Received: 28 March 2017 | Revised: 5 December 2017 | Accepted: 9 December 2017
DOI: 10.1002/ldr.2874

RESEARCH ARTICLE

WILEY

The role of human activity in decreasing ecologically sound land use in China

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Funding information
National Natural Science Foundation of China, Grant/Award Number: 41330750

Abstract
Ecologically sound land (ESL) represents a meaningful geographical spatial unit that provides ecological goods and services at various scales. However, few studies focusing on national- or regional-scale changes in ESL use and the degradation of the land ecosystem in China have been based on reliable and up-to-date land survey data. The study aimed to analyze the relationship between the changes in ESL use and human activities and regional policies, as well as land ecosystem degradation. The results indicated that land capitalization, resulting from rapid industrialization, urbanization, and the effects of regional land policies and large land projects, caused a clear decrease in grassland and wetland ecosystems, and an increase in forest ecosystem, varying in extent during different periods. Land ecosystem degradation, according to the decreased *ecosystem service provision index* (ESPI), was concentrated in the Yangtze River Delta, the southwestern regions, and the Inner Mongolia Plateau, where human activity was concentrated. From 2009 to 2015, such degraded land amounted to 9.51% of the Counties. The degradation in ESL use caused a decrease in the ecological goods and services provided by the ecosystems. Land ecosystem degradation resulting from the abandonment of natural grassland and farmland is a prominent and complex problem in China. Optimizing the regional spatial patterns of ESL use was critical for sustainable ecosystem management. Balancing compromises and synergies between providing ecological goods or socioeconomic benefits and ecological costs at a regional or national scale was found crucial for land policy making.

KEYWORDS

ecologically sound land use change, ecosystem service, human activity, land ecosystem degradation, land policy

1 | INTRODUCTION

Complex interactions between physical and biological factors and human activity result in ecosystems (Pickett & Cadenasso, 2002). Land use change and its links to human activity from the ecosystem perspectives have received worldwide attention in recent years. Land use changes affect ecosystem structures and processes and can change the supply capacity of ecosystem services (Perez-Soba et al., 2008; Verburg, Steeg, Veldkamp, & Willemen, 2009). China faces a dilemma of rapidly growing consumption of natural resources and resulting severe ecosystem degradation. An increasing challenge for sustainable land use and ecosystem management involves mediating the conflicting goals of different stakeholders and users of the land in response to rapid land use changes. Furthermore, to meet the challenge of ecosystem sustainability, an ecological perspective needs to be incorporated into decision making. It could be imperative with the aid of a clear understanding of the dilemma and its impacting factors from the view of ecosystem management.

Current research on land use change ranges from deforestation (Alix-Garcia et al., 2016; Newman, McLaren, & Wilson, 2014) to changes in farmland (Bucała-Hrabia, 2017; Deng et al., 2015; Feng, Liu, &Yang, 2005; J. Y. Liu et al., 2005) and wetlands (Nguyen, Dargusch, Moss, & Aziz, 2017; Wang, 2015), as well as from changes in land development (H. Li, Dennis Wei, & Zhou, 2017) to urban expansion (Deng & Srinivasan, 2016; Ho & Lin, 2004; Kuang, Liu, Dong, Chi, & Zhang, 2016; You & Yang, 2017). These studies provide a clear understanding of the changes and causes of changes in land use. Several studies have attempted to analyze the temporal and spatial changes in land use in China and their socioeconomic influencing factors (J. Y. Liu et al., 2010; J. Y. Liu et al., 2014; Siciliano, 2012;

Sun & Li, 1997; Wang, Chen, Shao, Zhang, & Cao, 2012). In addition, some sectoral studies have focused on agricultural production and farmland change (Deng, Huang, Rozelle, & Uchida, 2006; Feng, Yang, & Zhang, 2005), land policy effects and reform (Ding, 2003; Lichtenberg & Ding, 2008), and urban development (Ho & Lin, 2004; Kuang et al., 2016; X. L. Xu & Min, 2013). The results of such studies, identifying land use changes and their driving forces, have been invaluable to land management. In addition, measuring ecosystem services by changes in land use have provided a basis for evaluating the environmental costs and benefits of various decisions regarding land planning (Abulizi et al., 2017; Wood et al., 2015). Several studies have discussed the current knowledge on the effects of land use change on ecosystem services. These include studies on Spanish drylands with respect to the relationship between human activities and ecosystem services (Quintas-Soriano, Castro, Castro, & Garcia-Llorente, 2016); degraded Mediterranean rangelands, considering grazing regulations and reforestation (Papanastasis et al., 2015); African Savanna woodlands (Kalema, Witkowski, Erasmus, & Mwavu, 2015); and a case study in the Czech Republic on ecosystem sustainability (Frelichova & Fanta, 2015). Various studies have been carried out in China, such as in a mining ecosystem, regarding the local economy in response to land use (J. J. Zhang, Fu, Zeng, Geng, & Hassani, 2013); in a coastal region, regarding ecological land management (Chuai et al., 2016); and in an oasis region (Abulizi et al., 2017). In addition, Xie, Zhang, Zhang, Xiao, and Lu (2015) have measured the ecosystem service values of different land use types at the national scale in China. These authors reported that the effects of land use changes on ecosystem services and the resulting ecosystem degradation could vary from one region to another and could differ between regional and national scales. However, no study has been conducted on land ecosystem degradation in China focusing on the trends in national land use changes and the relationship with human activity and regional policies. Moreover, no study has analyzed synthetically the effects of land policies, urban expansion, and large land projects on land ecosystem degradation, employing reliable and up-to-date data from nationwide land surveys in China. The land survey contains the details of reliable data on various land use types (the areas, the land ownership, and the locations) in each county in each year (Y. Liu, 2000; K. W. Ma, 2000). This is a remarkably comprehensive survey, as a statutory survey in China (Lin & Ho, 2003; Y. L. Liu et al., 2015).

On the other hand, land use type (including vegetation, physical environment, climate, and both natural and human disturbance characteristics) is the smallest spatial unit of land ecosystems (Bailey, 2004; Cleland et al., 1997; Zonneveld, 1989). In view of the ecological goods and services of the ecosystem, the term 'ecologically sound land (ESL) use type,' that is, functioning ecologically, depicts a meaningful geographical spatial unit of land. Such land unit provides ecological goods and services at various scales and maintains the crucial ecological processes within the ecosystems (Bailey, 1987; Hills, 1960; Omernik, 1995; Wiken & Ironside, 1977).

In view of the above, the objectives of our study are as follows: (a) to investigate the trends in ESL use changes and the relationship with human activity and regional policies and (b) to detect land ecosystem degradation oriented to changes in ESL use in China, based on data derived from the national land surveys. An improved understanding and measuring of land ecosystem degradation and changes in ESL use as a result of human activity are crucial factors in the optimization of land spatial patterns and ecosystem management in China.

2 | MATERIALS AND METHODS

2.1 | ESL use category

Land use status classification scheme (covering 12 categories and 60 subcategories of usage; Ministry of Land and Resources (MLR), 2007) as a statutory standard produced by the MLR is widely used in China and play an important role in land management; however, it focuses on the production functions of land use type but lacks consideration of ecological functions (Long, Liu, Li, Wang, & Liu, 2015; Wang, 2015). In our study, a multiscale classification scheme of ESL use was developed for ecosystem management by incorporating ecological function zoning produced by the former State Bureau of Environment Protection, the Chinese Academy of Sciences, and the land use status classification scheme. The studied scheme included six levels (eco-zone, eco-region, eco-district, eco-space, ecosystem, and ESL use type). In the scheme, 26 subcategories of land use types with ecological functions as ESL use types were categorized into two kinds of eco-space (natural ecosystem and farmland ecosystem), six types of ecosystem (wetland, desert, forest, grassland, water, and farmland ecosystems), and a series of ESL use types according to their dominant ecological functions and human disturbance characteristics (Table 1). Natural ecosystem, which provides ecological goods and services, included wetland, desert, forest, grassland, and aquatic ecosystems, encompassing forest, shrub, swampland, shoaly land, lakes, rivers, natural grassland, other grassland, glaciers and snow, bare land, sandy land, and saline land (Table 1). Farmland ecosystem, which was defined as that used for producing cultivated goods and fiber and to some extent also providing ecological goods and services, includes paddy fields, dry land, irrigated land, man-made grassland, and garden land etc. In this context, farmland ecosystem was functioned ecologically, economically, and socially.

The focus of this study was on typical ESL use types, including river, lake, swampland, shoaly land, forest, and natural grassland. In addition, we focused on paddy fields as an important multifunctional type of ESL use in China.

2.2 | ESL use change analysis

The data on ESL use in China were obtained from the detailed nationwide land surveys, with the data for 1996 being derived from the first land use survey, which covered approximately 3,000 Counties (China State Land Administration Bureau, 1996; Y. Liu, 2000; Wang et al., 2012). The data for 2009 were collected from the second land survey, conducted by the MLR, and the data on land use for each year between 1997 and 2008 and between 2010 and 2015 were obtained from the annual surveys on nationwide land use change, conducted by the MLR. The Chinese land surveys and land use change surveys employed high-resolution remote sensing images (e.g., <1-m spatial resolution sensing images in the eastern regions, or <5 m in the western regions), aided by the field surveys (Y. L. Liu et al., 2015;

TABLE 1 Multiscale classification scheme of ecologically sound land use

Eco-zone[a]	Eco-region[a]	Eco-district[a]	Eco-space	Ecosystem	Ecologically sound land use types
1:1,000,000–1:4,000,000	1:500,000–1:1,000,000	1:250,000–1:500,000	1:100,000–1:250,000	1:50,000–1:100,000	1:10,000 –1:50,000
Eastern humid and semihumid eco-zone; Western arid and semiarid eco-zone; Qinghai Tibet Plateau eco-zone.	Northeast; North China; Central China; Southern China; Inner Mongolia; Northwest; Qinghai Tibet Plateau.	Forty-eight eco-districts[a]	Natural ecosystem	Wetland ecosystem	Swampland, Shoaly land, etc.
				Water ecosystem	River Lake Glacier and snow
				Forest ecosystem	Forest Shrub Other forest land
				Grass ecosystem	Natural grassland Other grassland
				Desert ecosystem	Bare land, Sandy land Saline land
			Farmland ecosystem	Farmland ecosystem	Paddy fields Dry land Irrigated land Man-made grassland Garden land Other farmland

[a]Cited from ecological function zoning produced by the former State Bureau of Environment Protection and the Chinese Academy of Sciences.

Wang et al., 2012). In the eastern regions of the country, the scale of the vector files of the land survey databases is 1:10,000 scale, whereas that of the western regions is 1:50,000 scale (Y. Liu, 2000; Y. L. Liu et al., 2015). The data on social and economic information from 1996 to 2015 were sourced from the New China's 50 Years 1949–1999 report and the China Statistics Yearbook (China State Statistical Bureau, 2000; China State Statistical Bureau, 2000–2016).

An analysis was carried out on the ESL use types in the land area of 31 Provinces (autonomous regions, municipalities) of China. The distribution of the various ecosystems in the land area of China's 31 Provinces (autonomous regions, municipalities) in 2009 is shown in Figure 1. A change in an ESL use type was analyzed, and the annual change rate was calculated by using the detail data obtained from the above-mentioned nationwide land surveys and annual change surveys at national, provincial, and county scales. The annual change rate for ESL use type, the conversion of one particular ESL use type *i* to another type *j* (decreasing), and the conversion of type *i* from type *j* (increasing) were calculated followed by Wang and colleagues (2012).

2.3 | Ecosystem service provision index analysis

Wang (2015) attempted an *ecosystem service provision index* (ESPI) by quantifying the various types of ecosystem services in China, using a synthetic index. The dominant types of ecosystem services in the different eco-regions in China, and the assessment factors related to the effects on the ecosystem service capacities, were chosen based primarily on an analysis of the literature and case-studies (Wang, 2015). ESPI was determined based on the distribution of natural geographical conditions and ESL use categories, in combination with the ecological goods and services provided by the ecosystems. The ESPI per unit area was calculated by Wang (2015) by synthesizing three categories and 13 subcategories of ecosystem services and considering a series of assessment factors, including topographic, climate, ESL use, vegetation and soil, water resource, and socioeconomic factors. Figure 2 shows the distribution of the ESPI per unit area in the land area of China's 31 Provinces (autonomous regions, municipalities).

In this study, the ESPI per unit area for each ESL use category in each county was also calculated and analyzed, based on the spatial distribution of ESL use in 2009 and the distribution of ESPI. The degradation of the land ecosystem was analyzed based on decreased ESPI, oriented to changes in typical ESL use types. The spatial distribution characteristics of ESPI per unit area and population density were also analyzed by employing ArcGIS10.3 (Esri, USA) software.

2.4 | Land ecosystem degradation analysis

An analysis of land ecosystem degradation was carried out based on decreased ESPI per unit area oriented to changes in typical ESL use types. In this study, the change in ESPI per unit area in county *j* was calculated as

$$CESPI_j = \frac{\sum_{i=1}^{m} ESPI_i \times LA(i, t2)}{LA_T} - \frac{\sum_{i=1}^{m} ESPI_i \times LA(i, t1)}{LA_T} \quad (1)$$

where $CESPI_j$ is the change in ESPI per unit area in county *j* resulting from changes in ESL use types during a period t_1–t_2, $ESPI_i$ represents ESPI per unit area of an ESL use type *i*, *m* represents the total number of ESL use types in county *j*, $LA(i, t_1)$ represents the area of ESL use type *i* at t_1 (the start of the period), $LA(i, t_2)$ represents the area type *i* at t_2 (the end of the period), and LA_T represents the total land area in county *j*. A positive CESPI indicates improvement in the ecological provision capacity, whereas a negative indicates the degradation of the ecological provision capacity. The CESPI value in a region appears to be more meaningful, in contrast with merely considering a single type of ecosystem service or ESL use type. All our calculations and the spatial analyses were carried out by employing ArcGIS10.3 (Esri, USA) software.

On the other hand, the land ecosystem degradation was analyzed based on the conversion of ESL use types to given land use types. The

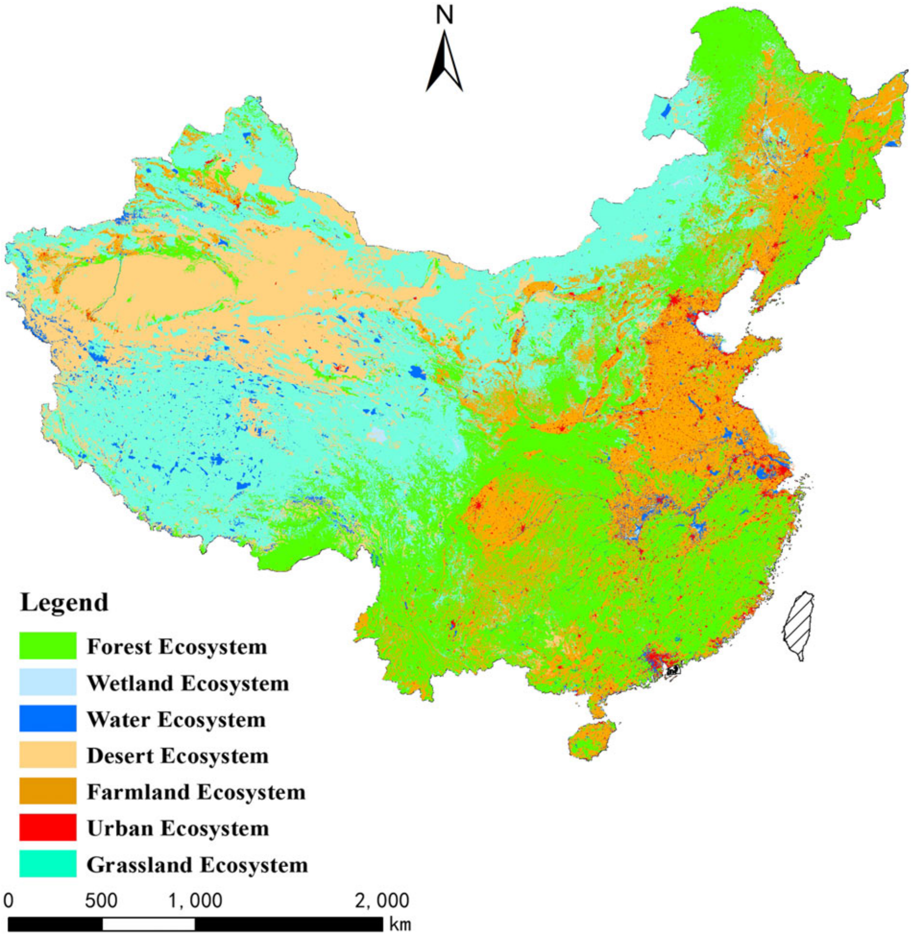

FIGURE 1 Distribution of different ecosystems in the studied land area of China's 31 Provinces (autonomous regions, municipalities) in 2009 [Colour figure can be viewed at wileyonlinelibrary.com]

degradation of the grassland ecosystem was analyzed by the conversion of natural grassland to wild grassland and barren land (abandonment) and the conversion of grassland to saline–alkaline land (salinization) and sandy land (sandy desertification). The farmland ecosystem degradation was analyzed by the conversion of farmland to wild grassland and barren land (abandonment), saline–alkaline land (salinization), and sandy land (sandy desertification).

2.5 | Hot spot analysis

In this study, analysis was conducted to identify statistically significant spatial clusters of high values (hot spots) and low values (cold spots) of ESL use distribution. The analysis was carried out in ArcGIS 10.3 (Esri, USA) software, using the Hot Spot Analysis tool to calculate the Getis-Ord Gi* statistic. Given a set of weighted features, statistically significant hot spots and cold spots were identified. A new output feature class was created, with a *z*-score, *p* value, and confidence level (Gi_Bin) of the areas of each ESL use type in each county in China as the input features. The result of *z*-scores and *p* values indicated the distribution of ESL use, with either high or low values clustered spatially. Statistically significant hot spots were identified based on having high value and being surrounded by other features with high values.

3 | RESULTS AND DISCUSSION

3.1 | Distribution characteristics of ESL use

Table 2 lists the areas and percentages of ecosystems and typical ESL use types in China for 1996, 2008, 2009, and 2015. In general, the percentages of each ecosystem varied with time, with wetland, water, forest, grassland, desert, and farmland ecosystems accounting for 1.2%, 3.5%, 26.7%, 30.0%, 17.3%, and 16.9% of the total area surveyed in 2015, respectively.

As shown in Figures 1 and 3, the forest ecosystems were distributed mainly in the Fujian, Jiangxi, Hunan, and Heilongjiang Provinces, as well as the southwest regions. The grassland ecosystems were concentrated in the Tibet Autonomous Region, Qinghai Province, and the Inner Mongolia Autonomous Region. Farmland ecosystems were distributed mainly across the eastern regions, concentrated in the Middle–Lower Yangtze Plain, and the northeast region. Most grassland and desert ecosystems were distributed in sparsely populated regions with the population density being less than 50 persons and the economic density being less than 300 RMB yuan (approximately US$ 44) in terms of gross domestic product per km^2. However, the farmland ecosystems were concentrated in the more densely populated parts and the high economic production regions of the country (i.e., in the east; Table 3). We observed considerable geographical variation in

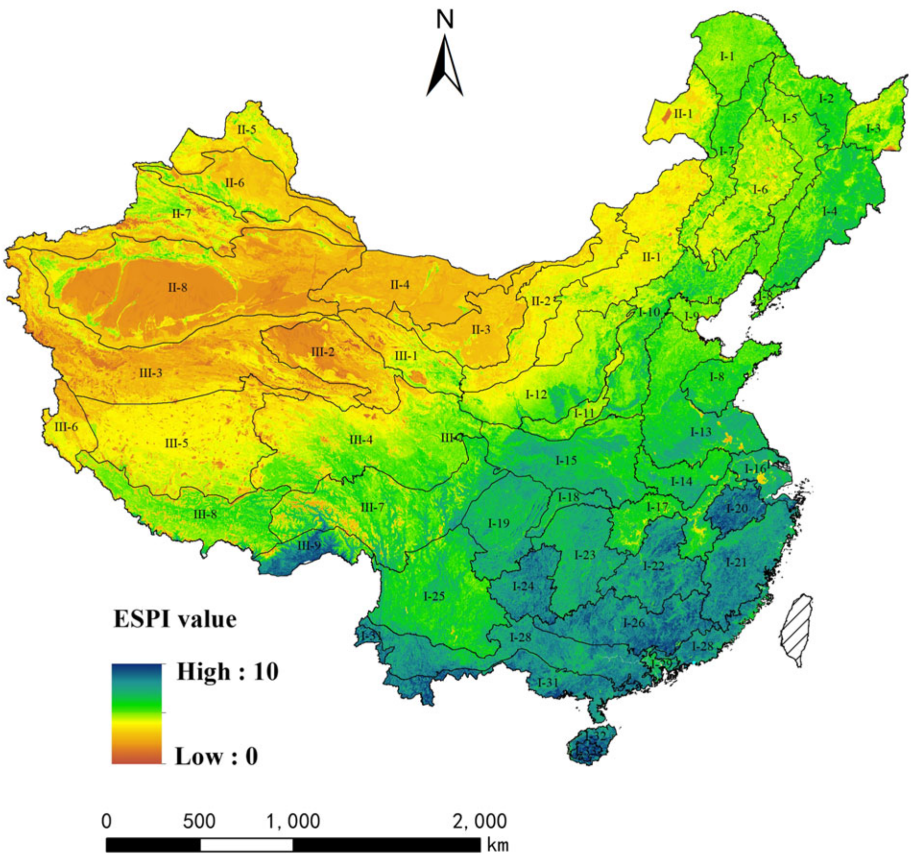

FIGURE 2 Distribution of the ecosystem service provision index (ESPI) per unit area in the studied land area of China's 31 Provinces (autonomous regions, municipalities) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Area and percentage of ecosystems and typical ecologically sound land use types in China

Ecosystem	ESL Use type	1996 Area×10^2 km^2	1996 Percent[a]%	2008 Area×10^2 km^2	2008 Percent[a]%	2009 Area×10^2 km^2	2009 Percent[a]%	2015 Area×10^2 km^2	2015 Percent[a]%
Wetland	Total	1,320.8	1.4	1,277.6	1.3	1,188.1	1.3	1,167.9	1.2
Ecosystem	Shoaly land	890.5	0.7	856.5	0.7	816.0	0.9	797.6	0.8
	Swampland	430.3	0.5	421.1	0.4	372.1	0.4	370.3	0.4
Water	Total	3,255.6	3.4	3,313.6	3.5	3,376.4	3.6	3,351.6	3.5
Ecosystem	River	756.9	0.8	761.8	0.8	801.7	0.9	797.3	0.8
	Lake	723.4	0.8	722.5	0.8	765.9	0.8	764.6	0.8
	Glacier snow	597.5	0.6	598.6	0.6	552.8	0.6	552.7	0.6
Forest	Total	22,760.9	23.9	23,609.2	24.8	25,395.0	26.8	25,299.2	26.7
Ecosystem	Forest	16,044.5	16.9	16,232.0	17.1	18,773.1	19.8	18,711.4	19.7
Grassland	Total	31,199.8	32.8	30,621.6	32.2	28,544.4	30.1	28,457.8	30.0
Ecosystem	Natural grassland	26,274.0	27.6	25,730.6	27.1	21,785.1	23.0	21,759.7	23.0
Desert Ecosystem		17,905.3	18.8	17,823.1	18.7	16,435.3	17.3	16,397.0	17.3
Farmland	Total	15,598.9	16.4	15,006.6	15.8	16,096.7	17.0	16,012.0	16.9
Ecosystem	Paddy fields	3,294.6	3.5	3,162.1	3.3	3,299.2	3.5	3,327.9	3.5

Note. ESL = ecologically sound land.

[a]The area to total area of surveyed land.

the distribution of ESL use, reflecting differences in natural environments, population density, and economic growth.

The spatial distribution of ESPI indicated that the distribution of regions with high ESPI per unit area was in the southern and eastern regions (Figure 2), where abundant hydrothermal resources were consistent with those of the densely populated parts. Moreover, the ecological provision capacity was found to be strongest in the southern regions of China and the Qinghai–Tibet Plateau. Of the group of ecosystems we observed, the ecosystem comprising high proportions of forest generated the highest ESPI value. The high ESPI values were

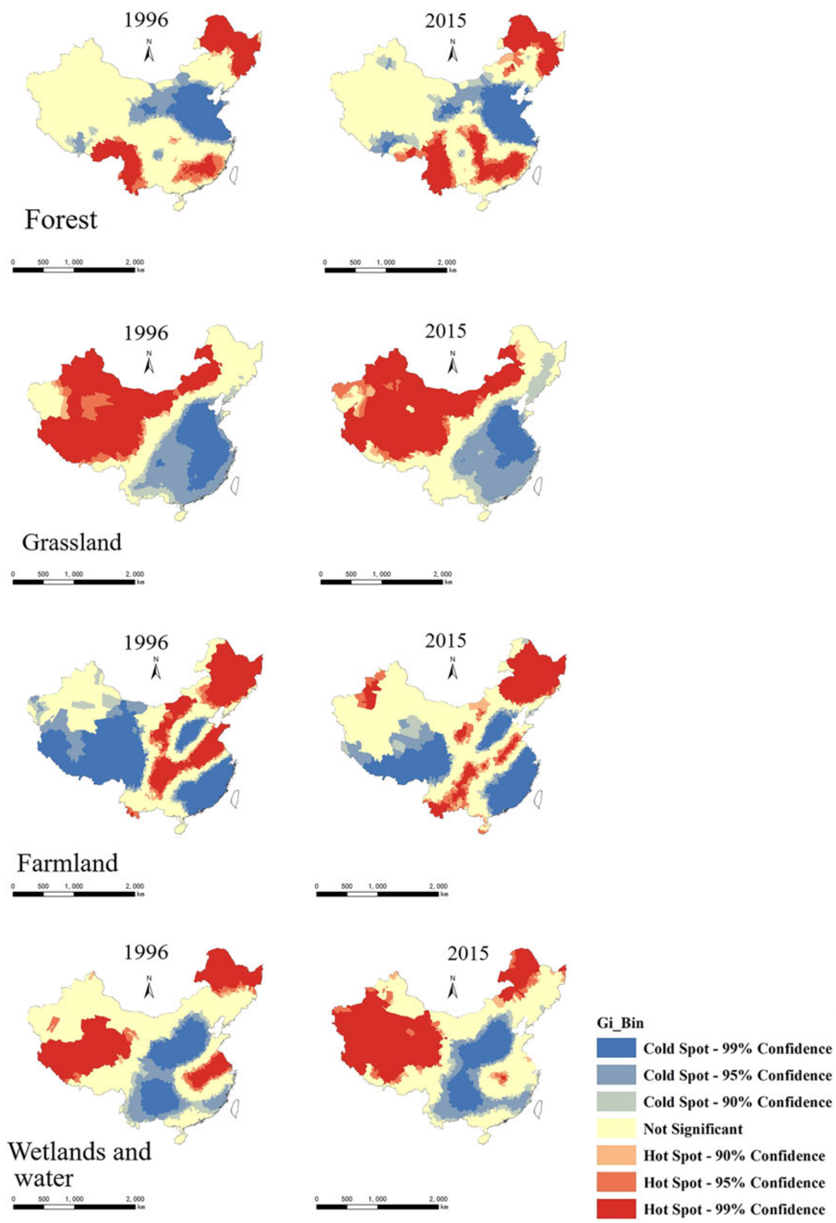

FIGURE 3 Distribution of hot and cold spots of forest, grassland, farmland, and wetland and water ecosystems in the studied land area of China's 31 Provinces (autonomous regions, municipalities) for the period 1996–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Percentage of ecosystems in different classes of gross domestic product per capita and population density in 2015 in China

	Forest ecosystem percent	Wetland ecosystem percent	Water ecosystem percent	Desert ecosystem percent	Farmland ecosystem percent	Urban developed land percent	Grassland ecosystem percent
Economic density (RMB yuan/km^2)							
0–300	2.54	0.80	0.65	61.00	3.04	0.24	31.72
301–500	34.49	0.90	2.39	8.17	19.68	0.36	34.02
501–2,000	8.40	0.87	3.01	0.58	78.12	5.00	4.01
2,001–6,000	8.02	0.86	3.14	0.48	70.72	14.97	1.80
6,001–10,000	4.63	0.65	3.31	0.45	52.81	35.72	2.44
≥10,000	6.50	0.50	3.51	0.52	26.44	61.27	1.25
Population density (person/km^2)							
0–50	27.65	1.05	2.39	20.82	7.53	0.23	40.33
51–100	49.96	0.37	1.53	1.44	33.19	0.82	12.68
101–500	29.40	0.38	1.63	0.75	61.56	1.84	4.44
501–1,000	8.53	0.35	1.23	0.17	83.27	5.42	1.03
≥1,000	6.25	0.44	1.86	0.22	48.24	41.87	1.13

attributed to the benefits of forest ecosystems, in particular timber provision, recreation, erosion control, and climate regulation (Chuai et al., 2016; Frelichova & Fanta, 2015; Papanastasis et al., 2015; Xie et al., 2015). In addition, the Qinghai–Tibet Plateau is the source of three major river systems. On the other hand, regions with relatively high ESPI were also distributed in intensively distributed paddy field regions, such as the Yangtze River Basin and the Chengdu Plain. The ESPI of farmland in these regions was more than that of grassland in the northern and western regions. Xie et al. (2015) and Chuai et al. (2016) presented similar conclusions, indicating that the ecological regulation role of farmland could be important in urban agglomeration regions in China. However, considerable geographic imbalance was found between population density and the supply of ecosystem services.

3.2 | Change in ESL use and effects of land policies

In this study, the changes in ESL use was divided into five periods (viz., 1996–2000, 2000–2005, 2005–2008, 2009–2012, and 2012–2015) in order to account for differences between the first and the second nationwide land surveys (1996 and 2009, respectively). The annual change rate of typical ESL use types in China for the different periods from 1996 to 2015 is shown in Figure 4, indicating an unequal distribution of ESL use in the country. Between 1996 and 2015, the cumulative decreases in both farmland and grassland ecosystems (0.79% and 0.71%, respectively) were significant, and smaller decreases occurred in the desert and wetland ecosystems (0.13% and 0.07%, respectively). In contrast, forest and water ecosystems increased between 1996 and 2008, but decreased slightly from 2009 to 2015 (Table 2).

In China, changes in ESL use are linked closely to shifts in government policies and human activity and socioeconomic development. The overdevelopment of real estate and overheated economic zones during 1996–2005 have led to the large-scale and widespread development on previous farmland, grassland, forest, and wetland ecosystems. In particular, a decline was indicated in paddy fields and shoaly land in the eastern coastal regions that amounted to 92.39×10^2 and 28.4×10^2 km^2, respectively, during 2000–2005. Moreover, the area of natural grassland decreased by 245.49×10^2 km^2 from 2000 to 2005, mostly in the central and western areas that had become the foci of urban development and transportation.

To prevent the sharp decrease in ESL use resulting in severe problems with respect to ecological security, several land policies and institutions and major projects for ESL use were implemented. These include the *Land Management Law* (revised edition), *Requisition-Compensation Equilibrium of Farmland*, and the *Grain for Green* program. The *Grain for Green* program resulted in the ecological restoration of forested area, particularly in the central and western regions. The area of forest ecosystems has been increasing during 1996–2008, with the most intensive afforestation taking place during 2000–2005 (Figures 4 and 5).

With the improved ecological provision capacity of these forest ecosystems, the eco-environment was significantly made better in the northwest regions. This is in stark contrast with the decreases in ESL use seen across the rest of the country. The importance of ESL use functions has gradually gained public prominence, and investment in major natural ecosystem protection projects and comprehensive land improvement has continued (Wang, 2015). For example, to protect and restore natural grassland ecosystem, a series of policies was implemented to ban or restrict grazing and encourage pasture rotation (Yan, Hu, Liu, & Yu, 2011). Such activities related to ecological conservation and construction increased after 2003, significantly slowing down the decreasing trend in natural grassland (Figure 4). Furthermore, a significant expansion in the grassland ecosystem occurred in the eastern fringe and the middle of hot spots (Figure 3). The concentrated distributed grassland was also spreading eastward from 1996 to 2015, where these compositing interaction regions of fragile ecological system and disturbance from human activity were concentrated.

The most significant expansion in farmland was distributed in the Middle–Lower Yangtze Plain and Sichuan Basin, where human activity was concentrated (Figure 3). The concentrated distributed farmland shrunk significantly in urban agglomeration regions, such as the Yangtze River Delta, Chengdu–Chongqing, Wuhan, and the Central Plains regions from 1996 to 2015. Moreover, a reduction in the Loess Plateau and part of the Inner Mongolia Autonomous Region was probably traceable in part to the success of ecological restoration by converting large-scale sloping farmland to grassland. However, a significant increase was observed in paddy fields from 2012 to 2015 (Figure 4). This could be explained by the newly increased areas of

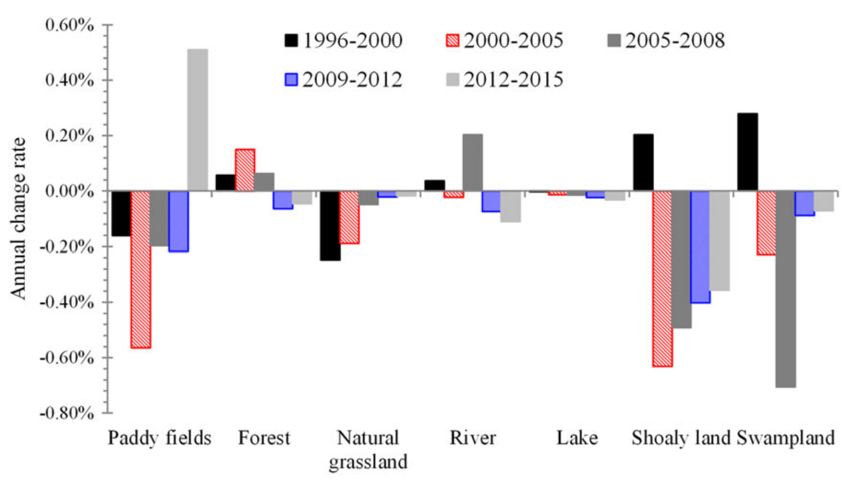

FIGURE 4 Annual change rate of typical ecologically sound land use types in China for the period 1996–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

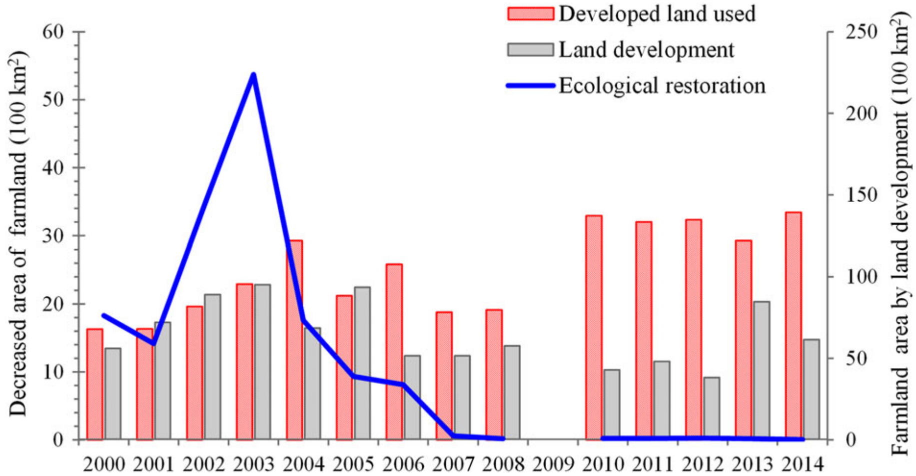

FIGURE 5 Annual change area of farmland by developed land use, land development, and ecological restoration in China for the period 2000–2014 [Colour figure can be viewed at wileyonlinelibrary.com]

paddy fields (74.69×10^2 km^2) in 2013 after the implementation of measures of the *Requisition-Compensation Equilibrium of Farmland* and the controlling index of annual land use plan. Relevant to this increase, the redevelopment of dry land and grassland ecosystems amounted to 68.61×10^2 and 1.35×10^2 km^2, respectively. This increase focused on the Heilongjiang Province (68.42×10^2 and 1.01×10^2 km^2, respectively) where producing grain has been concentrated gradually.

Wetland and water ecosystems play an irreplaceable role in global ecosystems. Our results showed that swampland decreased from 2000 to 2015, with the most significant decrease occurring in the eastern region, a focus for farmland development in China. The *Grain for Green* action was invalid for preventing the decreasing trend of wetland ecosystems in the eastern regions after 2000, reflecting the fact that most restored farmland had been converted into artificial fish ponds. On the other hand, in some areas, greater areas of shoaly land and swampland have been redeveloped as farmland under the *Requisition-Compensation Equilibrium of Farmland*. In the Zhejiang Province, the shoaly land was redeveloped to farmland (amounting to 0.47×10^2 km^2) and developed to urban land (amounting to 0.40×10^2 km^2) for the period of 2012–2015.

In summary, the evolution of policies has been the major driving force behind ESL use changes. The changes reflect the shifts in land policies and the different phases of socioeconomic development (Frelichova & Fanta, 2015). Drawing upon the available literature, land policies have dominated the influences in the changes in ESL use and are closely linked to such changes (Papanastasis et al., 2015; Q. F. Zhang, Oya, & Ye, 2015). Capitalization of land resources has been a crucial driver of economic development in the urbanization process in China. In view of the increasing pressure of the rapidly growing consumption of land, land policy and decision makers could mitigate or aggravate the dilemma of farmland protection, ecological conservation, and urban development. Moreover, this, in turn, could have social, economic, and environmental consequences (Carreño, Frank, & Viglizzo, 2012). Comprehensive consideration of these consequences from a regional and national perspective and balancing the interests between central and local governments in view of current administrative setups and financial systems could be crucial for policy making.

3.3 | Change in ESL use and effects of urban expansion and land development

The changes in ESL use and urban expansion in urban agglomeration regions over various time periods are shown in Figure 6. In China, rapid urbanization and industrialization caused a significant decrease in the natural and farmland ecosystems for developed land use. Since 2010, in addition to the Pearl River Delta and the Yangtze River Delta urban agglomerations, a strategic shift of the economic center has taken place to multiple urban agglomerations, that is, from the above two urban agglomerations to the Beijing–Tianjin–Hebei and the Central Plains regions and others. The trend of the annual increases in urban developed land and transportation land was found significantly consistent with that of decreases in the natural ecosystem and farmland ecosystem in terms of the annual change areas during the five periods, as well as the annual increase in the regional gross domestic product (Figure 6). This fitted the demands of regional economic development. Particularly since 2010, the rapid regional growth has been at the expense of consumer natural ecosystems. As shown in Figure 3, the most notable decreases in wetland and water ecosystems occurred in the eastern coastal regions and urban agglomeration regions. In total, farmland for urban development use accounted for 349.54×10^2 km^2 (or 25.98% of the total farmland decrease) from 2000 to 2014. The continued acceleration of urbanization has caused a notable decrease in farmland during two periods (2003–2006 and 2010–2014; Figure 5). Similar research has shown that urban expansion from human activities over the past years has resulted in a decrease in farmland and other agricultural land in typical regions in China (Kuang et al., 2016; You & Yang, 2017). The conversion of ESL use to developed land use produces significant economic benefits. Capital accumulation supported by land resources has continued to play a significant role in the Chinese urbanization process, particularly the more recent conversion of ESL use through capitalization (Wang, 2015; Wang et al., 2012). The conversion of ESL use for developed land use resulted in an expansion of urban impervious surfaces and the loss of irreplaceable ecological goods and services, including vegetation and biological production functions. This, in turn, caused various environmental issues. The economic growth mode overly depended on

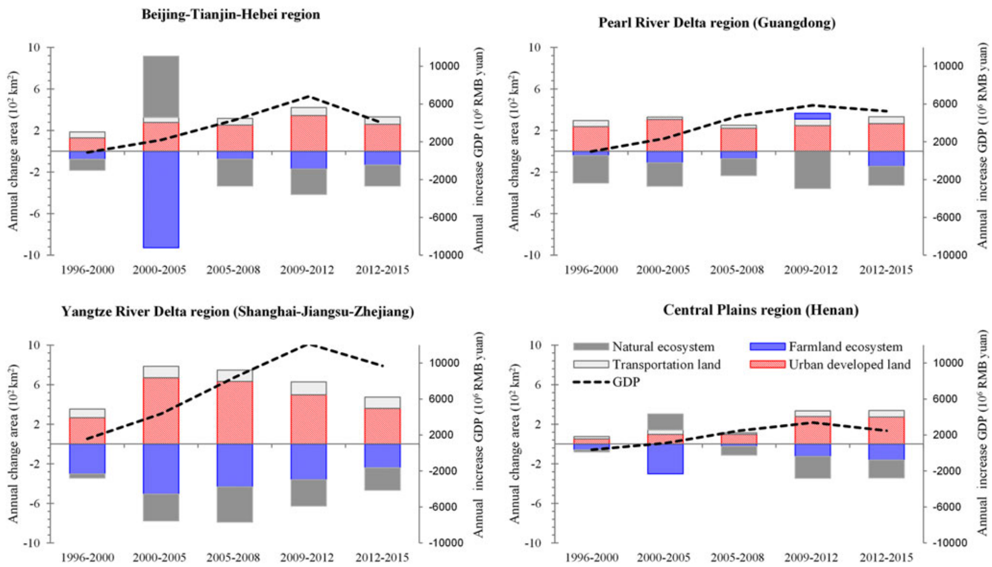

FIGURE 6 Annual changes in natural ecosystem, farmland ecosystem, urban developed land, transportation, and gross domestic product (GDP) in the four urban agglomerations in China for the period 1996–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

the consumption of ESL use, as well as land finance, which were unstable and unsustainable.

However, the implementation of large-scale ecological restoration projects remains the main source of the decrease in farmland. The effects of the decrease in farmland on the national grain yield have been limited (Figure 7), mainly because most of the farmland converted for ecological restoration was of inferior quality. This result was consistent with the results of other studies, which have shown reductions in grain yield attributed to ecological restoration of only 2% to 3% (Feng, Yang, et al., 2005; Z. Xu, Xu, & Deng, 2006). Our results showed that there was a need to optimize regional spatial patterns and functions of different types of ESL use in China, particularly given the rapid socioeconomic growth predicted for the coming years.

On the other hand, as shown in Figure 5, large-scale land development projects for agricultural use from the natural ecosystem occurred during 2000–2005. The total area of land development for agricultural use was 237.1 × 10^2 km^2 during the period 1999–2014, among which a major part of land development for agricultural use was from grassland and forest ecosystem related to large-scale land development projects. A significant decrease in shoaly land, particularly associated with the redevelopment and reclamation of land for agricultural use, industrial use, and urban development, accounted for 83.9 × 10^2 km^2 from 1996 to 2015 (Table 4), focused mainly in the eastern coastal areas and western inland tidal flat areas. In addition, the area of desert ecosystem (e.g., sandy land, barren land, and saline–alkali land) redeveloped for agricultural land use accounted for 74.36 × 10^2 km^2. The large-scale land development ran parallel with the overdevelopment of real estate and overheated economic zones, together with the rapid economic development and population growth in China. This result was consistent with the results of several studies indicating that the agricultural use of the natural ecosystem was increasing in most countries because of the population growth (Papanastasis et al., 2015; Zandi, Erfanzadeh, & Jafari, 2017). The report by Kashaigili and Majaliwa (2013) indicated that the principal causes of land use change included expanding agricultural activities, characterized by shifting cultivation and population increases. The conversion from natural to farmland ecosystems resulted in changes in the dominant goods and functions provided by the ecosystems within a region. The new

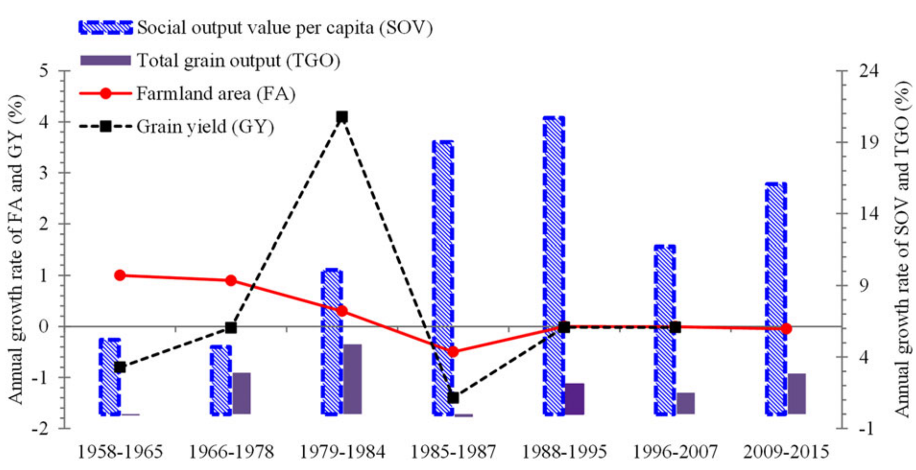

FIGURE 7 Changes in grain yield and farmland ecosystem in China since 1958 [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Conversion of river, lake, shoaly land, and swampland to other types in China (1996–2015)

Types	River area $\times 10^2$ km^2	Lake area $\times 10^2$ km^2	Shoaly land area $\times 10^2$ km^2	Swampland area $\times 10^2$ km^2
→ Dry land, irrigated land, paddy fields	5.85	2.41	42.77	22.30
→ Garden land	0.50	0.02	0.97	0.09
→ Woodland and others	2.16	0.31	4.27	1.92
→ Other grassland	0.16	1.37	2.59	1.02
→ Developed land	6.65	0.67	14.57	1.96
→ Other land	5.75	2.16	18.73	2.96
Total	21.07	6.94	83.90	30.26

cultivated farmland produced economic benefits over the short term; however, the loss of irreplaceable ecological goods and services was neither compensated nor justified (Carreño et al., 2012). In addition, the ecological and environmental effects of large-scale land development from natural ecosystems in China were still in dispute and needed to be reconsidered profoundly. The conversion of land from complex natural systems to simplified agricultural ecosystems is considered a major cause of biodiversity loss (Frelichova & Fanta, 2015). The land development is often accompanied by a decrease in the stocks of organic and microbial carbon and soil organic matter, as well as changes in microbial activity and litter decomposition (Pabst, Gerschlauer, Kiese, & Kuzyakov, 2016; Zandi et al., 2017). Balancing compromises and synergies between providing agricultural or ecological goods or socioeconomic benefits and ecological costs at a regional or macroscale remains challenging but is crucial to strengthen the policy making processes. Furthermore, the marginalized ecological goods and services provided by natural systems have been disputed by many studies (De Groot & Hein, 2007; Perez-Soba et al., 2008).

3.4 | Land ecosystem degradation

Land sandy desertification, salinization, abandonment, and vegetation loss are the main causes and forms of land ecosystem degradation and continuous productivity decline. In this study, we analyzed land ecosystem degradation attributed to the conversion to wild grassland and barren land (abandonment), saline–alkaline land (salinization), and sandy land (sandy desertification). From 1996 to 2015, the areas of farmland, forest, and grassland ecosystems degraded by human activity amounted to 167.24×10^2, 40.08×10^2, and 211.50×10^2 km^2, respectively (Table 5). The degradation of natural grassland ecosystems is a crucial problem in China, particularly in the northwestern region, with the most severe instances occurring during 1999–2002. Subsequently, for the years we examined, the total area of degraded grassland showed a significant downward trend (Figure 8). The degradation was being brought under control, in particular since 2003, following the implementation of the grassland–livestock balance, grazing prohibiting and restriction, pasture rotation, and returning pasture to grassland. Similarly, several studies, such as in eastern Xilin Gol (Yan et al., 2011), reported that the natural grass ecosystem had been extremely degraded in 2000. The principal causes of this degradation included inconsistent contract terms and ownership conflicts between public-owned grasslands and privately owned livestock (i.e., cattle; Fan & Zhang, 2009; M. Ma & Qiao, 2015). The degradation of farmland owing to abandonment (i.e., conversion of irrigated land, dry land, and other planted land to wild grassland and barren land) amounted to 154.22×10^2 km^2 from 1996 to 2015, accounting for 9.05% of the total decrease in the farmland area. The abandonment in terms of area varied with time, being low generally during 1997 to 1998, increasing from 2001 to 2006, and subsequently starting to decrease again (Figure 9). It was noted that policy abuse could contribute to farmland abandonment; for example, in some regions, significant areas of farmland were abandoned and allowed to convert to wild grassland or barren land to avoid the *Requisition-Compensation Equilibrium* policy. This land was subsequently redeveloped without the need to meet the controlling approval of the farmland index of the annual land use plan. Human activity, land marginalization, natural factors, and technological development all contributed to farmland abandonment; however, land marginalization was the dominant cause, reflecting a drastic increase in farming costs and a decline in agricultural labour forces following rapid urbanization (S. F. Li & Li, 2016). The positive and negative ecological and environmental effects of farmland abandonment remain disputed (S. F. Li & Li, 2016); however, the main negative effects are thought

TABLE 5 Degradation of farmland, forest, and grassland ecosystems (owing to conversion to wild grassland, saline–alkaline land, sandy land, barren land, and other types) in China (1996–2015)

	Farmland ecosystem		Forest ecosystem		Grassland ecosystem		Total	
Types	Area$\times 10^2$ km^2	Percent%	Area$\times 10^2$ km^2	Percent%	Area$\times 10^2$ km^2	Percent%	Area$\times 10^2$ km^2	Percent%
→ Wild grassland	138.01	8.10	31.77	8.48	174.67	18.73	344.46	11.44
→ Saline–alkaline land	5.07	0.30	0.65	0.17	20.83	2.23	26.55	0.88
→ Sandy land	7.94	0.47	3.88	1.04	5.66	0.61	17.48	0.58
→ Barren land	16.21	0.95	3.77	1.01	10.34	1.11	30.33	1.01
Subtotal	167.24	9.82	40.08	10.69	211.50	22.68	418.82	13.91
→ Other land use types	1,536.06	90.18	334.75	89.31	720.88	77.32	2,591.68	86.09
Total decreased area	1,703.30		374.83		932.37		3,010.50	

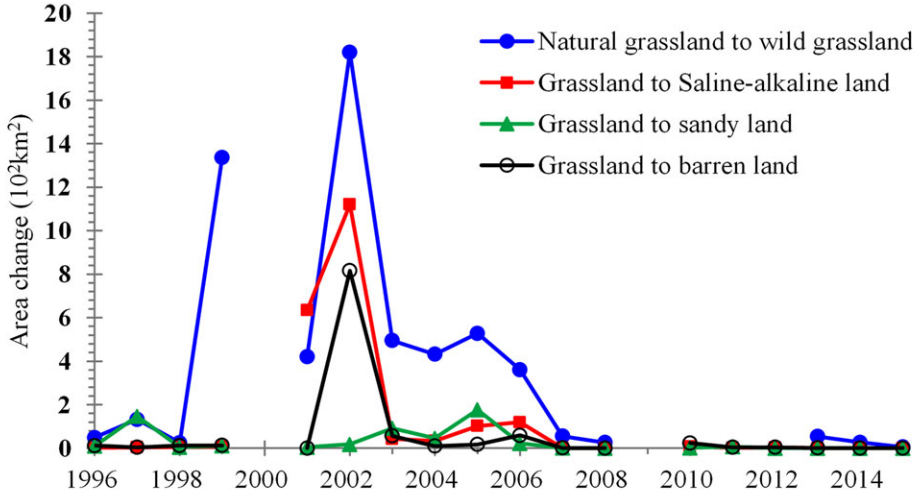

FIGURE 8 Annual change in grassland degradation by abandonment in China for the period 1996–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

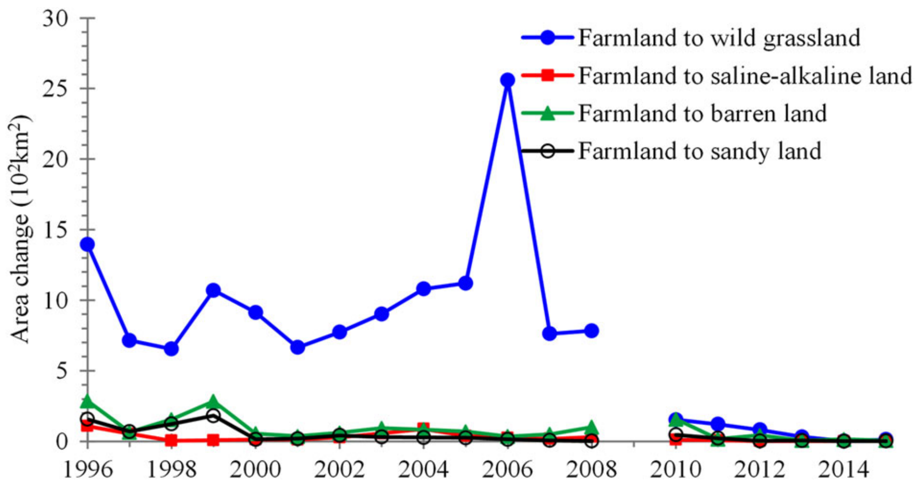

FIGURE 9 Annual change in farmland degradation by abandonment in China for the period 1996–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

to be the degradation of the agricultural landscape, a loss of traditional villages and farming culture, reduced aesthetic value, and a decline in tourist numbers (Benjamin, Bouchard, & Domon, 2007; Brouwer, Van Rheenan, & Dhillion, 2008; European Union, 2004). The functions of the farmland ecosystem have also varied with the socioeconomic conditions (Song, Wu, & Ouyang, 2014). The ecological functions (including atmosphere regulations and soil protection) and other nonproduction functions (including landscape aesthetics and leisure tourism for farmland) have become increasingly important (Peng, Liu, & Liu, 2014; Song et al., 2014).

In this study, we conducted ecosystem degradation analysis, based on decreased CESPI oriented to changes in the typical ESL use types. As shown in Figure 10, the significant degradation, indicating negative CESPI per unit area, was distributed among different regions in the eastern and southwestern regions in China, amounting to 23.69×10^4 km^2 or 9.51% of the total number of Counties, with the decreased CESPI per unit area ranging from −4.99 to −0.6. The concentrated distributed degradation (hot spots of CESPI per unit area) occurred in the Yangtze River Delta, Shandong Peninsula, and Liaodong Peninsula in the eastern coastal regions, where human activity is concentrated. The ecosystem degradation, indicated by decreased CESPI, had close relationships with the local economy. The result was consistent with the finding that the relationship between the ecosystem service and local economy was at an inverse curve under restrained conditions (Chuai et al., 2016; J. J. Zhang et al., 2013). In view of the total CESPI, in addition to the above regions, significant degradation was also concentrated in the Inner Mongolia Plateau and the northern part of Xinjiang, where land development occurred by converting grassland and forest into farmland. The decreasing ESL use, especially forest and natural grassland, resulted in loss of vegetation cover that threatened the ability to continue providing ecosystem services to support the biological circulatory system and the livelihoods of humans. In addition, such degraded areas are vulnerable to the effects of climate change (Kalema et al., 2015). The distribution of decreased CESPI per unit area was related closely with the distribution of the decreased ESL use and the regional economy, especially in the southern regions of China (Figure 10). Xie et al. (2015) have come to similar conclusions, based on land use data derived from

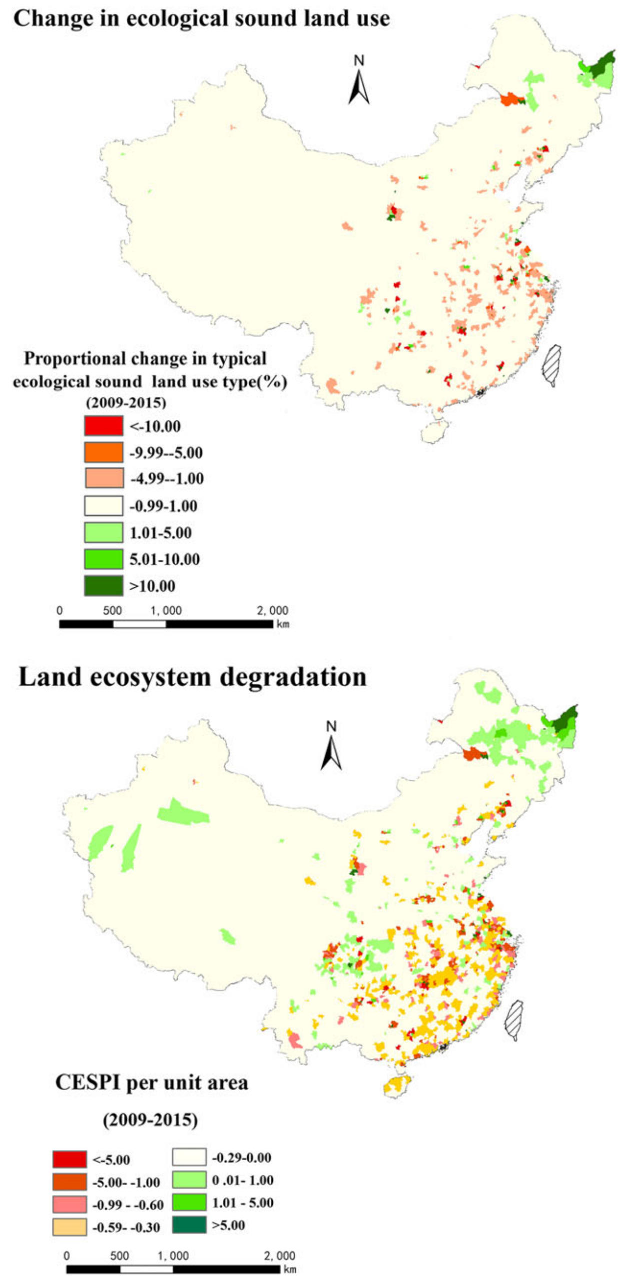

FIGURE 10 Land ecosystem degradation based on decreased change in ecosystem service provision index (CESPI) per unit area and proportional changes in typical ecologically sound land use types in the studied land area of China's 31 Provinces (autonomous regions, municipalities) for the period 2009–2015 [Colour figure can be viewed at wileyonlinelibrary.com]

Thematic Mapper/Enhanced Thematic Mapper (TM/ETM$^+$) remote sensing images at a national scale in China. Similarly, several studies showed that land use had a major influence on the ecosystem service value and, particularly, converting farmland into forests determined the entire ecosystem structure and functions (Abulizi et al., 2017; Chuai et al., 2016; J. J. Zhang et al., 2013). Improvements and restoration of the ecosystem are one of the sustainable development goal targets related to Chinese ecological civilization construction. Vast ecological construction investments have been made continuously in large national projects, including comprehensive land improvement, natural ecosystem conservation, and the *Grain for Green* and similar initiatives. However, significant ecosystem degradation occurred in regions where human activity was concentrated and land was being developed. Similar results have been reported, indicating that restoration and efforts to prevent degradation often failed to deliver the expected benefits (Sietz, Fleskens, & Stringer, 2017). Sietz et al. (2017) discussed the theory and measures for land degradation neutrality, requiring ongoing degradation to be balanced by restoration and sustainable land management. Against the background of Chinese ecological civilization construction, if the process of land improvement and restoration activities were to meet their intended goals, there is an urgent need to strengthen policy making scientifically and to improve the understanding of the close relationship between geographical conditions, ecosystem dynamics, regional economy, and land management. The national and local rapid economic growth in China should build on rational utilization of ESL with an emphasis on land degradation neutrality.

On the other hand, the above analysis of CESPI only represented a relative distribution, enabling rapid interpretation of ecosystem degradation, based on changes in ESL use. We analyzed the available trends in the effects of ESL use on ecosystems service. The analysis of ecosystem degradation was less time consuming and cost effective than were the methods to evaluate absolute degradation, or characterizing absolute provision value of ecosystem services based on extensive field surveys. This is significant for rapid monitoring and analysis of ecosystem degradation. Nevertheless, some issues need to be identified, such as that characterizing ecosystem degradation could be affected by natural conditions, various impacting factors, ecosystem dynamic circulation, and the interaction of different ecosystems, as well as the long-term trends of ESL use. These effects should be identified in detail and interpreted to avoid any inaccuracies in regional ecosystem degradation analysis. This could provide the basis for rational land spatial planning and sustainable ecosystem management.

4 | CONCLUSIONS AND SUGGESTIONS

ESL use provides ecological goods and services at various scales. In this study, a multiscale classification scheme of ESL use was developed based on the ecological function zoning and the land use statue classification scheme. The cumulative decreases in grassland, farmland, desert, and wetland ecosystems varied from 1996 to 2015. In contrast, those for forest and water ecosystems increased from 1996 to 2008 and decreased from 2009 to 2015. From 2000 to 2005, paddy fields and shoaly land significantly decreased in the eastern coastal regions of China. The degradation of farmland, forest, and grassland ecosystems owing to the conversion to wild grassland and barren land (abandonment), saline–alkaline land (salinization), and sandy land (sandy desertification), induced by human activity, amounted to 167.24×10^2, 40.08×10^2, and 211.50×10^2 km^2, respectively, from 1996 to 2015. The abandonment of natural grassland and farmland ecosystems has become a prominent and complex problem in China, compounded by abuses of the *Requisition-Compensation Equilibrium of Farmland* and the *Grain for Green* policies in some areas.

The significant ecosystem degradation, based on decreased CESPI oriented to changes in ESL use, was distributed among different regions in the eastern and southwestern regions in China, especially in the Yangtze River Delta, the southwestern regions, and the Inner Mongolia Plateau, where human activity was concentrated. This amounted to 23.69 × 10^4 km^2 or 9.51% of the total number of Counties, with the decreased CESPI per unit area ranging from −4.99 to −0.6. The effects of ESL use changes on ecosystem services were significant. The land ecosystem degradation from human activity, oriented to ESL use changes, resulted in a decrease in ecological goods and services provided by ecosystems; however, the exact ecological and environmental effects of such changes remain disputed. Furthermore, the different potential impacting factors on land ecosystem degradation should be identified and interpreted in detail to avoid inaccuracies in regional ecosystem degradation analysis.

Rapid economic and social transformation in China is projected to continue, and sustainable ecosystem management will become increasingly important. Under the national strategy of "ecological civilization construction," optimizing regional spatial structures and functions of ESL use and ecosystem services is critical. Balancing compromises and synergies between socioeconomic benefits and ecological costs at a regional or national scale is crucial for land policy decision. To this end, the systems of zoning control for ESL use and regional policies of ecosystem management must be established. Red line delineation of protected ESL use, elastic zoning control (incentive zoning and composite zoning), and rigid zoning control for ESL use should be implemented. A system of strict basic farmland protection should not only improve the supply of agricultural goods but also enhance the provision of ecological goods and services. To realize this, establishing linkage mechanisms between ecosystem services and farmers' income will be necessary. Strictly controlled destruction and development of natural forest and wetland by preservation and management are urgent. For grassland ecosystems, controlling the reclamation and degradation of natural grassland and reducing overgrazing should all be implemented. Finally, long-term ecological investments and compensation mechanisms for sustainable ecosystem restoration and preservation should be ensured.

ACKNOWLEDGEMENTS

The authors acknowledge financial support from the National Natural Science Foundation of China (41330750) and the project of high-level talents import plan in Wuhan University. The authors thank Professors Zhenyuan Zheng, Yanli Gao, Xiaofei Bai, Dingxiang Zhang, and Tao Li for their assistance in data collection.

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How to cite this article: Wang J, Lin Y, Zhai T, et al. The role of human activity in decreasing ecologically sound land use in China. *Land Degrad Dev*. 2018;29:446–460. https://doi.org/10.1002/ldr.2874