

GIS-based detection of land use transformation in the Loess Plateau: A case study in Baota District, Shaanxi Province, China

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Abstract: During the past decade, great efforts have been made to boost the land use transformation in the Loess Plateau, especially for reducing soil erosion by vegetation restoration measures. The Grain-for-Green project (GFG) is the largest ecological rehabilitation program in China, which has a positive impact on the vegetation restoration and sustainable development for the ecologically fragile region of west China. Based on the Landsat TM/ETM images for three time periods (2000, 2005 and 2010), this study applied the GIS technology and a hill-slope analytical model to reveal the spatio-temporal evolutionary patterns of returning slope farmland to grassland or woodland in Baota District, Yan'an city of Shaanxi province. Results showed that: (1) from 2000 to 2010, the area of farmland decreased by approximately 35,030 ha, which is the greatest decrease among all the land-use types, whereas grassland, woodland and construction land increased, of which grassland expanded rapidly by 26,380 ha. (2) The annual variation rate of land-use dynamics was 1.98% during the period 2000–2010, of which the rate was 1.05% for the 2000–2005 period and 2.92% for the 2005–2010 period, respectively. Over the past decade, returning farmland to woodland or pastures was the main source of increased grassland and woodland, and the reduction of farmland contributed to the increase in grassland and woodland by 97.39% and 85.28%, respectively. (3) As the terrain slope increases, farmland decreased and woodland and grassland increased significantly. Areas with a slope ranging from 15° to 25° and less than 15° were the focus of the GFG project, accounting for 85% of the total area of farmland reduction. Meanwhile, the reduction in farmland was significant and spatially correlated with the increase in woodland and grassland. (4) Between 2000 and 2010, the area of destruction of grass and trees in grasslands and woodlands for the reclamation of farmland was approximately 4596 ha. The area subject to the GFG policy was 4456 ha with a slope greater than 25° over the decade, but the area of farmland was still 10,357 ha in 2010. Our results indicate that there has still a great potential for returning the steep-slope farmlands to woodlands or grasslands in the Loess Plateau.

Keywords: Loess Plateau; the Grain for Green project; land use transformation; quantitative detection; Baota District

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1 Introduction

Various researches have shown that the land use and cover changes (LUCC) mainly happen in

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wood, grass, farm and construction land (Tan *et al.*, 2005; Gao *et al.*, 2006; Liu *et al.*, 2008; Liu *et al.*, 2010). But to what extent these changes affect the environment needs to be further evaluated quantitatively (Bonilla *et al.*, 2010; Shao *et al.*, 2011; Lu *et al.*, 2013). The Loess Plateau, a typical area that suffered from the most serious soil erosion in the world, has received much attention from both the government and academia (Ritsema, 2003; Liu *et al.*, 2003; Ostwald and Chen, 2006; Long *et al.*, 2009; Fu *et al.*, 2011; Chen *et al.*, 2013; Hou *et al.*, 2014). It has been evidenced that grassland degradation, desertification and ecological deterioration have seriously affected the sustainable development in China (Di, 2003; Di *et al.*, 2006; Fu *et al.*, 2011; Li *et al.*, 2013). The eco-environmental degradation in the Loess Plateau can be attributed mainly to land reclamation for farming and low vegetation coverage (Fu, 1989; Zhou *et al.*, 2012). To cope with the ever increasing ecological problems, the Grain-for-Green (GFG) project has been implemented in the Loess Plateau by the Chinese Central Government since 1999 (Bennett, 2008; Liu *et al.*, 2014). The GFG advocates three types of land conversion: sloping farmland to grassland, sloping farmland to woodland, and wasteland to woodland. About 27.67 million ha of farmland were converted to woodland from 1999 to 2009, according to the census data from the State Forestry Administration, and the ecological environment of the Loess Plateau has recovered to some extent (Cao *et al.*, 2009; Deng *et al.*, 2012). However, it is unclear the quantity of conversion and transition from sloping farmland to grassland or woodland, especially in the hilly- gullied region.

The soil and water conservation, land use changes and ecological construction in the Loess Plateau have long attracted great attention of the academic community (Cao *et al.*, 2009; Liu *et al.*, 2014). Previous studies on the effects of anthropogenic activities on the environment in the Loess Plateau can be roughly divided into four areas. The first area of research primarily focuses on LUCC and its socio-economic driving force (Guo *et al.*, 2006), and on the rationality and potential of land use changes by different slopes (Shao *et al.*, 2011). The second area of research largely investigates the impact of LUCC on the biome transition zones, the relationships between land use changes and both human activities and climate changes, and the response of soil erosion to LUCC (Feng *et al.*, 2010; Fan *et al.*, 2013; Fan *et al.*, 2015; Xiao *et al.*, 2014). The third area of research mainly examines the influence of human activities on ecosystem, and driving forces of both human activity and climate change to desertification (Ren and Wang, 2007; Wang *et al.*, 2012; Sun *et al.*, 2012). The fourth area of research mainly explores the impact of the GFG on vegetation cover change and the livelihood of farmers, and the effect of gully land consolidation on soil and water conservation as well as ecological protection in the Loess Plateau.

The Loess Plateau is an ecologically fragile region and the key area of the GFG policy in China due to its unique regional characteristics where both soil erosion and the contradiction of man-land relationship were very serious. In the past 10 years, significant changes have taken place in the land use/cover patterns in this region due to the GFG and the Closed Forest policies. Understanding the impact of ecological construction measures on variations and spatio-temporal characteristics of vegetation in the hilly area of the Loess Plateau and assessing the rationality of these policies and their future development paths have a great theoretical and practical value in guiding China's construction of ecological civilization.

Using Baota District of Shaanxi Province as an example, the specific objectives of this study are to 1) explore the spatio-temporal characteristics of LUCC in Baota District in 2000,

2005 and 2010, 2) analyze the flow among different land-use types in recent decade based on the land use transfer matrix, and 3) assess the spatial patterns of farmland changes for different slopes and the effectiveness of returning farmland to woodland or grassland policy. The findings of this study would provide a reference for policymakers in formulating the ecological restoration strategy and the sustainable land use planning in the hilly area of the Loess Plateau, China.

2 Materials and methods

2.1 Study area

Baota District (109°14'10"–110°50'43"E, 36°10'33"–37°2'5"N) is located in the lower reaches of the Yanhe watershed, which lies in the middle part of the Loess Plateau in the northern Shaanxi Province of China, and covers an area of 354,510 ha. It has a typical semiarid continental monsoon climate with an average temperature of 7°C and an average annual precipitation of 550 mm, of which more than 60% fall from July to September in the form of heavy rains that can cause severe soil erosion. The terrain is a typical loess hilly-gullied landscape with elevations ranging from 860.6 m to 1525 m above sea level (average 1192.8 m). The higher northwest and southwest and the central uplift form a terrain of hill and valley with two ring-like titled to the east (Figure 1).

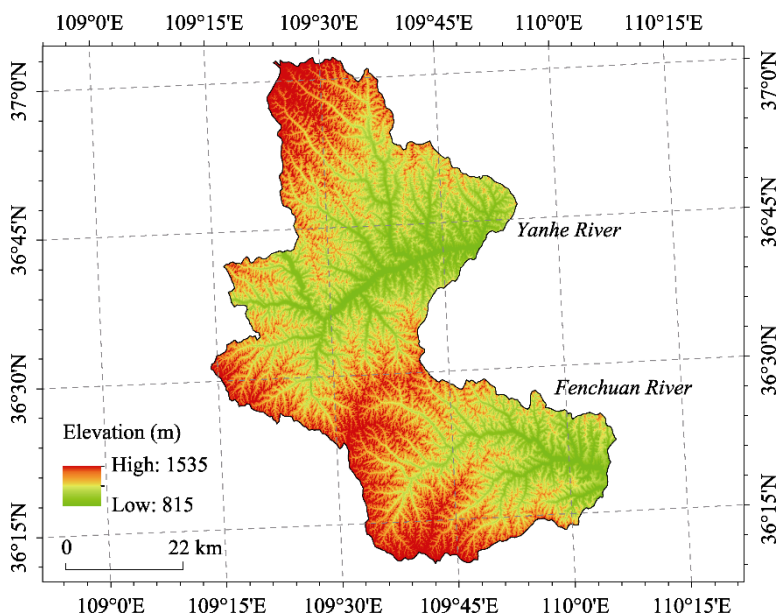


Figure 1 Location of Baota District, Shaanxi Province, China, and its terrain

There is the Yanhe River Basin to the north and the Fenhe River Basin to the south. In this region, the valley geomorphology is well developed with a geographic feature of hills and gullies intertwining, and the gully density is between 3.04 and 5.01 km/km². Baota District is a rugged and rough region where the area of gullies and ridges accounts for 90% of the whole region, which increases the potential risks of flood in the lower reaches of the Yellow River. The slope of Baota District ranges between 7° and 23°. Baota District shares the typical

characteristics of the Loess Plateau including the terrain of hills and gullies, and the fragile ecosystem. Baota District is also one of the key areas of the GFG implementation. Therefore, investigating the impact of the GFG on land use/cover changes in Baota District over the past decade would have an extremely vital practical value for guiding the ecological construction in the Loess Plateau in the future.

2.2 Data acquisition and processing

The land use data used in this study are Landsat TM/ETM images recorded in the 2000, 2005, and 2010 for Baota District. These data were obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC). Based on the ArcGIS 10 software platform, these vector data were converted into grid data at the grid cell size of 5 m×5 m to ensure data quality and accuracy. The classification scheme of the land use data consisted of six first-level classes and 25 second-level classes. The Raster Reclass module which is a raster reclassification tool in ArcGIS 10 was used to reclassify the rasterized land use into six first-level classes such as farmland, woodland, grassland, water body, construction land, and wasteland, and the spatial database was constructed to store the classification data. Then the Raster Calculator module was used to build up the land use transition matrix. Lastly, we obtained the land use change maps for the 2000–2005 period and for the 2005–2010 period by running the overlay analysis.

2.3 Extraction of hill slope use

In order to evaluate both the land use and the hill-slope land use conversion, the land use changes on different slopes were investigated. Firstly the slope map was generated from a digital elevation model (DEM) constructed from a digital topographic map of 1:50,000 with a 30 m spatial resolution in Baota District using the 3D Analyst Tools of ArcGIS 10. Secondly, the slope maps were segmented into three slope categories: $<15^\circ$, $[15^\circ, 25^\circ)$ and $\geq 25^\circ$, according to the basic requirements for returning farmland to woodland or grassland. Areas with a slope less than 15° can be used as the main agrarian cultivation areas; areas with a slope between 15° – 25° can be arable but need strong engineering measures to prevent soil erosion; and areas with a slope greater than or equal to 25° are not suitable as farmland and need to be returned to woodland and grassland. Thirdly, we overlaid the land use maps with the segmented slope map to extract the corresponding areas of land use/cover changes for the different land use classes on different slopes for various periods (Figure 2). Lastly, based on the aforementioned analysis we further assessed the implementation situation of returning farmland to woodlands or grassland and its rationality.

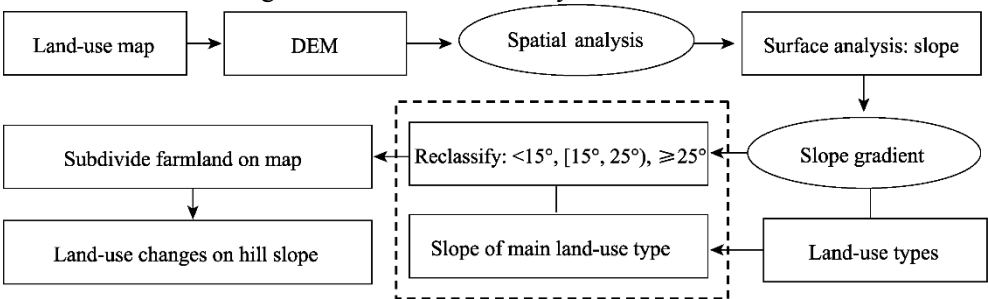


Figure 2 Work flow for land use transformation in this study

2.4 Models

1) The single land-use dynamics

The single land-use dynamics reflect the situation of land use changes with a certain type and at a certain time. The formula is as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where K is the land use change dynamics of one type, T is the study period, and U_a and U_b denote quantity of a certain land-use type in the beginning and end of the study period.

2) The integrated land-use dynamics

The degree of integrated land-use dynamics can be used to describe the rate of regional land use change. The formula is as follows:

$$LC = \left[\frac{\sum_{i=1}^n \Delta LU_{i-j}}{2 \sum_{i=1}^n LU_i} \right] \times \frac{1}{T} \times 100\% \quad (2)$$

where LU_i means the land area of types in the beginning of the study period, ΔLU_{i-j} means the absolute area change of land-use type from the beginning of the study period (i) to the end of the study period (j).

3) The land use transfer matrix

Land use transfer matrix reflects the structure and status of dynamic changes of land-use types in two stages. Transition matrices have often been used to analyze and quantitatively estimate the rate of change. The equation is as follows:

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \cdots & S_{2n} \\ S_{31} & S_{32} & S_{33} & \cdots & S_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ S_{n1} & S_{n2} & S_{n3} & \cdots & S_{nn} \end{vmatrix} \quad (3)$$

where S_{ij} is the area transited from land-use type i at the beginning of a time period to type j at the end of the time period and n is the number of total land use classes.

Two more indices have been defined in this study to measure the rate of land use change. The first one is the transition rate (Rt_{ij}), which is defined as:

$$Rt_{ij} = S_{ij} / U_i \times 100\% \quad (4)$$

where U_i is the total area of land-use type i at the beginning of a period, and S_{ij} is the area of land-use type j at the end of the period which was land-use type i at the beginning of the period.

The second one is the contribution rate (Rc_{ij}), which is defined as:

$$Rc_{ij} = S_{ij} / U_j \times 100\% \quad (5)$$

where U_j is the total area of land-use type j at the end of a period, and S_{ij} is the same as in Equation 4.

3 Results and analysis

3.1 Land use changes

1) Land-use type conversion

Figure 3 shows the land use of the study area in the years 2000, 2005 and 2010, respectively. From the figure we can find that land use change was quite remarkable in Baota District from 2000 to 2010, which was characterized by grassland and woodland expansion and farmland shrinkage (Table 1). During the period from 2000 to 2010, 30,721.14 ha and 7751.43 ha of farmland were converted to grassland and woodland, respectively.

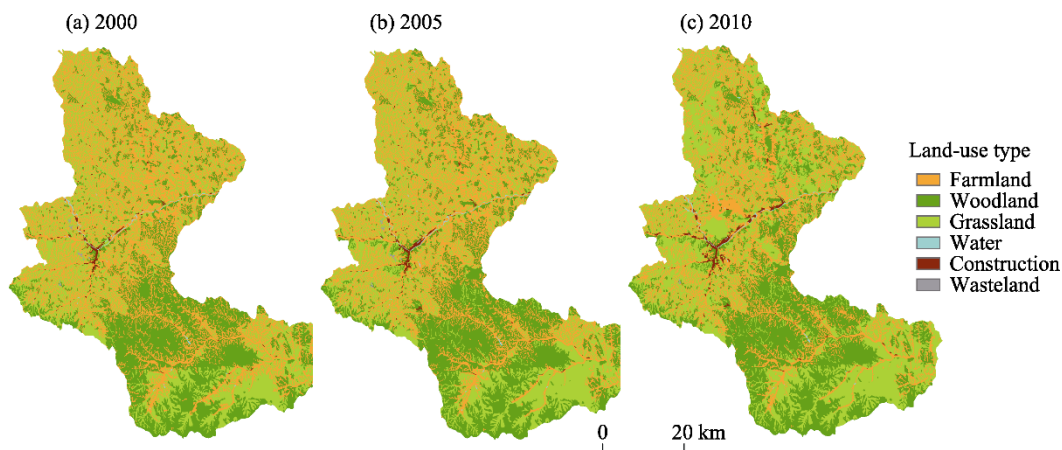


Figure 3 Land use maps of Baota District in 2000, 2005 and 2010

Table 1 The area of different land-use types of Baota District in 2000, 2005 and 2010

Land-use type	2000		2005		2010	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Farmland	137,240	38.71	127,950	36.09	102,210	28.83
Woodland	99,630	28.10	102,460	28.90	106,810	30.13
Grassland	114,690	32.35	120,780	34.07	141,070	39.79
Water	1030	0.29	1050	0.30	1050	0.30
Construction land	1730	0.49	2080	0.59	3320	0.94
Wasteland	190	0.05	190	0.05	50	0.02

Table 1 shows that in 2000, farmland was the main type of land use with an area of approximately 137,240 ha, accounting for 38.71% of the whole region. Grassland was the second largest land-use types with an area of 114,690 ha (32.35%). In 2000, there were approximately 99,630 ha of woodland and 20 ha of wasteland. In 2005, the dominant classes of land use were also farmland (36.09%), grassland (34.07%) and woodland (28.90%), but the areas of farmland shrank by 9,290 ha and of grassland expanded by 6,090 ha, compared to the levels of 2000. By 2010, grassland became the largest land-use type with an area of 141,070 ha (39.79%), while farmland decreased 35,030 ha, the largest decrease in all land-use types from year 2000. During the same period, the areas of grassland, woodland and construction land increased, of which grassland expanded most rapidly with an increase of 26,380 ha.

2) The magnitude of land-use dynamics

The annual variation rate of overall land-use dynamics in Baota District was 1.98% between 2000 and 2010. The annual variation rates were 1.05% and 2.92% for the periods of 2000–2005 and 2005–2010, respectively (Table 2). This result indicated that land use changes in Baota District in the latter period were faster. Among all land-use types during the decade, the areas of farmland and wasteland decreased steadily, whereas the grassland and construction land increased consistently. In terms of the dynamic magnitude of single land-use types, the wasteland had the largest annual decrease of 7.12% over the decade, followed by farmland with an annual decrease of 2.55%, while the construction land and grassland increased 9.18% and 2.30%, respectively. In addition, the changing degree for various types of land use during the period 2005–2010 was larger than that during the period 2000–2005. Among them, the decrease of wasteland was the largest with an annual reduction of 14.23%, followed by farmland with 4.02%, whereas the increase of construction land was the largest with an annual increase of 4.02%, followed by grassland with 3.36%.

Table 2 The dynamic degree of land use in Baota District (%)

Dynamic degree		2000–2005	2005–2010	2000–2010
Integrated dynamic degree		1.05	2.92	1.98
Single dynamic degree	Farmland	−1.35	−4.02	−2.55
	Woodland	0.57	0.85	0.72
	Grassland	1.06	3.36	2.30
	Water	0.38	0.02	0.20
	Construction	4.05	11.89	9.18
	Wasteland	0.01	−14.23	−7.12

3.2 Land use transitions

A transition matrix was constructed to understand the extent of various types of land use conversion for the periods of 2000–2005 and 2005–2010 (Table 3). Investigating the dynamic change characteristics of various land-use types by calculating the values and probabilities of land use transitions would help to understand clearly the conversion process of land-use types, which would help to recognize the rationality of land use structures. Results demonstrated that during the period of 2000–2010, the area of grassland increased by 31,540 ha, among that 30,720 ha (97.39%) was converted from farmland; woodland increased by 9090 ha, among that 7750 ha (85.28%) was converted from farmland. Over the same period, 4596 ha of grassland and woodland were destroyed for farmland, of which grassland was 3375 ha.

Farmland was mainly converted to grassland and woodland. The area of farmland decreased sharply from 2000 to 2010 by 35,021.88 ha, accounting for 9.88% of the whole region. The decrease of farmland was mainly due to the conversion of farmland to grassland and woodland at the transition rate of 22.39% and 5.65%, respectively. The increase of grassland from 2000 to 2010 was primarily from converted farmland with an area of 26,265.59 ha, which accounted for 7.44% of the whole region. Concurrently, the increase of woodland mainly came from the reduction of farmland with the transition rate of 7.26% (2.02%). However, the changes of construction land, water and wasteland were insignificant during the period 2000–2010 with an annual change rate of 0.88%, −0.19% and −0.04%,

respectively. The conversion of farmland to grassland and woodland was the main types of land use transition induced by the GFG.

Table 3 Land use transition (Rt) and contribution rate (Rc) from 2000 to 2010

	Area/ha	2000						Total
		Farmland	Woodland	Grassland	Water	Construct ion	Wasteland	
2010	Farmland (ha)	97,476.93	7751.43	30,721.14	43.74	1196.55	20.79	137,210.58
	Rt (%)	71.04	5.65	22.39	0.03	0.87	0.02	
	Rc (%)	95.39	7.26	21.78	4.18	36.06	37.68	
	Woodland (ha)	1221.03	97,686.00	618.57	9.81	62.28	0.27	99,597.96
	Rt (%)	1.23	98.08	0.62	0.01	0.06	0.00	
	Rc (%)	1.19	91.49	0.44	0.94	1.88	0.49	
	Grassland (ha)	3374.82	1323.81	109,504.44	61.11	417.60	0.90	114,682.68
	Rt (%)	2.94	1.15	95.48	0.05	0.36	0.00	
	Rc (%)	3.30	1.24	77.64	5.84	12.59	1.63	
	Water (ha)	54.63	1.89	25.56	929.16	12.33		1023.57
	Rt (%)	5.34	0.18	2.50	90.78	1.20		
	Rc (%)	0.05	0.00	0.02	88.79	0.37		
	Construction (ha)	42.12	11.79	43.74	2.70	1629.27		1729.62
	Rt (%)	2.44	0.68	2.53	0.16	94.20		
	Rc (%)	0.04	0.01	0.03	0.26	49.10		
	Wasteland (ha)	19.17		134.82			33.21	187.20
	Rt (%)	10.24		72.02			17.74	
	Rc (%)	0.02		0.10			60.20	
	Total 2010 (ha)	102,188.70	10,6774.92	141,048.27	1046.52	3318.03	55.17	354,431.61
	Rate (%)	28.83	30.13	39.80	0.30	0.94	0.02	
	Net change (ha)	-35,021.88	7176.96	26,365.59	-683.10	3130.83	-132.03	
	Change rate (%)	-9.88	2.02	7.44	-0.19	0.88	-0.04	

3.3 Gradient differentiation of land use

The terrain slope significantly impacts the agricultural production conditions and field management. Predatory farming on a steep slope leads to increased soil erosion and deterioration of ecological environment and thus disturbs seriously the balance of natural ecosystem. Studying land use/cover changes of farmland on different slopes in the climate-sensitive regions of the Loess Plateau is meaningful on guiding effective land use and the implementation of the GFG project.

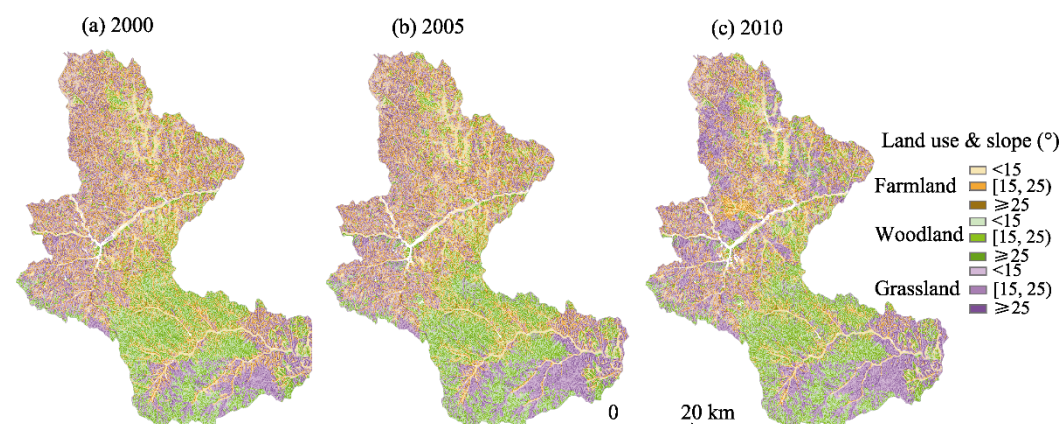


Figure 4 Land use on different slopes of Baota District in 2000, 2005 and 2010

In Baota District, areas with slope less than 15° accounted for 48.6% of the total area, and those with slope between 15° and 25° and greater than 25° accounted for 39.86% and 11.5%, respectively. These terrain characteristics provide a basic condition for the implementation of returning farmland to woodland or grassland.

Figure 4 shows the spatial distribution of various land-use types on different slopes. Woodland was mainly concentrated on the mountainous and hilly areas of the upper reaches of Fenhe River with a slope greater than 25°. Farmland was primarily concentrated on the hilly sloped regions north of the Yanhe River and the Chuandao region along the river, with a slope between 15° and 25°.

Table 4 The changes of main land-use types on different hill slopes in Baota District (ha)

Slope	Year	Farmland	Woodland	Grassland	Period	Farmland change	Woodland change	Grassland change
<15°	2000	68,783	46,711	54,303	2000–2005	–4.49	1.25	2.98
	2005	64,289	47,960	57,285	2005–2010	–10.87	1.47	8.43
	2010	53,415	49,429	65,711	2000–2010	–15.36	2.72	14.41
[15°, 25°)	2000	53,549	41,203	46,052	2000–2005	–3.84	1.19	2.57
	2005	49,712	42,389	48,623	2005–2010	–11.31	2.19	9.13
	2010	38,402	44,579	57,751	2000–2010	–15.15	3.38	11.70
≥25°	2000	14,813	11,607	14,268	2000–2005	–0.93	0.38	0.53
	2005	13,875	11,994	14,797	2005–2010	–3.52	0.75	2.77
	2010	10,357	12,739	17,565	2000–2010	–4.45	1.03	3.30

There were three main characteristics of land use/cover changes on different slopes in Baota District. Firstly, as the slope increases, the areas of farmland decreased significantly but the woodland and grassland increased obviously from 2000 to 2010. This suggested that the GFG has realized marked achievements. Secondly, the GFG was mainly implemented in regions with the slope between 15° and 25° and less than 15°, accounting for 85% of the total area of farmland reduction (Table 4). Over the past decade, the effect of the GFG was more significant in the period 2005–2010 than that in the period 2000–2005, showing that the areas of farmland reduction in the latter period were 2.8 times that in the previous period, whereas the areas of increased grassland and woodland in the latter period were 3.34 and 1.56 times that in the previous period, respectively. Further investigations indicated that there was

a significant spatial correlation between farmland shrinking and the increase in woodland and grassland. These results demonstrated that the increased woodland mainly came from farmland in Baota District over the past decade, and that the reclamation of farmland in the past mainly occurred in the steep areas (Figure 5). These findings also suggested that the GFG still has a great potential for the improvement of ecological environmental in Baota District.

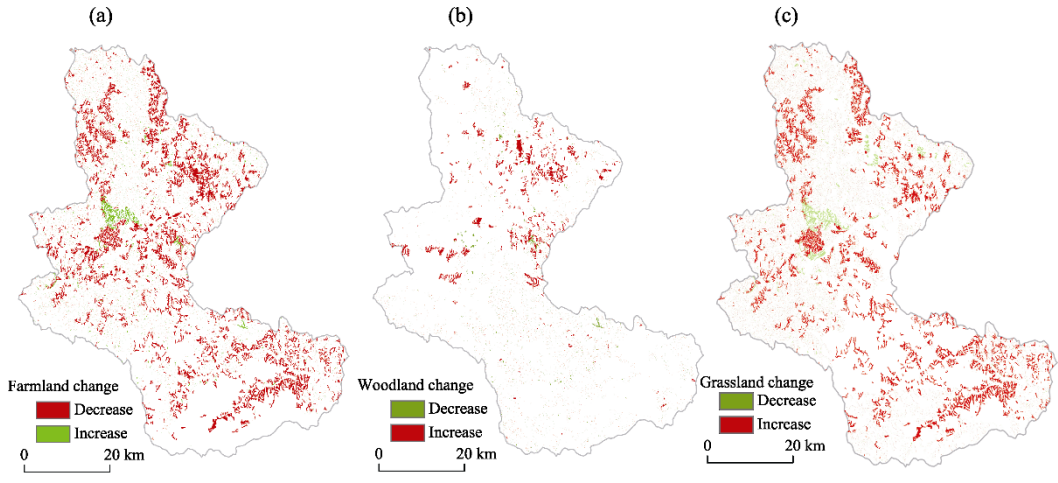


Figure 5 Comparison of the farmland, woodland, and grassland changes of Baota District during 2000–2010

4 Conclusions

(1) Over the period 2000–2010, the area of farmland in Baota District decreased by 35,030 ha, the greatest decrease among all land-use types. Meanwhile, the areas of grassland, woodland and construction land increased, of which grassland expanded most rapidly with an increase of approximately 26,380 ha.

(2) The annual rate of overall land use change in Baota District was 1.98% between 2000 and 2010, of which the rate in the second period (2005–2010) was larger than that in the first period (2000–2005). The conversion of farmland to woodland or grassland was the main driving force for land use changes in the Loess Plateau. Over the past decade, the contribution rate of the GFG to the increase in grassland and woodland were 97.39% and 85.28%, respectively.

(3) Along with slope increases, the areas of farmland decreased significantly but the woodland and grassland increased obviously from 2000 to 2010. The implementation of returning farmland to grassland and woodland has achieved marked accomplishments in Baota District. The GFG was mainly implemented in regions with a slope between 15° and 25° and less than 15°, accounting for 85% of the total area of farmland reduction. Further analysis revealed a significant spatial correlation between farmland reduction and grassland (woodland) increase.

(4) Over the past 10 years, the area of destruction of grasses and trees for the reclamation of farmland was approximately 4596 ha, of which 3375 ha was from the destruction of grasses. This result suggested that problem of destroying the grassland and woodland for farmland reclamation still existed in Baota District. The area subject to the GFG policy was 4456 ha with a slope greater than 25° over the decade, but the area of farmland had still

10,357 ha in 2010. Our findings demonstrated that it is urgent to further work in returning farmland to woodland or grassland on steep slopes and ecological construction in the Loess Plateau in the future.

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