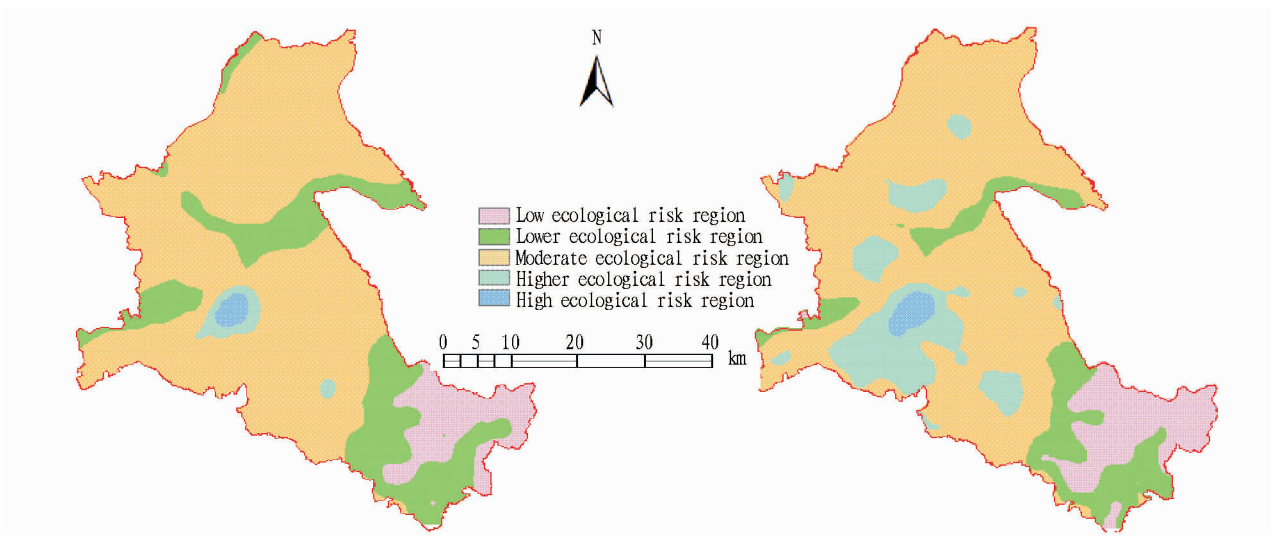

Fig. 1 Spatial distribution of each ecological risk region in the area studied in 1989 and 2007

From the aspect of ecological risk area (Table 2), it is seen that the moderate ecological risk level was major, while the proportion of high ecological risk was the lowest in both 1989 and 2007. That is, the area of high ecological risk region increased from 58.25 km^2 in 1989 to 91.62 km^2 in 2007, rising by 57.29%. This region expended from urban area to the transition zone from urban to suburban region, which is mainly related to rapid growth of economy, continuous expanding of the city, and migration of previous old industrial area out of the city. Thus, it is a key problem to coordinate the rational expanding of urban land for sustainable utilization of land. The area of higher ecological risk region rose by 788.24 km^2 from 1989 to 2007, and under the effects of economic policy for promoting the old industrial bases in Northeast China as well as urban spatial development strategy, this region expanded from the transition zone from urban to suburban area and central Acheng City in 1989 to surrounding districts and towns of Harbin in 2007, such as Hulan District, Songbei District, Pingdang District, Tuanjie Town, Taiping Town and so forth. Meanwhile, there was an increase of 130.24 km^2 in the area of low ecological risk region, and region increased mainly distributing in forestland in mountains. On the contrary, the areas of lower and moderate ecological risk region decreased by 584.07 and 367.78 km^2 respectively from 1989 to 2007, and the moderate ecological risk region decreased mainly distributed in the mudflat along Songhua River and some grassland. In a word, the changes of land use pattern resulted in the variation of ecological risk intensity and distribution in local in some areas, and made spatial distribution more centralized.

2.3 Dynamnic analysis of ecological risk According to the change of ERI from 1989 to 2007, the ecological risk variation could be divided into four grades, namely basically becomeing worse ($-2 \leqslant \Delta ERI < -1$), slightly becoming worse ($-1 \leqslant \Delta ERI < 0$), no change ($0 \leqslant \Delta ERI < 1$), and slightly becoming better ($1 \leqslant \Delta ERI < 2$). According to Table 3, ecological risk of the region showed an increasing trend during past 18 years, so the overall situation of eco-environment was not good. The area proportion of ecological risk becoming worse basically or slightly was 19.25%, and ecological risk slightly becoming better accounted for 2.41%, while the area proportion of ecological risk without change reached 78.34%. The variation becoming worse basically mainly resulted from the transformation from forestland to farmland. The policy "returning farmland to forestland" has obtained certain achievements, but because of continuous increase in population pressure in some areas, unreasonable land use patterns like deforestation still existed driven by economic interests. Therefore, it is necessary to continue to implement the policy "returning farmland to forestland" and make the effort to protect forestland. Ecological risk slightly became worse in the transition zone from urban to suburban area, surrounding towns and along Songhua River. In the transition zone and surrounding towns, the land use variation resulted from the transformation of farmland into residential and urban land as the rapid development of regional economy and acceleration of the urbanization process. Besides, large numbers of population increasing rapidly need more housings, thereby leading to continuous decrease of farmland and outward expansion of urban area, so contradiction between man and land will be deepened without cessation. Along Songhua River, grassland (forestland and unused land) mainly changed into faremland. Due to the increase in the range and intensity of human activity and excessive pursuit of short-term economic benefit, human had damaged, changed and utilized forestland, grassland and unused land more greatly, thereby speeding up the ecological risk based on land use besides improving grain yield, so eco-environmental quality had worsened. There was no change in ecological risk in plains and some mountains where people engaged in the production and life, and there were certain proportions of farmland and forestland, so contradiction between man and land should be coordinated properly[27], and some unreasonable land development and utilization activities should be stopped to realize rational utilization of land resources. Additionally, ecological risk became slightly better in mountains and hills due to the transformation of land use from farmland to forestland, which was attributed to the implementation of the policy "returning farmland to forestland".

Table 2 Areas and proportions of ecological risk at each level

Grade	1989		2007	
	Area//km^2	Proportion//%	Area//km^2	Proportion//%
Low ecological risk region	586.96	8.38	717.20	10.24
Lower ecological risk region	1 485.55	21.22	901.48	12.87
Moderate ecological risk region	4 749.65	67.83	4 381.87	62.58
Higher ecological risk region	121.42	1.73	909.66	12.99
High ecological risk region	58.25	0.84	91.62	1.32

Table 3 Classification of ecological risk

Grade	Area//km^2	Proportion//%
Basically becomeing worse	6.49	0.09
Slightly becoming worse	1 341.86	19.16
No change	5 485.13	78.34
Slightly becoming better	168.35	2.41

2.4 Spatial variation of ecological risk According to Table 4 and Fig. 2, the center of gravity in low ecological risk region moved by 2.30 km toward southwest from 1989 to 2007. It is because that forest mainly distributed in this region, and affected by slope and altitude, human activity was infrequent here; due to the implementation of natural forest protection project and the policy returning farmland to forestland", forestland area increased continuously, and its center of gravity moved from mountains to hilly areas. The center of gravity in lower ecological risk region with grassland, mudflat and shrub land moved most greatly by 12.31 km toward southeast. It is because that large areas of wetland, mudflat and some grassland along the northern Songhua River was developed into farmland as the constant increase of population and human activity range, so that the area of lower ecological risk region reduced. In addition, shrub land and other secondary environment in the southeast also promote the movement of the center of gravity. The center of gravity in moderate ecological risk region with farmland moved by 3.74 km toward northeast. It is because that wetland and grassland along northern Songhua River were developed into farmland, so farmland area went up; due to the construction of the dam in Dadingzi Mountains, a long wetland corridor formed along Songhua River, and some farmland along southern Songhua River was flooded, so that farmland area went down here. Besides, the policy "returning farmland to forestland" implemented in hilly areas also promoted the movement to a degree. Meanwhile, the center of gravity in higher ecological risk region shifted by 5.67 km toward northwest. At present, according to the development strategy of Harbin City, its urban space will transformed from sphere spreading to axial expansion, changing from compact clumps to dispersed groups, thereby forming new ecological risk regions in Songbei District, Hulan District and Songbei development area. Thus, aggressive urbanization, blind expansion and random spreading of urban land should be avoided in future. The movement toward southwest in high ecological risk region was the smallest, namely 0.57 km. With the rapid growth of economy and constant expansion of urban area, especially the amalgamation between economic technology and high-tech industries development areas in the south and southwest in 2001, the city expended toward development areas, which occupied some farmland and affected the potential for agricultural development, so ecological risk based on land use improved. At the same time, the center of gravity in high ecological risk region moved from old industrial areas to new industrial parks with favourable conditions and prosperous economy developing rapidly.

Table 4 Changes in the center of gravity in various ecological risk regions

Grade	1989		1989		Variation
	X(0)	Y(0)	X(0)	Y(0)	
Low ecological risk region	127.391 6	45.454 3	127.362 3	45.452 3	(−0.029 3, −0.002 0)
Lower ecological risk region	126.990 9	45.663 7	127.071 4	45.568 5	(+0.080 5, −0.095 2)
Moderate ecological risk region	126.744 4	45.879 6	126.765 7	45.909 3	(+0.021 3, +0.029 7)
Higher ecological risk region	126.701 1	45.698 7	126.649 4	45.734 6	(−0.051 7, +0.035 9)
High ecological risk region	126.659 3	45.736 4	126.654 4	45.732 5	(−0.004 9, −0.003 9)

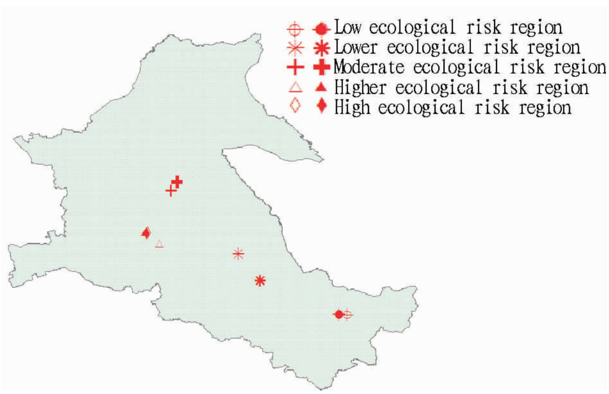

Fig. 2 Spatial variation in the center of gravity in various ecological risk regions

3 Conclusions and discussion

First, farmland area was the largest, followed by forestland, showing that agricultural and forestry production is its dominant industry in the area studied. In recent 18 years, the areas of forestland, grassland, water as well as residential and urban land went up, especially residential and urban land, while the areas of farmland and unused land went down, especially unused land. The forestland increased was mainly from farmland, while the grassland increased was mainly from water and unused land, and unused land was mainly transformed into farmland and grassland.

Second, during the past 18 years, the moderate ecological risk level was major, while the proportion of high ecological risk was the lowest; the area of low, higher and high ecological risk region increased continuously, while that of lower and moderate ecological risk region decreased constantly; the changes in the area of higher and lower ecological risk region were the greatest.

Third, the high and higher ecological risk were focused on the urban region and the transition zone from urban to suburban region, while the low and lower ecological risk mainly distributed in forestland with higher vegetation coverage, water bodies, grassland, shrub land and so on. Meanwhile, the transition zone from high to low ecological risk was very obvious. In addition, the center of gravity in lower ecological risk region shifted most greatly, while the shift was the smallest in the high ecological risk region, namely 12.31 and 0.57 km respectively.

Fourth, according to the urban spatial development strategy of Harbin City, it is predicted that total area planned will reach 4 969 km^2, and the area of urban region will be 4 272 km^2 in 2050, so we discussed the ecological risk of land use during urbanization process, and the ecological risk index constructed based on land use can reflect the spatial distribution and temporal evolution process of ecological risk, which is of certain practical significance to the rational expansion of urban land in future. Besides, the influencing process and mechanism of land use pattern on regional ecological risk need to be studied further. Population, economy, policy and transport can affect the evolution of urban land use pattern, but limited by data and technological means, transport factor was paid less attention to in this study, so the indicator chosen might not be comprehensive, and the process of weight determination might have certain subjectivity. Ecological risk index can only measure the comprehensive probability of occurrence for an ecological problem, but it can provide certain references for the exploration of land resource potential, rational establishment of land policy, urban ecological reconstruction, minimizing the land use risk during urbanization process, research on the urbanization of Northeast China and other regions.

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(To page 69)

certain quantities of farmland in the primary stage of socialism even longer period, so the mode should be implemented continuously. It can be expressed in the form of mathematical set as below:

Subsistence mode = {Farmland}

2.2 Fairly well-off mode With the development of society and economy and improvement of people's living level, China has stepped into well-to-do society, and people's consumption attitudes have changed into meeting grain and other food consumption demands instead of only basic grain demand. Hence, to adapting to the change, land use structure should be adjusted to meet consumption demands, including garden plot, grassland, water surface for aquaculture producing fruits, beef and mutton, aquatic products respectively. Fairly well-off mode was a land use model built based on meeting people's various demands, and it is expressed in the form of mathematical set as follows:

Fairly well-off mode = {Farmland, garden plot, grassland, water surface for aquaculture}

2.3 Ecological mode Ecological mode for agricultural land protection aims to meet people's material and spiritual needs, and the latter includes landscape and other special environments. Therefore, the mode is a higher level mode for agricultural land protection based on subsistence and fairly well-off modes, and it can be expressed in the form of mathematical set as follows:

Ecological mode = {Farmland, garden plot, grassland, water surface for aquaculture, ⋯, recreation site, Y_i}

2.4 Discrete mode Based on subsistence, fairly well-off and ecological modes, discrete mode has been established due to uneven distribution of land resources and difference of economic and socio-cultural factors in various regions. There are great differences of land resources in the east, middle and west of China as well as in various provinces or regions, which is asymmetry with consumption structure, so we ought to conduct regional coordination and resource integration according to the differences and establish reasonable modes for agricultural land protection. In addition, due to economic and cultural differences, the concept of land use in ethnic minority areas is different from other areas, so reasonable modes for agricultural land protection should also be established according to local conditions. Discrete mode can be expressed as follows:

Discrete mode = {Farmland} ∪ {Farmland, garden plot} ∪ {Farmland, grassland} ∪ {Farmland, water surface for aquaculture} ∪ {Farmland, ⋯,}

3 Conclusions

The results show that farmland protection should be in accordance with food consumption structure, and the scope protected should be adjusted according to food structure. In recent years, there was an asymmetrical relationship between farmland protection scale and per capita food consumption structure in China, and it is urgent to make farmland protection develop toward diversification. The subsistence, fairly well-off , ecological and discrete modes built in our study was suitable for the different developments of various regions, and they can promote farmland protection and relieve the pressure of farmland production. Hence, conditioned by land resources, establishing reasonable modes for agricultural land protection and diversifying farmland protection are the development trends of farmland protection in China in future.

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