J. Geogr. Sci. 2018, 28(5): 547-562
DOI: https://doi.org/10.1007/s11442-018-1490-0

Spatiotemporal patterns and characteristics of land-use change in China during 2010–2015

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Abstract: Land use/cover change is an important theme on the impacts of human activities on the earth systems and global environmental change. National land-use changes of China during 2010–2015 were acquired by the digital interpretation method using the high-resolution remotely sensed images, e.g. the Landsat 8 OLI, GF-2 remote sensing images. The spatio-temporal characteristics of land-use changes across China during 2010–2015 were revealed by the indexes of dynamic degree model, annual land-use changes ratio etc. The results indicated that the built-up land increased by 24.6×10^3 km^2 while the cropland decreased by 4.9×10^3 km^2, and the total area of woodland and grassland decreased by 16.4×10^3 km^2. The spatial pattern of land-use changes in China during 2010–2015 was concordant with that of the period 2000–2010. Specially, new characteristics of land-use changes emerged in different regions of China in 2010–2015. The built-up land in eastern China expanded continually, and the total area of cropland decreased, both at decreasing rates. The rates of built-up land expansion and cropland shrinkage were accelerated in central China. The rates of built-up land expansion and cropland growth increased in western China, while the decreasing rate of woodland and grassland accelerated. In northeastern China, built-up land expansion slowed continually, and cropland area increased slightly accompanied by the conversions between paddy land and dry land. Besides, woodland and grassland area decreased in northeastern China. The characteristics of land-use changes in eastern China were essentially consistent with the spatial govern and control requirements of the optimal development zones and key development zones according to the Major Function-oriented Zones Planning implemented during the 12th Five-Year Plan (2011–2015). It was a serious challenge for the central government of China to effectively protect the reasonable layout of land use types dominated with the key ecological function zones and agricultural production zones in central

Received: 2017-11-30 **Accepted:** 2018-01-22
Foundation: National Key Research and Development Program, No.2017YFC0506501; National Key Basic Research Program of China, No.2014CB954302
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and western China. Furthermore, the local governments should take effective measures to strengthen the management of territorial development in future.

Keywords: land-use change; spatial-temporal characteristics; remote sensing; Major Function-oriented Zones; China

1 Introduction

Land use/cover change is the most direct manifestation of the impact of human activities on the earth's surface system and is very important in the global environmental change process (Lawler *et al*., 2014; Wulder *et al*., 2008; Mooney *et al*., 2013). Human activities influence directly or indirectly the surface albedo, surface energy, surface roughness, and evapotranspiration through interaction between the biosphere and atmosphere and thus have a profound impact on the surface radiation energy balance, biogeochemical cycles, and eco-system services (Zhu *et al*., 2014; Deng *et al*., 2014; Meyfroidt *et al*., 2013). Land use/cover change is also one of the important factors characterizing the response of human activities to global change. It is an important input parameter to simulate global climate and biogeochemical effects. The measurement and simulation of its spatiotemporal process and understanding of the dynamic mechanisms have reached the forefront of scientific attention. The Land Use and Cover Change Science Research Program and Global Land Project, developed jointly by the International Geosphere and Biosphere Program (IGBP) and International Human Dimensions Program (IHDP) in 1995 and 2005 respectively, take land use/cover change as the core of global change research (Lambin *et al*., 1995; Turner *et al*., 1995; GLP, 2005; Howells *et al*., 2013; Wright and Wimberly, 2013). The International Council for Science (ICSU) and International Social Science Council (ISSC) launched the "Future Earth" research program in 2012. The measurement of land use and cover spatio-temporal processes has become important to deepen the understanding of the research plan of the Dynamic Planet and to achieve future sustainability objectives (Future Earth, 2013). The monitoring and simulation of land use/cover change has gradually become a focus of research.

Since the beginning of the 21st century, with sustained and rapid socio-economic development, China has entered a rapid urbanization and industrialization stage and a critical period of strategic transformation. In order to protect and develop land resources, optimize the development structure, strengthen land spatial-pattern control and ecological protection, China has implemented a series of land management strategies in its 12th Five-Year Plan period (2011–2015). In 2010, the State Council issued the Major Function-oriented Zones Planning. In this plan, national land is divided into four main function zones, namely optimal development, key development, restricted development and forbidden development, according to development methods. The government chooses reasonable means to develop and protect national land based on the main function zone locations (Fan, 2015). At the same time, an ecological civilization construction plan is implemented, which focuses on the protection and management of national key ecological function zones, biodiversity conservation priority zones, nature reserves, and other important ecological regions. The implementation of a series of major national strategic decision-making factors will have a profound impact on land-use change. Remote sensing satellite images have become an important data source for land-use change monitoring because of their long-term monitoring ability and high spatial resolution (Pflugmacher *et al*., 2012). In the present study, we carried out long-term land-use change monitoring at national scale, obtaining the spatiotemporal pattern and change characteristics of land use at that scale. This has important strategic significance for scientific and effective development of future national land management strategies and implementation of sustainable development goals (Wang *et al*., 2012; Kuang *et al*., 2016; Kuang *et al*., 2013).

To master and reveal the spatiotemporal patterns and dynamic characteristics of land-use change in China, the land-use change database at national scale of the late 1980s was built based on satellite remote sensing image data. The land-use change data have been updated every 5 years based on the same satellite remote sensing information source (Liu, 1996; Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010; Liu *et al*., 2014; Liu *et al*., 2017). Recently, our research group has released the latest 2010–2015 national land-use change database and latest research results of dynamic monitoring. We have completed six national land-use vector databases at 1:1 million scale and a 1-km proportional composition classification grid database from 1990 to 2015. Our study systematically reveals spatiotemporal patterns and new aspects of China's land-use change in 2010–2015 for the first time, which lays a solid foundation for understanding the national law for land-use change during the 12th Five-Year Plan period, and provides valuable spatial information for global change and sustainable development research.

2 Data and methods

2.1 Land use/cover change data update at national scale

Land-use change data were updated based on remote sensing satellite imagery data, such as Landsat 8 OLI and GF-2, with reference to China's land-use remote sensing mapping system (Liu, 1996; Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010; Liu *et al*., 2014). Using a high-resolution remote sensing–UAV–ground survey observation system, we constructed the latest land-use vector status dataset of 2015 via human–computer interaction, based on geographic knowledge. Then, we obtained a land-use dataset on a 1-km grid for 2015 (Figure 1) and built a national land-use database for the past 25 years, including land use in 1990, 1995, 2000, 2005, 2010 and 2015. Based on the above database, land-use change polygons from 2000 to 2010 and 2010 to 2015 were drawn, and comprehensive characteristics of national land-use change and differences of land-use change types over 2010–2015 were mapped and analyzed.

In order to ensure quality and consistency of interpretation of land-use data in each period, we performed uniform quality control and checking of the dataset. Firstly, nationwide subgroup field trips were taken for investigation of land use in the provinces, and a large number of field investigation records, photos, and UAV aerial images were obtained. Secondly, within the partition, according to stratified random sampling, we improved data quality through GF-2, UAV images, and field survey data onsite verification. Finally, we conducted unified integration and quality inspection in the country, and data quality was further improved by the identification of peer experts. The classification and overall accuracies were ultimately evaluated through the confusion matrix. The comprehensive evaluation accuracy of the first level of land use is > 93% and that of the second level is > 90%, which can meet user mapping accuracy demands at a scale of 1:1 million.

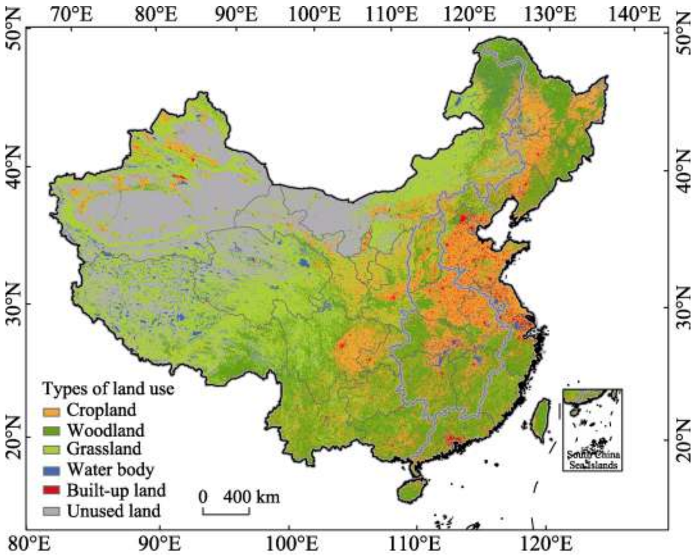

Figure 1 National land use map of China in 2015

2.2 National development zones

In order to better reveal regional characteristics and differences of land-use change, we divided the country into four regions, i.e., eastern coastal region, central region, western region, and northeastern region. The northeastern region (NER) includes Heilongjiang, Jilin and Liaoning provinces, and has an area of ~79.0×10^4 km^2. The eastern coastal region (ECR) includes provinces (municipalities and special administrative regions), Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan, Hong Kong, Macao, and Taiwan, with an area of ~95.5×10^4 km^2. The central region (CR) includes provinces of Shanxi, Henan, Anhui, Hubei, Hunan and Jiangxi, with an area of ~102.8×10^4 km^2. The western region (WR) includes autonomous regions (provinces and municipality) Inner Mongolia, Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Chongqing, Sichuan, Guizhou, Yunnan, Guangxi, and Tibet, with an area of ~682.7×10^4 km^2.

2.3 Indicators of land-use change

To better analyze characteristics of land-use change and reveal its rate, we used four indicators for each land-use change type. These are net total area of change, annual area of change, annual rate of change, and dynamic degree.

The equation for calculating the annual rate of change (K_i) of land-use type i was

$$K_i = \left\{\sum_j^n \left(\frac{\Delta S_{i,j}}{S_i}\right)\right\} \times \frac{1}{t} \times 100\%, \tag{1}$$

where S_i is the area of i at the start of monitoring, $\Delta S_{i,j}$ is the total net area of other changed land-use types j from and to i, and t is the time period. K_i reflects the annual change rate of i within the study area during t.

The equation for calculating the dynamic degree (S_i) of i was

$$S_i = \left\{\sum_j^n \left(\frac{\left|\Delta S_{i,j}\right|}{S_a}\right)\right\} \times \frac{1}{t} \times 100\%, \tag{2}$$

where S_a is the total study area, $|\Delta S_{i,j}|$ is the total area of absolute value of other changed land-use types j from and to i. S_i reflects the change intensity of i within the study area during t.

3 Dynamic characteristics of land-use change in China

Based on the dynamic model of land-use change and a map visualization method, the spatial distribution of the main land-use change types in China from 2010 to 2015 was mapped (Figure 2). The major land-use change in that period was built-up land expansion (Table 1), with a total area of ~2.57×10^4 km^2 at the expense of other land-use types. It was followed by cropland reclamation, with a total area of ~1.10×10^4 km^2 of woodland and grassland conversion to cropland. There was ~8.29×10^3 km^2 of dry land converted from and to paddy land. Water body shrinkage and expansion was also substantial.

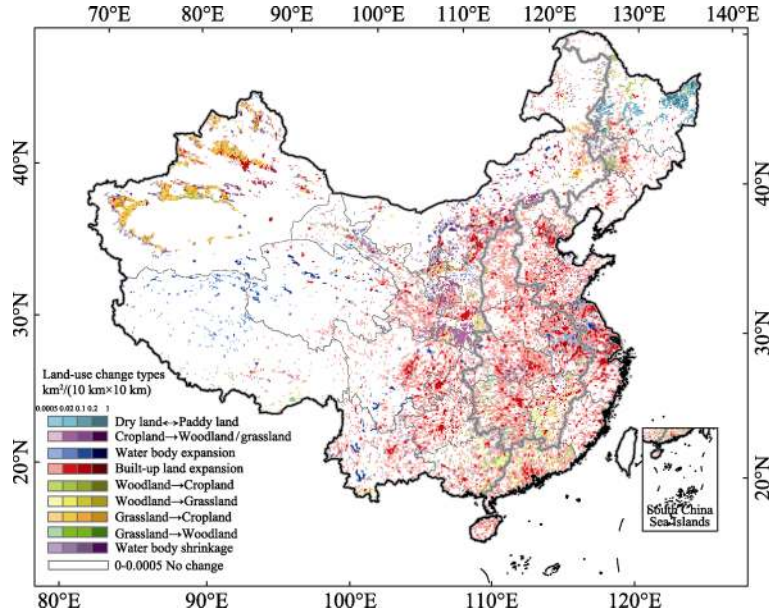

Figure 2 Distribution of dominant land-use conversion in China during 2010–2015

Table 1 Change area of dominant land-change types by region in China during 2010–2015 (×100 km^2)

Region	Dry land ↔ paddy land	Cropland →woodland / grassland	Other land →water body	Other land →built-up land	Wood-land→ cropland	Wood-land→ grassland	Grass-land→ cropland	Grass-land→ woodland	Water body→ other land
NER	76.00	1.06	0.75	10.43	4.17	0.00	3.95	0.02	8.63
ECR	5.71	2.46	8.81	70.09	1.00	4.05	0.32	1.64	0.26
CR	0.31	0.49	6.52	68.74	1.17	4.24	0.18	1.77	0.15
WR	0.87	14.67	36.97	107.39	4.61	5.00	94.84	3.60	66.43
Total	82.89	18.68	53.05	256.65	10.95	13.29	99.29	7.03	75.47

From the spatial distribution, built-up land expansion in the country was vigorous over 2010–2015. The largest area of such expansion was in the western region, accounting for ~41.8% of the national expansion area. However, the largest area proportion of built-up land expansion was found in the eastern and central regions, accounting for about 0.734% and 0.669% of those regions, respectively. The conversion of woodland to cropland was mainly in the northeastern and western regions. The total area of conversion of woodland to cropland in the two regions accounted for > 80% of the total area of that change nationally. The change from grassland into cropland mainly occurred in the northwest Xinjiang oasis area, constituting >95.5% of the national total change. The change from cropland into grassland and woodland was mainly in the Loess Plateau. There was a slight change in Xinjiang and northeastern regions. The area of change from cropland into grassland and woodland in the western region accounted for nearly 80% of the national total area of such change. The change between dry land and paddy land mainly occurred in the northeastern region, making up ~91.7% of the total area of national change. The expansion of water body across the country was mainly in the western and northeastern regions.

Compared with the spatial distribution of land-use change in 2000–2010, there were new features. In the northeastern region, dry land changed into paddy land continuously. The range narrowed, and the change concentrated on the Sanjiang and Songnen plains. In the southeastern coastal region, the built-up land expansion was accelerated continuously, with expansion of both large urban agglomerations and small cities and towns. In the central region, built-up land expansion was also accelerated. In the western region, the range of change from cropland into woodland shrank, only concentrating in the southern ecotone between agriculture and animal husbandry in Inner Mongolia and southern Loess Plateau. The reclamation center of the western region concentrated on the northwest oasis agricultural area, with cropland mainly converted from grassland. Cropland reclamation in eastern Inner Mongolia and Gansu Province was rare. Built-up land expansion in the western region was mainly found in relatively developed areas such as the Sichuan Basin and Loess Plateau. The scope of water body expansion in the western region was enlarged.

4 Dynamic characteristics of regional land-use change

4.1 Northeastern region

In 2015, the main land-use types in the northeastern region were woodland and cropland, with ~33.7×10^4 km^2 and ~31.2×10^4 km^2, accounting for 42.7% and 39.5% of the total area of the northeast, respectively. Built-up land occupied ~3.1×10^4 km^2, about 3.9% of the total area of the northeast. From 2010 to 2015, the total area of land-use change in the northeastern region was ~2.9×10^3 km^2, or 0.4% of its total area (Table 2). Cropland area in the region

Table 2 Change area of land-change types in northeastern China during 2010–2015 (km^2)

2010	2015						
	Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Total
Cropland	–	93.86	12.32	33.51	840.62	7.88	988.19
Woodland	417.22	–	0	5.23	96.17	6.86	525.48
Grassland	395.08	1.78	–	11.52	60.53	2.31	471.22
Water body	36.85	0	3.71	–	24.77	17.07	82.40
Built-up land	5.84	0.02	0	0.61	–	0	6.46
Unused land	634.91	1.13	179.34	24.80	23.07	–	863.25
Total	1489.90	96.79	195.37	75.67	1045.16	34.12	2937.00

*Only land-use change between the first class of land-use types was considered, without conversion between the two land-use types in the first class continued to increase, by ~0.5×10^3 km^2 over the afore-mentioned period. The area of woodland and grassland decreased slightly, ~0.7×10^3 km^2, and the expansion of built-up land was only ~1.0×10^3 km^2. In this region, the expansion of built-up land exceeded that of other types of land-use change. However, compared with other regions, this expansion was relatively small.

The main types of land-use change in the northeastern region were from cropland into built-up land and unused land into cropland, with ~840.6 km^2 and ~634.9 km^2 respectively, or 28.6% and 21.6% of the land-use change area in the region. This was followed by change from woodland and grassland into cropland with ~417.2 km^2 and ~395.1 km^2, respectively, or 14.2% and 13.5% of the land-use change in the region.

4.2 Eastern coastal region

In 2015, the main land-use types in the eastern region were cropland and woodland with ~39.4×10^4 km^2 and ~33.2×10^4 km^2, accounting for 41.3% and 34.8% of the region, respectively. The proportion of built-up land was relatively large with ~10.8×10^4 km^2, making up 11.3% of the total area in the region. From 2010 to 2015, the total area of land-use change in the eastern region was ~9.6×10^3 km^2, or 1.0% of the total regional area (Table 3). Built-up land in the region continued to increase, about ~7.0×10^3 km^2 from 2010 to 2015, but cropland area continued to decrease, by ~5.5×10^3 km^2.

Table 3 Change area of land-change types in eastern China during 2010–2015 (km^2)

2010	2015						
	Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Total
Cropland	–	231.88	14.01	563.47	5503.62	3.75	6316.72
Woodland	99.75	–	407.35	18.41	873.21	4.69	1403.42
Grassland	32.21	165.77	–	28.02	176.50	1.16	403.66
Water body	259.18	3.76	74.39	–	399.55	3.08	739.96
Built-up land	446.87	71.12	18.33	165.42	–	6.50	708.25
Unused land	14.20	0.79	0	1.02	7.27	–	23.28
Total	852.21	473.32	514.08	776.34	6960.15	19.18	9595.29

*Only land-use change between the first class of land-use types was considered, without conversion between the two land-use types in the first class

The main type of land-use change in the eastern region was cropland into built-up land, with an area of ~5.5×10^3 km^2, or 57.4% of total regional land-use change. It was followed by the conversion of woodland to built-up land and grassland, with ~873.2 km^2 and ~407.4 km^2 respectively, or 9.1% and 4.2% of total land-use change in the eastern region.

4.3 Central region

In 2015, land-use types in the central region were dominated by woodland and cropland with ~43.0×10^4 km^2 and ~40.9×10^4 km^2, accounting for 41.9% and 39.8% of the total area of the region, respectively. Built-up land occupied 6.18% of the total regional area with ~6.3×10^4 km^2. From 2010 to 2015, the total area of land-use change in central China was ~8.6×10^3 km^2, making up 0.8% of the total area of that region (Table 4). Built-up land in the central region continued to increase over the study period, by ~6.9×10^3 km^2. Cropland area continued to decrease, by ~5.2×10^3 km^2.

Table 4 Change area of land-change types in central China during 2010–2015 (km^2)

2010	2015						
	Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Total
Cropland	–	35.10	14.10	529.06	4906.73	14.39	5499.38
Woodland	117.06	–	424.27	70.98	1569.34	15.92	2197.56
Grassland	18.10	175.43	–	24.21	242.30	3.75	463.78
Water body	101.11	5.40	6.06	–	159.03	12.69	284.29
Built-up land	105.21	9.11	10.60	19.77	–	2.40	147.09
Unused land	0	0.63	0.12	13.64	0.35	–	14.74
Total	341.48	225.67	455.15	657.66	6877.75	49.15	8606.84

*Only land-use change between the first class of land-use types was considered, without conversion between the two land-use types in the first class

The main types of land-use change in the central region were cropland into built-up land, constituting 57.0% of the total area of land-use change in the region, followed by the conversion of woodland to built-up land, accounting for 18.2% of the total land-use change in the region.

4.4 Western region

In 2015, land-use types in the western region were dominated by grassland and unused land with ~246.1×10^4 km^2 and ~217.2×10^4 km^2, constituting 36.6% and 32.3% of the region's total, respectively. The proportion of built-up land was relatively small with ~6.1×10^4 km^2, accounting for only 0.9% of the total area of the western region. From 2010 to 2015, the total area of land-use change in the region was ~33.9×10^3 km^2, or 0.5% of the total regional area (Table 5). Built-up land in the western region obviously increased, by ~10.8×10^3 km^2 from 2010 to 2015, and cropland area increased by ~5.2×10^3 km^2. The area of woodland and grassland continued to decrease, by ~13.2×10^3 km^2.

Table 5 Change area of land-change types in western China during 2010–2015 (km^2)

2010	2015						
	Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Total
Cropland	–	150.51	1316.95	627.74	5394.10	127.35	7616.65
Woodland	461.37	–	497.59	373.16	924.88	43.83	2300.84
Grassland	9489.45	360.13	–	1324.36	3363.35	463.72	15001.01
Water body	127.45	4.79	330.23	–	107.59	1663.74	2233.80
Built-up land	15.40	20.79	21.36	36.61	–	4.99	99.14
Unused land	2743.03	363.82	1238.42	1335.55	970.26	–	6651.08
Total	12836.70	900.04	3404.55	3697.42	10760.18	2303.63	33902.52

*Only land-use change between the first class of land-use types was considered, without conversion between the two land-use types in the first class

The main type of land-use change in the western region was grassland into cropland. A total of ~10,000 km^2 of grassland was converted to cropland, accounting for 28.0% of the region's total land-use change area. This was followed by change from cropland to built-up land, representing ~16.0% of the total area of land-use change in the region. The area of change from grassland to cropland and that from unused land to cropland was ~3.4×10^3 km^2 and ~2.7×10^3 km^2, respectively. There exist many differences between the characteristics of regional land-use changes during 2000–2010 and 2010–2015 (Table 6).

Table 6 Regional characteristics of land-use change across China during 2000–2010 and 2010–2015

Region	Land-use features from 2000 to 2010	Land-use features from 2010 to 2015	Variations in regions between the two periods
1. NER	The main land-use change type was conversion from cropland to built-up land, with ~0.9×10^3 km^2. It was followed by change from woodland and grassland to cropland, with 0.7×10^3 and 0.6×10^3 km^2 respectively.	The main land-use change type was conversion from cropland to built-up land and from unused land to cropland. That was followed by change from woodland and grassland to cropland.	There was little difference in area of the main land-use change types. The change area from cropland to the woodland decreased. The change area from unused land into cropland increased.
2. ECR	The main land-use change type was conversion from cropland to built-up land, with ~14.5×10^3 km^2. It was followed by change from woodland to built-up land, with ~2.2×10^3 km^2.	The main land-use change type was conversion from cropland to built-up land. It was followed by change from woodland to built-up land and grassland.	The area of dynamic land-use change declined. The area of cropland and woodland change into built-up land greatly decreased.
3. CR	The main land-use change type was conversion from cropland and woodland to built-up land, accounting for 5.6×10^3 and 1.2×10^3 km^2 respectively. It was followed by cropland change into woodland, ~0.8×10^3 km^2.	The main land-use change type was conversion from cropland to built-up land. It was followed by change from woodland to built-up land.	The change from cropland and woodland to built-up land showed small differences, but the conversion area from cropland into woodland shrank.
4. WR	The main land-use change type was conversion from grassland to cropland, accounting for 16.1×10^3 km^2. It was followed by change from cropland to grassland, and from grassland to woodland, both accounting for 6.4×10^3 km^2.	The main land-use change type was conversion from grassland to cropland. It was followed by change from cropland and grassland to built-up land. Reclamation of unused land was also substantial.	The area of grassland change to cropland decreased. In addition, the area of cropland return to woodland and grassland decreased obviously.

5 Change of main land-use types

5.1 Expansion characteristics of built-up land

Built-up land in China from 2010 to 2015 increased by ~24.6×10^3 km^2. The largest area of increase was observed in the western region, where there was an increase by 10.6×10^3 km^2, or 43.0% of the total increase area of built-up land in China. The second largest increase area was in the central region, with ~6.7×10^3 km^2. The smallest increase area was in the northeastern region, only 1.0×10^3 km^2. The expansion of built-up land was mainly at the expense of cropland, with ~67.5% of new built-up land coming from the expropriation of cropland. There was 14.0% and 15.6% of new built-up land originating from the occupation of woodland and grassland. The expansion of built-up land in the western region was mainly in flat-terrain, relatively developed areas such as the Sichuan Basin, Loess Plateau, and national key development zones under strategic deployment of the Major Function-oriented Zones Planning (Figure 3). The expansion of built-up land in the central region was mainly in the Central Plains, Wuhan, and Changsha-Zhuzhou-Xiangtan urban agglomerations. The expansion was mainly in economically developed and densely populated areas such as the Beijing-Tianjin-Hebei, Yangtze and Pearl river delta urban agglomerations, plus other large and medium-sized cities.

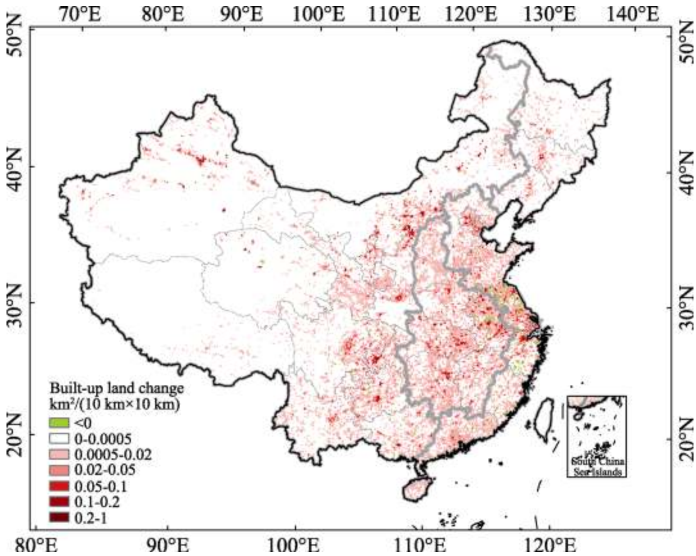

Figure 3 Distribution of built-up land change in China during 2010–2015

Compared with 2000–2010, the spatial pattern of built-up land change during 2010–2015 was almost the same, still featuring the "Concentrate in the eastern region and spread to the central and western regions". However, the change area and rate of built-up land had major differences between 2010–2015 and 2000–2010 (Figure 4). Considering the total area of change, the increase area of built-up land in the eastern region reduced greatly from 2010 to 2015, while it reduced slightly in the central region. The increase area of built-up land in both the northeastern and western regions shows an increasing trend. The new built-up land has shifted from the eastern region during 2000–2010 to the western region during 2010–2015.

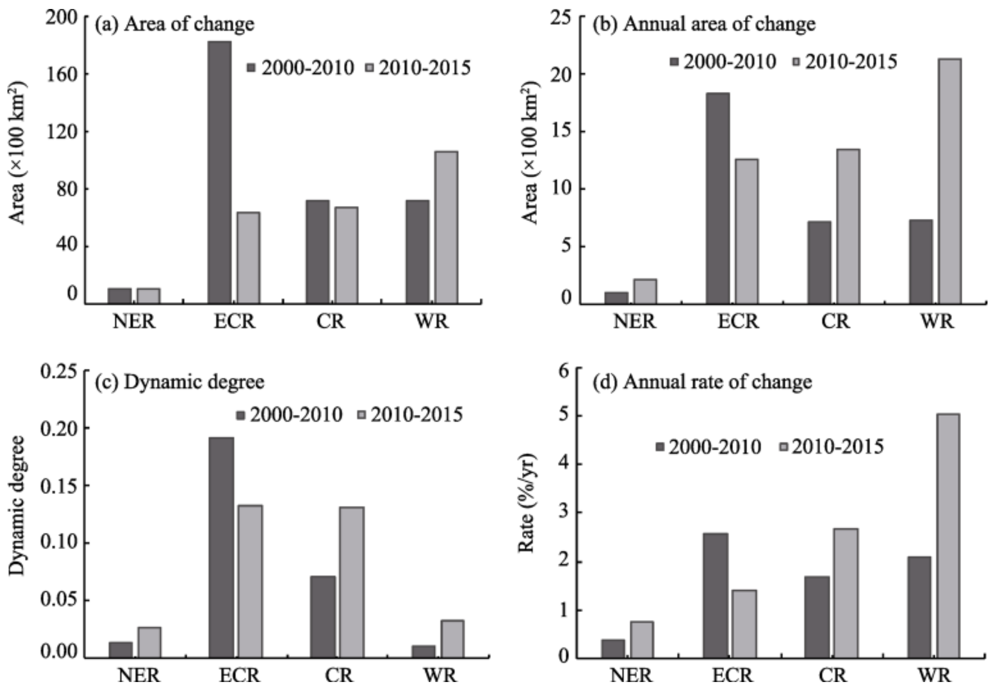

Figure 4 Statistical histogram of built-up land change by region during 2000–2010 and 2010–2015

The average annual change area, dynamic degree and annual rate of built-up land change in the northeastern and western regions during 2010–2015 were sharply greater than those of during 2000–2010. Those in the eastern region were smaller during 2010–2015. In the latter period, the dynamic degree of built-up land increase in the central region was nearly the same as in the eastern region. However, the annual rate of change in the central region was much larger than that of the eastern region. This shows that during 2010–2015, the expansion rate of built-up land in the eastern region declined, while the expansion rate in the northeastern, central and western regions increased substantially.

Therefore, the change of built-up land in China from 2010 to 2015 was such that the eastern region was still the core, but spread to the central and western regions. The eastern expansion slowed, and expansion accelerated in the northeastern, central and western regions. Built-up land development in the eastern and central regions was equal, but both were greater than in the northeastern and western regions. That development in the western region accelerated overall, and the rate was much higher than in the central and eastern regions.

5.2 Change of cropland

The total area of cropland in China decreased by 4.9×10^3 km^2 over 2010–2015, among which the conversion area of cropland to other land-use types was ~20.4×10^3 km^2, and the conversion area of other land-use types to cropland was 15.5×10^3 km^2. Cropland in the eastern and central regions declined by 5.5×10^3 km^2 and 5.1×10^3 km^2, respectively, and in the northeastern and western regions increased continuously, by 0.5×10^3 km^2 and 5.2×10^3 km^2 respectively. The decrease of cropland was mainly from the occupation of built-up land, and the area of this occupation accounted for 81.5% of cropland reduction in the country. The increase of cropland was mainly from occupation by grassland and reclamation of unused land. The conversion from grassland and unused land to cropland represented 64.0% and 21.9% of the new cropland area, respectively. The decrease of cropland in the eastern coastal region was largely from occupation by built-up land (Figure 5). The reduction of cropland in the central region was mainly from large-scale expansion of built-up land and the conversion of cropland to woodland and grassland. This occurred under the influence of the "Rise of Central China" strategy and implementation of national ecological protection projects. A small increase in cropland in the northeastern region mainly owed to the reclamation of the Northeast China Plain. In the western region, implementation of ecological projects to return cropland to woodland and grassland on the Loess Plateau and in the Sichuan Basin increased cropland area. In Xinjiang, because of the development of oasis agriculture, substantial surrounding cropland was reclaimed. The intensity and area of reclamation was much greater than returning cropland to woodland and grassland. Therefore, cropland area in the western region substantially increased.

Compared with 2000–2010, the spatial pattern of cropland change during 2010–2015 was nearly the same. It continued a trend toward "increase in the north and decrease in the south, with the center of increasing cropland moving from northeast to northwest". The change rate and area had major differences between the two periods (Figure 6). Total change areas in the eastern, central and western regions during 2010–2015 were all less than those of the period 2000–2010, but change in the northeastern region was greater in this period. Meanwhile, the decrease rate in the eastern region declined, while in the central region it accelerated. The increase rate in the northeastern and western regions rose.

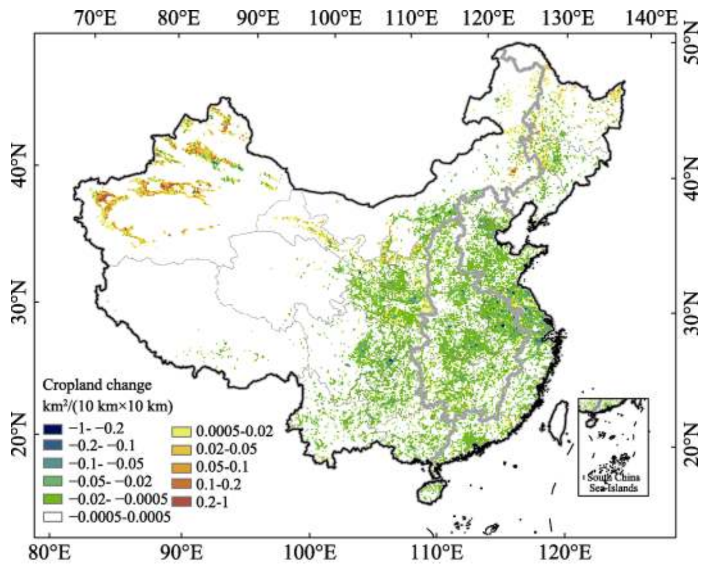

Figure 5 Distribution of cropland change in China during 2010–2015

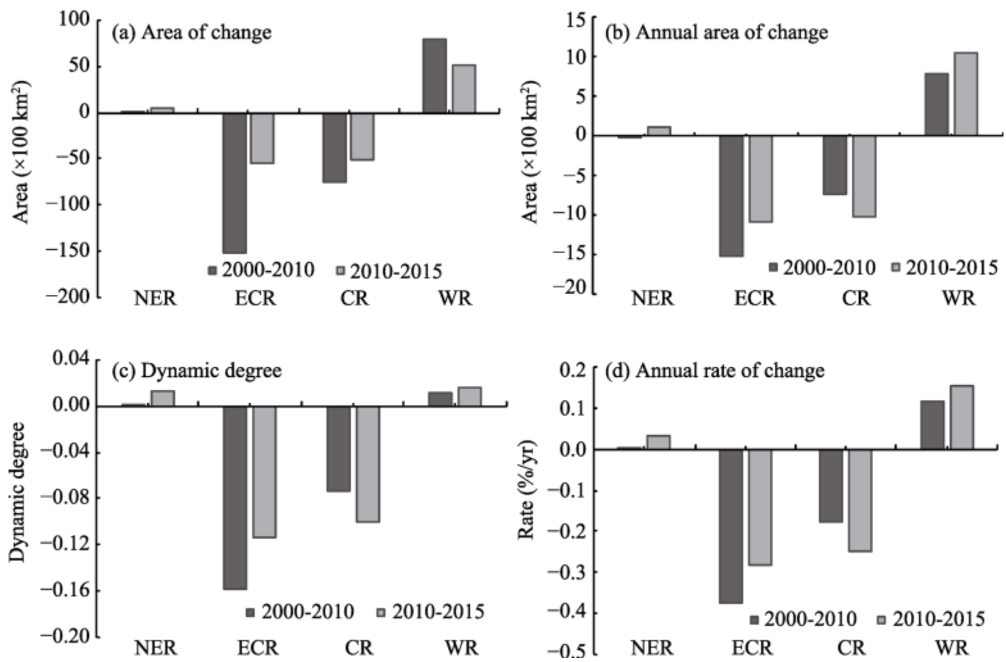

Figure 6 Statistical histogram of cropland change by region during 2000–2010 and 2010–2015

Therefore, cropland change in China from 2010 to 2015 showed a southward decrease and northward increase, and the total amount of cropland was nearly unchanged. The center of new cropland moved gradually from northeast to northwest. Cropland in the eastern and central regions continued to decrease, while in the northeastern and western regions it continued to increase. The decrease slowed in the western region and accelerated in the central region. The increase accelerated in both the northeastern and western regions.

5.3 Change of woodland and grassland

The area of woodland and grassland in China decreased by 16.4×10^3 km^2 over 2010–2015, in which the conversion of woodland and grassland to other land area was 20.7×10^3 km^2; other land conversion to woodland and grassland area was 4.3×10^3 km^2. The largest area of decline was in the western region, at 13.0×10^3 km^2, much greater than the other three regions. This was followed by the central region, with a total reduction of 2.0×10^3 km^2, while the eastern and northeastern regions had a smaller woodland and grassland areas of decrease of <1000 km^2. The reduction of woodland and grassland was mainly by reclamation from cropland and built-up land expansion. Cropland reclamation and built-up land expansion accounted for 53.2% and 35.2% of the total decrease area of grassland and woodland. The increase of woodland and grassland was mainly caused by conversion of cropland and unused land, accounting for 44.2% and 42.2% of the increased area of woodland and grassland, respectively. In the western region, the woodland and grassland increase concentrated in the Xinjiang oasis area, Loess Plateau, Sichuan Basin, and other regions (Figure 7). In oasis of Xinjiang, a large amount of woodland and grassland changed because of cropland reclamation, which greatly reduced the area of woodland and grassland. In some areas, such as the Loess Plateau and Sichuan Basin, the expansion of built-up land occupied large areas of woodland and grassland because of the strategic influence of the Major Function-oriented Zones Planning of the country. From 2010 to 2015, the scale and scope of national ecological protection projects somewhat decreased. The projects focused on supplementation and consolidation, such as the return of cropland to woodland and grassland. Therefore, the entire area of woodland increase was relatively small. Projects for returning cropland to woodland and grassland have been implemented in western China, augmenting the area of grassland and woodland. However, that area was small compared with the cropland reclamation and built-up land expansion. The decrease of woodland and grassland in central China was mainly in the national key development zones. This occurred under the strategic deployment of the Major Function-oriented Zones Planning, and was mainly caused by the expansion of built-upland. The decrease of woodland and grassland in the northeastern and eastern regions was less, mainly due to the expansion and occupation of built-up land.

Compared with 2000–2010, the spatial pattern of woodland and grassland change during

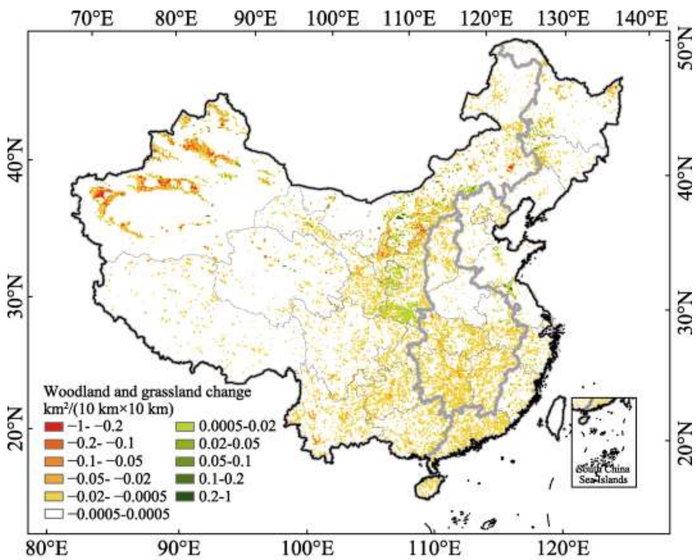

Figure 7 Distribution of woodland and grassland change in China during 2010–2015

2010–2015 was nearly the same. However, the range of woodland increase area gradually decreased, and the range of woodland decrease area gradually increased. This shows that "the increase area in the central region shrank, while the decrease area in the eastern and western regions expanded". There were large differences in the change rate of woodland and grassland between 2010–2015 and 2000–2010 (Figure 8). The total area of woodland and grassland decrease in the eastern and northeastern regions declined during 2010–2015, especially in the former region. However, the decrease area in the central and western regions increased.

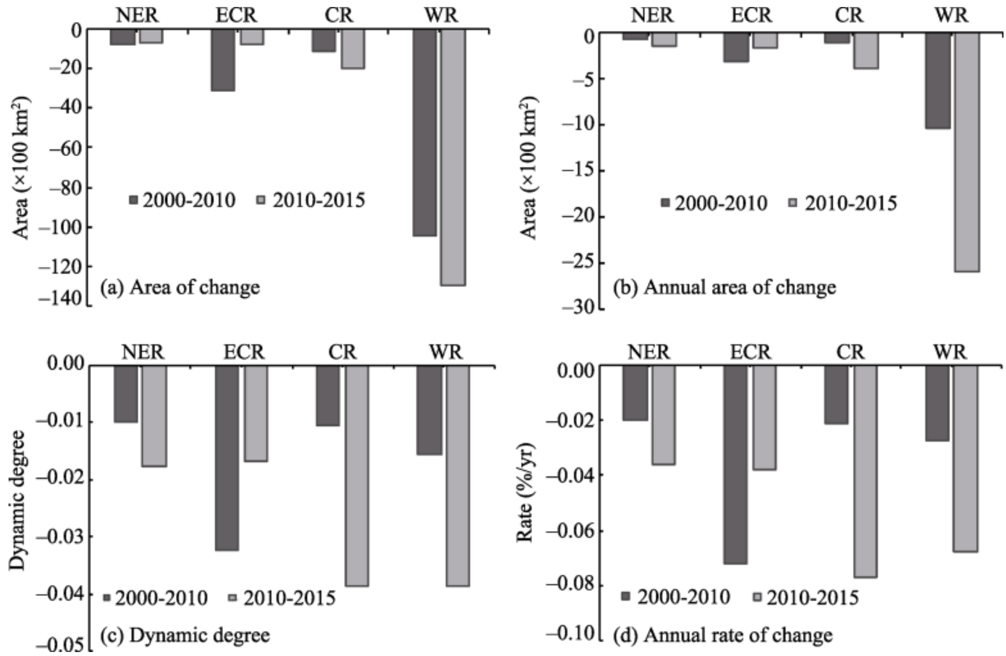

Figure 8 Statistical histogram of woodland and grassland change by region during 2000–2010 and 2010–2015

The decrease area of woodland and grassland in the western region was much smaller than that in the central region. The dynamic degree of woodland and grassland in the central and western regions was nearly identical, considering the difference of regional area and area of woodland and grassland in the central and western regions. The annual rate of woodland and grassland reduction in the central region was slightly higher than that in the western region. The dynamic degree of grassland and woodland decrease in the northeastern region was slightly greater than that in the eastern region, while the annual rate of woodland and grassland reduction in the northeastern region was almost the same as that in the eastern region. This indicates that the reduction rate of grassland and woodland in the eastern region slowed during 2010–2015, but that rate in the northeastern, central and western regions accelerated. The annual rate of woodland and grassland reduction in the central region was slightly higher than in the western region and much higher than in the eastern and northeastern regions. The dynamic degree of woodland and grassland change in the central region was almost the same as in the western region, and both were much greater than in the eastern and northeastern regions.

Therefore, the change of woodland and grassland in China over 2010–2015 was such that the increase area in the central region declined, while the decrease area in the eastern and western regions expanded. The decrease rate in the eastern region slowed, while the decrease rate in the northeastern, central and western regions accelerated. The reduction in the western and central regions was almost equal, and both were greater than in the eastern and northeastern regions. The reduction rate of the central region was much higher than in the western, eastern and northeastern regions.

6 Conclusions and discussion

Based on satellite remote sensing image data and the national land-use change database of China from the late 1980s to 2010, we updated land-use change data of 2015 by artificial interactive interpretation. Compared with the spatiotemporal patterns of land-use change from 2000 to 2010, we analyzed those patterns and new features of land-use change in China over 2010–2015.

Compared with 2000–2010, the regional spatial pattern of land-use change in China during 2010–2015 was basically the same. However, new characteristics appeared in regional land-use change. The main features of that change are as follows. Built-up land in eastern China expanded and cropland shrank, but the rate of change decreased. Built-up land expansion and cropland shrinkage in central China accelerated. In western China, built-up land expansion obviously accelerated. The increase rate of cropland accelerated. The shrinkage rates of both woodland and grassland accelerated. In northeastern China, built-up land expansion continued to slump, cropland increased steadily, and the area of woodland and grassland decreased slightly.

From 2010 to 2015, the characteristics of land-use types varied greatly. Built-up land expansion was such that the eastern region remained the core and radiated to the central and western regions. Expansion in the eastern region slowed, while the northeastern, central and western regions showed acceleration. The development of built-up land in the eastern and central regions was basically flat, while that in the western region accelerated. The change of cropland was such that cropland decreased in the northern region and increased in the southern, with the total area basically in balance. The center of new cropland moved farther from the northeast toward the northwest. Cropland in the eastern and central regions continued to decline, while that in the northeastern and western regions continued to increase. The decrease of cropland in the eastern region slowed. There was cropland reduction in the central region, while an increase of cropland in the northeastern and western regions accelerated. The decrease area in the western region was similar to that of the central region, but both were larger than in the eastern and northeastern regions. The decrease rate in the central region was higher than in the western, eastern and northeastern regions.

In the Major Function-oriented Zones Planning implemented during the 12th Five-Year Plan, the national optimal development and key development zones are mainly in the eastern coastal and northeastern regions. The main type of land-use change in the eastern region during 2010–2015 was built-up land expansion, but at a decreasing rate. These characteristics basically match the spatial pattern of land management requirements of the national optimal development and key development zones. Agricultural production and key ecological function zones were mainly in the western and central regions. Land-use change in those regions over the same period showed that local governments of central and western regions face severe challenges in effectively protecting land-use types associated with the key ecological function and agricultural production zones. Therefore, it is necessary to further increase effective control of land development patterns by central and western governors.

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