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Effects of Land Use Change on Ecosystem Services in Arid Area Ecological Migration

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Abstract: Ecological migration is the process of increasing the population density in the immigration area and transferring the ecological pressure from emigration area to immigration area. This process may result in significant changes in land use and land cover in the area of immigration and have an important effect on ecosystem services. Therefore, scientifically revealing the effects and differentiation mechanisms of ecological migration on ecosystem services is becoming an important issue related to the implementation of the national ecological migration strategy in China. This study employed the Hongsibu District as a typical example of ecological migration. Hongsibu District is located in the central Ningxia steppe and desert steppe areas. Remote sensing data covering five periods from the period before ecological migration in 1995 and after migration in 2000, 2005, 2010, and 2015 was used to measure the value of ecosystem services (ESV). A geographical detector model and the value of ecosystem services model were used to diagnose the dynamic mechanism of the effects of land use change on ecosystem services. The results showed that: 1) The development of large-scale ecological resettlement has caused the area of cultivated land and urbanized land area to increase significantly in the area of immigration, while the grass area decreased significantly. 2) The overall value of the Hongsibu ecosystem services increased in a form of a 'V'. Among them, during the period of 1995–2005, the overall ESV decreased and had an annual rate of change of −0.67%. During the period of development 2005–2015, the ESV increased steadily, with an annual rate of change of 0.79%. 3) The proportion and total ESV in soil formation and protection, waste treatment, and biodiversity conservation of the Hongsibu District decreased from 57.61% in 1995 to 56.17% in 2015, indicating that the region's ecological regulation function slightly decreased. 4) The ESV in the Hongsibu District, showed a low distribution pattern of ecosystem services increasing from northeast to southwest, and the capacity of three townships, Hongsibu, Taiyangshan, and Liuquan, to provide ecosystem services gradually declined over time. The ecological service function of Xinzhuangji Township and Dahe Township gradually improved. 5) The sensitivity index of the ESV of each land use type was less than 1, indicating that the environment lacks flexibility in providing a strong ESV index in Hongsibu, which shows that the research results are reliable and believable. 6) During the study period, the decisive force of the change of land use on ecosystem services in Hongsibu District was: grassland (0.9934), climate regulation (0.9413), soil formation and protection (0.9321) and waste treatment (0.9241).

Keywords: ecological migration; land use change; ecosystem services; geo-detector; arid area; Hongsibu district

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1 Introduction

In 2001, the United Nations Millennium Ecosystem Assessment (2000–2005) warned that 60% of global ecosystem services that are useful to humans are being degraded (Ma, 2005; Xu et al., 2009). By 2004, the American Ecological Society's 21st century action plan identified ecosystem service science as the primary research area within the field of ecology (Palmer et al., 2004). In 2012, the United Nations approved the Intergovernmental Science Policy Platform for Biodiversity and Ecosystem Services under the auspices of the United Nations Environment Programme (Fu and Zhang, 2014). This platform reflects the increasing importance of the international community in addressing problems related to ecosystem services and identifies the frontiers and hotspots of ecology and geography.

Changes in land use and landscape diversification can lead to changes in biogeochemical cycles, hydrological processes and landscape dynamics. Changes in land use and management affect the state, characteristics, and functions of the ecosystem (Ning et al., 2015; Xiao et al., 2016; Zhang et al., 2016). This plays a decisive role in the value of ecosystem services (ESV) provided by those ecosystems. The results provide an important scientific basis for decision-making related to regional environmental protection and sustainable development. In recent years, research on the relationship between land use change and ecosystem services has been relatively abundant, including discussions of land use change and approaches using ecosystem services theory (Daily, 1997; Costanza et al., 1998; Xie et al., 2008; Fu and Zhang, 2014). In addition, research has been conducted on the effects of land use change on ESV based on 3S technology (remote sensing, geographical information, and global positioning system). The 3Ses have been used to analyze models of ecosystem services for cities (Fan and Ding, 2015; Ye et al., 2016; Zhang et al., 2017; Zhou et al., 2017; Zhu et al., 2017), reservoir areas (Yan et al., 2014; Feng et al., 2014), coastal zones (Yu, 2016; Liu et al., 2017), travel corridors (Gao et al., 2016; Patarasuk and Binford, 2012) and watersheds (Wang and Meng, 2017; Korbeľová and Kohnová, 2017; Wang et al., 2017).

Arid and semi-arid areas account for 42% of the total land area worldwide, support about 38% of the world's population, and are mainly distributed in poor, developing countries (Huang et al., 2017). Research has shown that the arid and semi-arid areas will accelerate their expansion in the future, and the combined effects of climate warming, drought intensification, and population growth will increase the risk of desertification in developing countries (Huang et al., 2017); therefore, these regional ecosystems are facing great pressure. In recent years, the scholars have conducted research on sustainable development in arid areas in light of the fragile tension between the environment and the needs of humans. For example, in the arid areas of Northwest China, especially in arid counties (Yang et al., 2014) and areas with oases (Yao et al., 2014), studies on the effects of land use change on ecosystem services have yielded fruitful results. In practice, the central and local governments in China have implemented a series of ecological projects and policies, among which the analysis of ecological migration is one of the important projects that coincides with both the alleviation of poverty and ecologically sustainable development (Liu and Wang, 2013; Liu et al., 2017). Since 2001, the state has carried out large-scale poverty alleviation and relocation to support the poverty-stricken population living in poor living environments and 'one side of the natural resources can not afford one person' area and has relocated more than 6.8 million people. During the '13th Five-Year Plan' period, the country will plans to help poor people to relocate 10 million poor people at ease. Academia has carried out studies related to ecological immigration projects. These studies have analyzed the willingness of people to respond to ecological issues and related factors (Tang et al., 2011), farmers' responses to such issues (Tang et al., 2011), placement models (Wang et al., 2009; 2014; Bai and Zhang, 2015), life transformation (Shi et al., 2015), benefit evaluation (Jia, 2016), sustainable development and strategy for resettlement areas (Jin et al., 2013; Shi et al., 2015; Yang et al., 2015), land use change in urban resettlement areas (Li et al., 2016), ecological compensation (Li et al., 2013), carbon source and sink calculations (Guan et al., 2014), and ecological immigration policies (Lu and Zhao., 2009). The most direct manifestation of the process of ecological migration is the centralized development of land in the relocation areas. Theoretically, ecological migration will have an impact on the ecosystem services in the area of relocation. However, little research has been conducted on the effect of the combination of ecological migration and land-use change on ecosystem services.

Ningxia is a typical and representative area of the early period of ecological migration in China. From 1983 to 2000, Ningxia implemented the 'Diaozhuang immigrants' program, an ex-situ ecological resettlement program from 2001–2007, and an eco-migration in the counties of the central arid zone from 2007–2011, and an eco-migration in central and southern Ningxia since 2011. The ecological migration project has gone through four stages in Ningxia since 1983. The present paper takes Hongsibu, China's largest ecological resettlement and poverty alleviation/development zone, as a typical case study. Using the dynamic degree of land use change, an ESV index, and a sensitivity index, combined with geographical detector model, this study reveals the changes in land use that affect the characteristic mechanisms of ecosystem services. The goal was to provide a theoretical reference and scientific basis for land use and ecological development in ecological resettlement areas and similar areas.

2 Materials and Methods

2.1 Study area

The Hongsibu District, located in the central Ningxia arid zone, lies between 37°28'N–37°37'N, 105°43'E–106°42'E; this mountain basin area is connected to the four corners of Ningxia (Fig. 1). The terrain ranges from high in the south to low in the north, with an average elevation of 1240–1450 m. The typical temperate continental climate has an average annual temperature of 8.4℃, a frost-free period of 155 days, and long days with 3036.4 h of sunshine. The region receives a small, concentrated, and annually highly variable amount of precipitation averaging 277 mm. In 1995, the region became the main location for the National Large Water Conservancy Project: the Ningxia Poverty Alleviation and Irrigation Project ('1236' project). In 1999, the Communist Party of China Hongsibu Development Zone Working Committee was established. In 2009, the Hongsibu District as a part of Wuzhong City. The region mainly includes seven counties (districts), Haiyuan, Jingyuan, Longde, Pengyang, Tongxin, Xiji, and Yuanzhou that were used for the relocation of migrants. In 2015, Hongsibu covered a total area of 2767 km^2, with two towns, three townships, one street, 61 administrative villages, and two urban communities, with a total population of about 189 566. The Hui people accounted for 62.3% of the total population.

2.2 Data acquisition

Digital elevation model data were taken from the International Science Data Service Platform (http://srtm.datamirror.csdb.cn) of the Chinese Academy of Sciences and the Geospatial Data Cloud Platform of the Computer Network Information Center of the Chinese Academy of Sciences. Under the support of Cognition

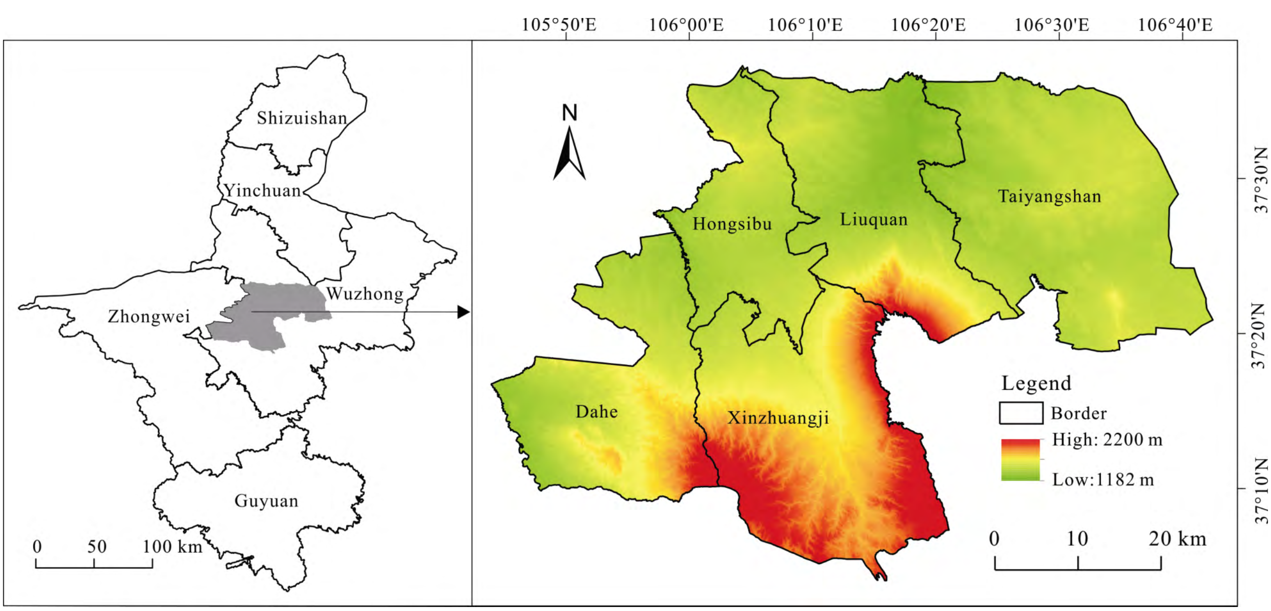

Fig. 1 Geographical location of study area

(Definiens Imaging, GER), the Earth Resources Data Analysis System (ERADAS ver. 9.2, Atlanta, GA, USA), and ArcGIS 10.0 (ESRI, Redlands, CA, USA), we interpreted five sets of Landsat Enhanced Thematic Mapper and Landsat Thematic Mapper remote sensing images over five periods. These included the period before the ecological migration in 1995 and after migration in 2000, 2005, 2010, and 2015. These periods were analyzed through a combined use of such things as administrative and topographic maps for the study area. These maps referred to the soil, vegetation, climate, and other natural geographic information and field investigation data. Five land use datasets were obtained, one each for 1995, 2000, 2005, 2010, and 2015. Furthermore, the land use types of study area were divided into seven categories: cultivated land, woodland, grassland, water area, urbanized land, sandy land, and unused land (Fig. 2). Using ENVI 4.6 software (ITT Visual Information Solutions, Boulder, CO, USA), the accuracy of the remote sensing image classification was verified, and the total accuracy of the five years was more than 0.90. The classification accuracy satisfied the research requirements. In addition, the commissariat production data used in the study were derived from the *Ningxia Statistical Yearbook* (1996–2016).

2.3 Research methods

2.3.1 Spatial extent of land resource area change and rate of change

The change of land use type and the rate of change directly reflect the size and magnitude of changes in land use type (Zhang et al., 2017) and can be calculated using Equations (1) and (2):

$$\Delta U = U_b - U_a \tag{1}$$

$$R = \frac{\Delta U}{U_b} \times 100\% \tag{2}$$

where ΔU and R are the amount and rate of change in a land use type during the study period, respectively; U_a and U_b are the areas of the same land use type at the initial and final stages of the study, respectively.

2.3.2 Dynamic degree of land resources

The dynamic degree of land use quantitatively describes the rate of land use change in the studied region, which aids the comparison of regional differences in land use changes and in predicting future trends in land use (Wang and Bao, 1999). The single dynamic degree of a land use type can indicate the change of the land use type in a certain time period within a certain time period. Equation (3) can be used as follows:

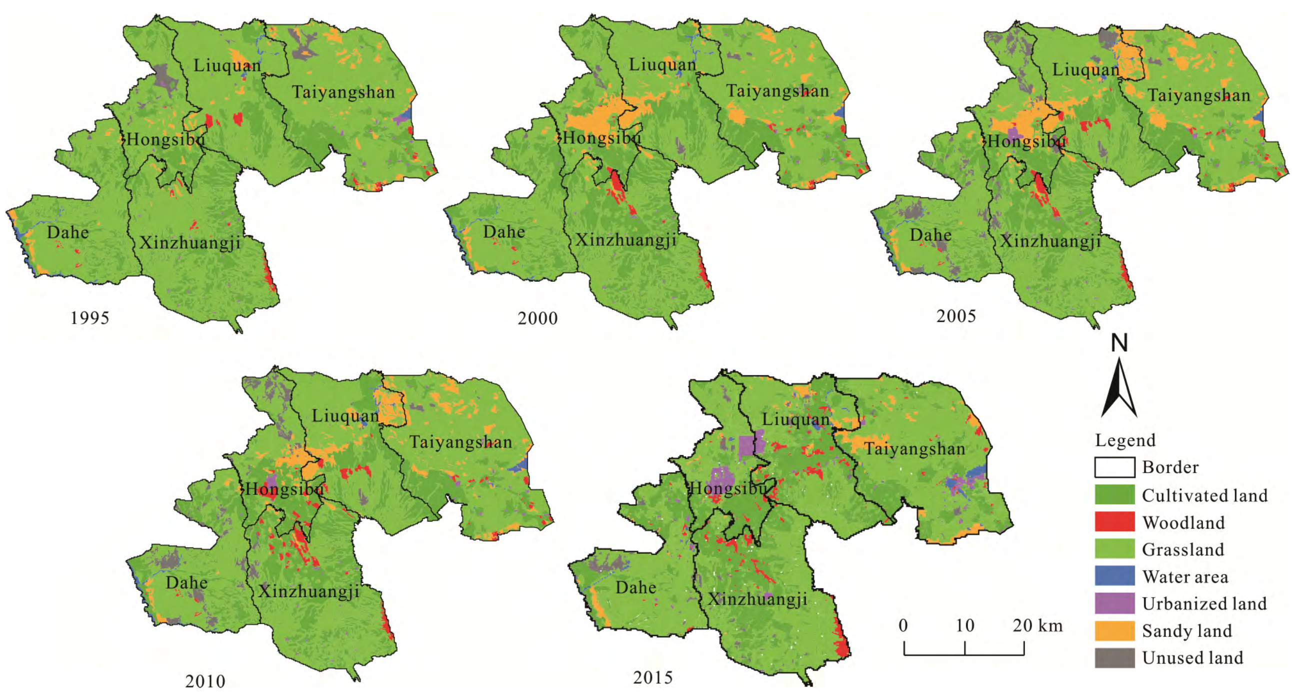

Fig. 2 The classification map of land use types in Hongsibu District from 1995 to 2015

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (3)$$

where K represents the dynamic degree of land use types in the study period; T represents the study period.

2.4 Ecosystem services value index

Based on the calculation principles and methods of Costanza et al. (1998), the ESV in the study area was evaluated by using the ESV equivalent factor table of China's ecosystems estimated by Xie et al. (2008). According to the actual situation of Hongsibu District, with reference to Xie et al. (2008), the China terrestrial ecosystem service equivalent factor table and the economic value equivalent factor of Hongsibu was determined. These were based on 391 yuan for average grain output (1014 kg/ha) and grain price (2.7 yuan/kg) from 1995 to 2015 in the Hongsibu District of Ningxia. Based on the findings of previous research that were (Yang et al., 2014) combined with the specific situation of Hongsibu District, each land use type was linked with the closest ecosystem as follows. Five basic ecosystem types were analyzed: 1) cultivated land corresponded to farmland; 2) woodland corresponded to forest; 3) grassland area corresponded to grassland; 4) water area corresponded to water; and 5) The economic value of sandy land and urbanized land was not calculated based on its ecosystem service function. Then, the value of the ecological service of each ecosystem was calculated (Table 1) using Equations 4 and 5.

$$ESV = \sum \left(A_k \times VC_k \right) \quad (4)$$

$$ESV_f = \sum A_k \times VC_{fk} \quad (5)$$

where ESV is the value of the ecosystem service function (yuan), A_k is the study area of land use type k; VC_k is the value of the ecological service function coefficient (yuan/(ha·yr)); ESV_f is the total value of a service for the f type of ecosystem (yuan); and VC_{fk} is the f land use type of the k type of ecosystem service (yuan/(ha·yr)).

2.5 Sensitivity index

The sensitivity index is defined as the ratio of the percentage change in the dependent and independent variables; this is used to determine the degree of dependence of ESV on VC change over time. If the sensitivity index (CS) >1 (or <1), these show that the value of an ecosystem service varies (or does not vary significantly). The CS was calculated using Equation (6) through adjusting about 50% of the VC, respectively, to explain the degree of sensitivity (Wang et al., 2010; Chen, 2013; Li et al., 2017):

$$CS = \left| \frac{\left(ESV_j - ESV_i \right) / ESV_i}{\left(VC_{jk} - VC_{ik} \right) / VC_{ik}} \right| \quad (6)$$

where CS is the sensitivity index; ESV_i and ESV_j represent the total value of an ecological service before and after adjustment, respectively; VC_{ik} and VC_{jk} represent the value coefficient of an ecological service before and after adjustment, respectively.

2.6 Geographic detectors

Geodetector (www.geodetector.org) is a type of software based on a GIS space superposition technique and uses established theory to identify the interactions between multiple factors (Wang and Xu, 2017; Liu and Li, 2017). It is widely used in the analysis of the evolution of

Table 1 Values of ecosystem services in the Hongsibu District (yuan/(ha·yr))

Ecosystem service	Cultivated land	Woodland	Grassland	Water area	Unused land
Gas regulation	195.50	1368.50	312.80	0.00	0.00
Climatic regulation	347.99	1055.70	351.90	179.86	0.00
Water conservation	234.60	1251.20	312.80	7976.40	11.73
Soil formation and protection	570.86	1524.90	762.45	3.91	7.82
Waste disposal	641.24	512.21	512.21	7116.20	3.91
Biodiversity conservation	277.61	1274.66	426.19	973.59	132.94
Food production	391.00	39.10	117.30	39.10	3.91
Raw material	39.10	1061.60	19.55	3.91	0.00
Entertainment and culture	3.91	500.48	15.64	1696.94	3.91
Total	2701.81	8543.35	2830.84	17989.91	164.22

geographical factors and regional spatial differentiation (Liu and Li, 2017).

Based on the geographical detector method, we introduced the differentiation determinants value q of ecosystem services. An ESV index y is assumed to exist in the study area. The index y is collected in the study area using the lattice system consisting of the sampling unit i (i = 1, 2, 3, ..., n, where n is the total number of sampling units), assuming that $A = \{Ah\}$ is a possible factor that affects the ESV, H = 1, 2, 3, …, L, L is the factor classification number, A_h represents the different types of factors A. A type h corresponds to one or more sub-regions on the space. In order to detect the spatial correlation between factor A and the ESV index y, the ESV index layer and the factor A layer are superimposed. In the first h of the factor A (corresponding to one or more sub-regions), y discrete variance is recorded as σ^2, and factor A on the ESV index y of the decision force size:

$$q = 1 - \frac{1}{n\sigma^2}\sum_{h=1}^{L} n_h \sigma^2 \tag{7}$$

where n_h is the number of samples within the type h of the factor A (corresponding to one or more sub-regions); n is the number of samples in the entire study area H; $n = \sum_{h=1}^{L} n_h$ is the number of samples within the factors for the number of A; and σ^2 is expanded to the entire region of the discrete variance.

When the factors have a decisive effect on the ESV, the discrete variance of each type (corresponding to one or more sub-regions) σ_h^2 will be small, and the discrete variance between the types (corresponding to one or more sub-regions) will be large. When the discrete variance approaches 0, the determinant force of factor A is q = 1, which is the ideal state determined by the factor A of the ecosystem service. When the determinant of factor A is q = 0, the ESV index is randomly distributed, and factor A has no effect on the differentiation of ecosystem services. The greater the decision value, the greater is the effect of a factor on the differentiation of ecosystem services. The dominant factors of ESV differentiation were determined by comparing the determining factors (Liu et al., 2017).

3 Results

3.1 Land use change

Overall, during the study period 1995–2015, cultivated land and grassland experienced the largest increase and decrease, respectively. The largest change in the area was urbanized land (79.78%), followed by forest land (59.66%), and the smallest change in the area was that of sandy land (1.15%) (Figs.3, 4).

Land use change varied significantly in different periods (Fig. 5). Among the five time periods analyzed in the present study, during 1995–2000, cultivated land had the largest increase, grassland had the largest reduction, and unused land had the largest change in area (−154.55%) followed by sandy land (55.48%); water area experienced the smallest change (1.38%). This occurred because the primary task of ecological migration in the initial population was to reclaim grassland and unused land in a way that would solve problems of livelihoods for residents. However, during 2000–2005, the spatial extent of cultivated land fell instead of increasing. This occurred primarily because of the harsh natural environment in Hongsibu, an extreme lack of infrastructure, and because some of the immigrants withdrew from the program, causing the abandonment of arable land that had been previously reclaimed. With the improvement in the living conditions of the resettlement areas related to production, the area of cultivated land increased significantly in both 2005–2010 and 2010–2015. As a result, the ecological immigrants have been ‘moving and living steadily’, while the government sponsored large-scale urbanization and the development of infrastructure so that the area of urbanized land increased rapidly.

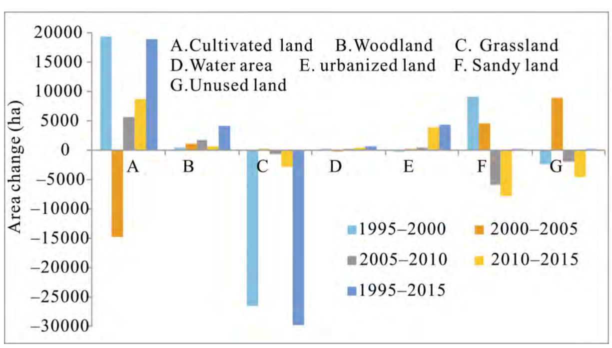

Fig. 3 Change of area of each land utilization of Hongsibu District from 1995 to 2015

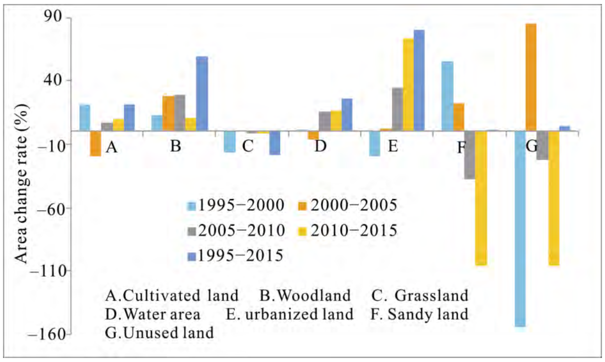

Fig. 4 Change of land utilization rate in Hongsibu District from 1995 to 2015

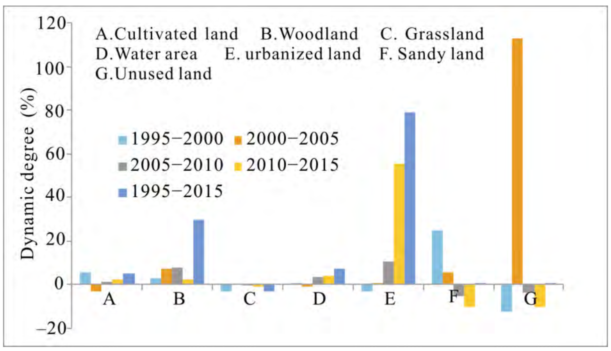

Fig. 5 Change of land utilization dynamic in Hongsibu District from 1995 to 2015

3.2 Change in the value of ecosystem services

3.2.1 Changes in the **overall value of ecosystem services**

During 1995–2015, the ESV in Hongsibu District exhibited a 'V' type pattern of change (Fig. 6). For example, the ESV decreased from 782.6 to 733.55 million yuan from 1995 to 2005, with an annual rate of change of −0.67%. The contribution of the ESV provided by cultivated land, forest land, and water area increased by 3.29%, 2.13% and 0.12%, respectively, in this period. This was caused by large-scale development in the middle of the ecological resettlement areas. The contribution rate of grassland and unused land to ecosystem services decreased by 5.54% and 0.01%, respectively, which led to the overall decrease in the ESV in this period. After 2005, the ecological resettlement area of Hongsibu entered into a period of stable development. Although the ESV provided by grassland and unused land decreased by 5.99% and 0.09%, respectively, the value of the contributions of cultivated land, forest land, and water to ecosystem services increased by 2.66%, 2.19%, and 1.23%, respectively, increasing the overall ESV in the region during this period.

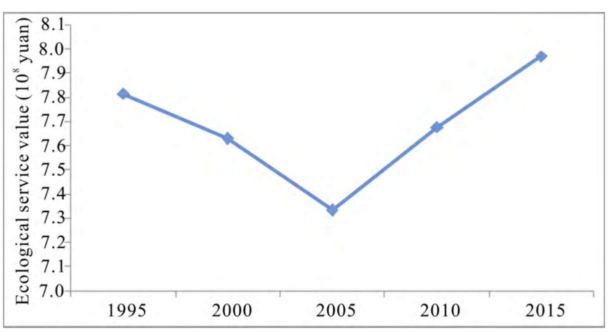

Fig. 6 Changes of ecosystem services value of Hongsubu District from 1995 to 2015

3.2.2 Changes in ecosystem service values

In the study period, the individual ESV aligned in the following order: soil formation and protection > waste disposal > biodiversity conservation > climate regulation > water conservation > gas regulation > food production > raw material > entertainment and culture. The top three on this list contributed nearly 60% of all ecosystem services. Climate regulation and water conservation contributed more than 30%. Thus, the value of the support and regulation services provided by the Hongsibu District ecosystem was much greater than the value of the supply services. In general, the value of the vast majority of different types of ecosystem services increased from 1995 to 2015, with the largest increase seen in water conservation, with an increase of 5.43 million dollar (U.S.). This increase was mainly caused by a large increase in Water area of Hongsibu during the study period. This was followed by food and raw material production, which were mainly related to the expansion of cultivated and forest lands, respectively. Among them, the value of raw materials and entertainment culture increased by 1.45 and 0.36 million yuan from 1995–2005, respectively. The value of other ecosystem services generally experienced a declining trend over time. During the period 2005–2015, the total ESV continued to increase. The ESV provided by water for conservation and waste treatment was the largest, at 11.2 and 13.9 million, respectively (Table 3).

3.2.3 Change in the value of ecosystem services in space

The ESV can be used to characterize regional differences in this value (Zhang et al., 2017). Using the natural discontinuity classification method and ArcGIS 10.0 (ESRI), Jenks divided the ESV into five grades: very low, low, average, high, very high. Overall, during the

Table 2 Values of ecosystem services in Hongsibu District from 1995 to 2015

Year	Item	Cultivated land	Woodland	Grassland	Water area	Unused land	Total
1995	Value/10^8yuan	1.899	0.243	5.320	0.345	0.019	7.826
	Percentage/%	24.263	3.108	67.980	4.409	0.240	100
2000	Value/10^8yuan	2.417	0.282	4.580	0.349	0.003	7.630
	Percentage/%	31.670	3.690	60.030	4.570	0.040	100
2005	Value/10^8yuan	2.020	0.385	4.580	0.333	0.018	7.335
	Percentage/%	27.550	5.240	62.440	4.530	0.240	100
2010	Value/10^8yuan	2.167	0.541	4.563	0.391	0.015	7.676
	Percentage/%	28.230	7.040	59.450	5.090	0.190	100
2015	Value/10^8yuan	2.407	0.592	4.498	0.459	0.012	7.969
	Percentage/%	30.210	7.430	56.450	5.760	0.150	100

Table 3 Value of ecosystem services (EVS) for different land use types in Hongsibu District

Ecosystem service	1995		2000		2005		2010		2015	
	ESV/10^7 yuan	Percentage /%	ESV/10^7 yuan	Percentage /%	ESV/10^7 yuan	Percentage /%	ESV/10^7 yuan	Percentage /%	ESV/10^7 yuan	Percentage /%
Gas regulation	7.642	9.763	7.260	9.520	7.140	9.730	7.480	9.740	7.660	9.600
Climatic regulation	9.394	12.002	9.190	12.040	8.800	12.000	9.170	11.940	9.470	11.870
Water conservation	9.427	12.044	9.120	11.950	8.850	12.070	9.460	12.320	9.970	12.510
Soil formation and protection	18.784	23.999	17.950	23.520	17.300	23.580	17.840	23.240	18.260	22.920
Waste disposal	15.647	19.992	15.570	20.410	14.630	19.950	15.270	19.890	16.020	20.110
Biodiversity conservation	10.662	13.622	10.010	13.120	9.870	13.450	10.230	13.330	10.480	13.140
Food production	4.975	6.357	5.420	7.100	4.850	6.610	5.060	6.590	5.390	6.760
Raw material	0.945	1.208	1.000	1.310	1.090	1.480	1.300	1.690	1.400	1.750
Entertainment and culture	0.794	1.014	0.780	1.030	0.830	1.130	0.970	1.230	1.070	1.340
Total	78.270	100	76.300	100	73.350	100	76.790	100	79.700	100

period 1995–2015, the ESV in the Hongsibu ecological resettlement area showed a distribution pattern from low in the northeast to high in the southwest. The capacity of the landscape to provide ecosystem services in the three townships of Hongsibu, Taiyangshan, and Liuquan gradually decreased over time. Meanwhile, the ecological service function of the Xinzhuangji and Dahe townships gradually improved over time (Fig. 7). Among them, during the period 1995–2005, the very low and low value areas were distributed in Tai yangshan town and Dahe township. The average area shifted location from Xinzhuangji township to Hongsibu town. The high value area shifted from Hongsibu town to Liuquan township. The very high value area shifted from Liuquan township to Xinzhuangji township. In the period from 2005 to 2010, the very low value area shifted from Taiyangshan town to Hongsibu town. The low value area shifted from Dahe township to Taiyangshan township. The average area shifted from Hongsibu town to Dahe township. The high and very high value areas were found in the townships of Liuquan and Xinzhuangji. During the period 2010–2015, the very low value area shifted from Hongsibu town to Liuquan township. Meanwhile, the low value area shifted from Taiyangshan town to Hongsibu town. The average area in Dahe township shifted to Taiyangshan township. The high value of the district by the town of Liuquan township shifted to Xinzhuangji township. The very high value area of Xinzhuangji township shifted to Dahe township.

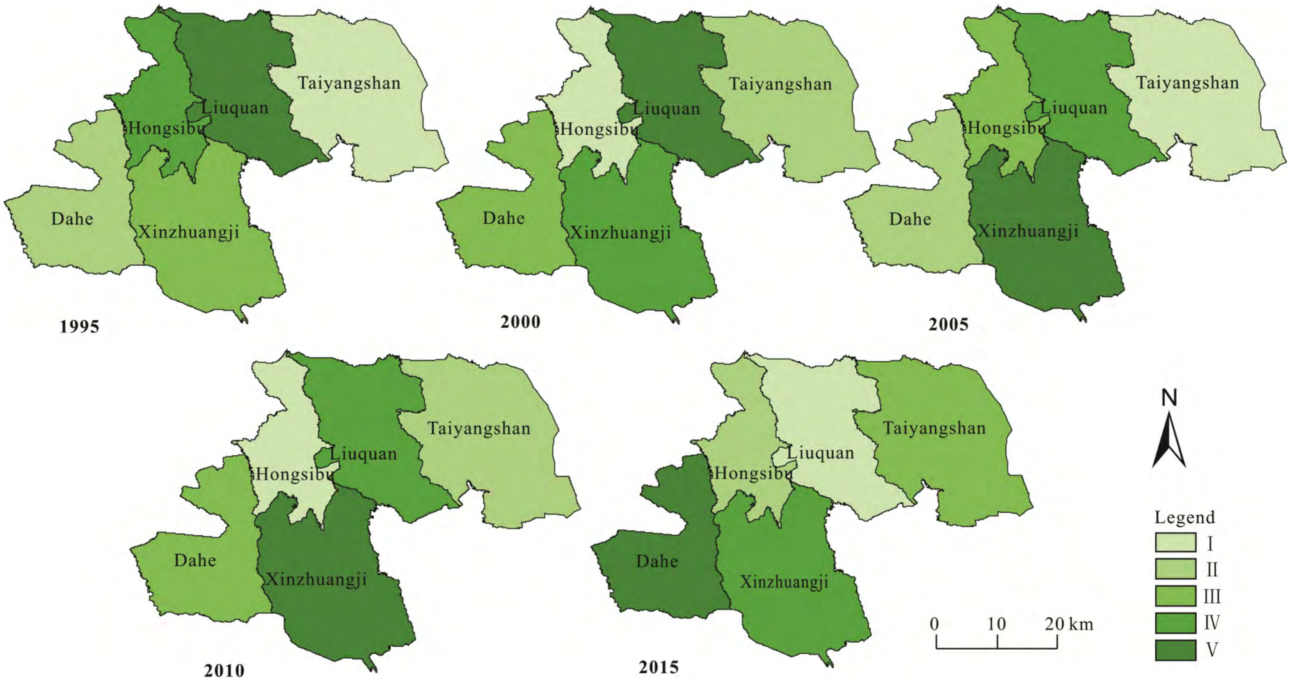

Fig. 7 Spatial distribution of ecosystem service value in Hongsibu District at different time

3.3 Ecosystem sensitivity analysis

Using Equation (6) to adjust the value coefficient (*VC*) for all types of ecosystem services up and down 50%, the sensitivity coefficient of land use types was calculated for 1995, 2000, 2005, 2010, and 2015 in Hongsibu (Table 4). The results show that the order of the value of the *VC* from high to low was the following: grassland > farmland > forest land > water area > unused land. The large *CS* values for grassland and cultivated land, between 0.563–0.681 and 0.242–0.316, respectively, shows that these two land types had a strong influence on the ESV in the ecological resettlement area. Meanwhile, water area, woodland and unused land had a small but steadily growing effect.

Overall, the sensitivity index of the *ESV* to the *ESV* coefficient (*CS*) in the ecological resettlement area was <1. That is, the *ESV* in the study area is not affected much by the *CS*, the *CS* is scientifically sound, and the results are credible.

3.4 Analysis of factors influencing differentiation of ESV of land use change

Geographical spatial factors have effects on the variation in ESV. Based on the evaluation of the ESV of the Hongsibu District during the study period, the land use area was classified, and ESV equivalent factors that affect ESV were identified. The direct division method was used to divide cultivated land, woodland, and grassland as well as the use of land for gas regulation, climate regulation, water conservation, soil formation and protection, waste disposal, biodiversity conservation, food production, raw material production, enter-

Table 4 The coefficients of sensitivity for the values of ecosystem services

Value coefficient	1995		2000		2005		2010		2015	
	Change percentage/%	*CS*	Change percentage/%	*CS*	Change percentage/%	*CS*	Change percentage/%	*CS*	Change percentage/%	*CS*
Cultivated land ± 50%	12.121	0.242	15.813	0.316	13.741	0.275	14.126	0.283	15.112	0.302
Woodland ± 50%	1.539	0.031	1.795	0.036	2.574	0.051	3.465	0.069	3.743	0.075
Grassland ± 50%	34.054	0.681	29.950	0.599	31.126	0.623	29.665	0.593	28.141	0.563
Water area ± 50%	2.168	0.043	2.249	0.045	2.207	0.044	2.491	0.050	2.885	0.058
Unused land ± 50%	0.119	0.002	0.193	0.004	0.351	0.007	0.254	0.005	0.119	0.002

tainment and culture, and other 14 indicators into five levels. These were used calculate the decision *q* value of ESV differentiation. According to the simulation of the geographical detector (Table 5), the area of change in land use types in Hongsibu District affected the differentiation decision of *q* values of ESV were grassland (0.993) and woodland (0.742) > cultivated land (0.733) >water area (0.476) >unused land (0.408); Among the 9 ecosystem service value equivalent factors, climate regulation (0.941)>soil formation and protection (0.932)> waste disposal (0.924) > biodiversity conservation (0.806)> gas regulation (0.805)> water conservation (0.733)> raw materials (0.732) > production of food (0.700)> entertainment and culture (0.424). This shows that in steppes and desert steppes attention should be paid to upgrading the functions of grassland, woodland, and cultivated land ecosystem services. This is extremely important to the regulation of climate, for soil formation and protection, for the treatment of livestock and poultry manure along with other waste, for the maintenance of biodiversity, and for water conservation.

4 Discussion

Ecological migration addresses the dual functions of poverty alleviation and ecologically sound development. In addition, ecological migration is the process of the spatial transfer of population density and ecological pressure. This process can significantly change land use and cover change in a resettlement area in the short term, which will have important effects on various ecosystem services. The present stage of ecological migration in China is still based on the need to reduce poverty in the emigration areas, and more consideration is given to the factors of water, soil, the economy, employment opportunities, and other factors. In the initial stage of the study, grasslands covered the largest area, but since the implementation of the ecological immigration project, the spatial extent of grassland area has declined greatly and that of cultivated land area has increased rapidly, so that a grassland and cultivated land landscape pattern has emerged. The change of this pattern led to a change of the ESV of different land uses in the study area. The results of the present study show that the value of ecosystem services provided by grassland has decreased by 11.64%, and the value of ecosystem services provided by cultivated land has increased by 8.91% since the implementation of the ecological resettlement project. Since 2000, the spatial extent of urbanized land in the study area has increased greatly, especially since 2010, with a rate of change that has reached 50.47%. However, at the same time, the implementation of

Table 5 Geographic detected power of influencing factors for ecosystem value

Index	Threshold					q^*
	The first district	The second district	The third district	The fourth district	The fifth district	
Cultivated land	≤74109	>74109–77942	>77942–81775	>81775–85607	>85607–89440	0.733
Woodland	≤3664	>3664–4481	>4481–5298	>5298–6116	>6116–6933	0.742
Grassland	≤164702	>164702–170508	>170508–176314	>176314–182120	>182120–187926	0.993
Water area	≤1988	>1988–2129	>2129–2269	>2269–2410	>2410–2550	0.476
Unused land	≤3477	>3477–5295	>5295–7113	>7113–8931	>8931–10749	0.408
Gas regulation	≤7.31	>7.31–7.47	>7.47–7.64	>7.64–7.80	>7.80–7.97	0.805
Climatic regulation	≤8.93	>8.93–9.07	>9.07–9.20	>9.20–9.34	>9.34–9.47	0.941
Water conservation	≤9.07	>9.07–9.30	>9.30–9.52	>9.52–9.75	>9.75–9.97	0.733
Soil formation and protection	≤17.60	>17.60–17.87	>17.87–18.16	>18.16–18.46	>18.46–18.78	0.932
Waste disposal	≤14.91	>14.91–15.19	>15.19–15.46	>15.46–15.74	>15.74–16.02	0.924
Biodiversity conservation	≤10.01	>10.01–10.15	>10.15–10.28	>10.28–10.42	>10.42–10.56	0.806
Food production	≤4.96	>4.96–5.08	>5.08–5.19	>5.19–5.31	>5.31–5.42	0.700
Raw material	≤1.02	>1.02–1.12	>1.12–1.21	>1.21–1.31	>1.31–1.40	0.732
Entertainment and culture	≤0.84	>0.84–0.90	>0.90–0.95	>0.95–1.01	>1.01–1.07	0.424

Note: q^* is the differentiation determinants value of ecosystem services natural forest protection, returning farmland to forest, sand control afforestation, and other ecological urbanization projects has caused the total ESV in the study area to remain stable or to be slightly increased (15.49 million yuan). Because the available data are limited, the ESV in this study only uses the model proposed by Costanza et al. (1998) and others. If the material quantity, value, and emergy methods were used to analyze the effects of ecological land use on ecosystem services, the evaluation results would be more scientific and accurate.

5 Conclusions

Land use and diversification will lead to changes in biogeochemical cycles, hydrological processes, and landscape dynamics. Changes in land use and management will affect the state, characteristics, and functions of ecosystems and will play a decisive role in ESV. The results of the present study provide an important scientific basis for decision-making for land managers and policy makers related to regional environmental protection and sustainable development.

Ecological migration is the process of increasing population density in an area of immigration and transferring the ecological pressure from the area of emigration to the area of immigration. This process can significantly change the land use and cover in the immigration area and has important effects on ecosystem services. Scientifically revealing the effects and differentiation mechanisms of ecological migration on ecosystem services has become an important issue related to implementing the national ecological migration strategy of China. This paper employed Hongsibu, China's largest ecological resettlement and poverty alleviation/ development zone, as a typical case study. Five years of remote sensing data collected in 1995, 2000, 2005, 2010, and 2015 were used to estimate the regional ESV. This data along with a geographical detector model and the dynamic mechanism of ecological migration were used to diagnose the effects of land use change on ecosystem services. 1) During the study period, the spatial extent cultivated and urbanized land in the Hongsibu area increased by 1.90×10^4 ha and 0.43×10^4 ha, respectively, with the spatial extent of grassland decreasing by 2.97×10^4 ha. Changes in the extent of wood land, water area, sandy land, and unused land were small. 2) The overall value of ecosystem services (ESV) in Hongsibu increased in the form of a 'V'. Among the changes in various ecosystem services during the period from 1995 to 2005, the ESV decreased as a whole, with an annual rate of change of −0.67%. During the period from 2005 to 2015, the ESV exhibited stable growth, with an annual rate of change of 0.79%. 3) The proportion of ecosystem services and the total ESV in the form of soil formation and protection, waste treatment, and biodiversity conservation in the Hongsibu area decreased to 56.17% in 2015, while the proportion of the contribution of raw materials and entertainment culture to ESV was the lowest. In 2015, value was added by 0.542% and 0.326%, indicating that the Hongsibu Ecosystem provides values related to the support and adjustment of ecological services that is far greater than the value of supply services. 4) In the Hongsibu area in the study period, the ESV showed a low distribution pattern of ecosystem services increasing from northeast to southwest, and the ecosystem service capacity of the three towns, Hongsibu, Taiyangshan, and Liuquan, gradually declined over time. The ecological service function gradually increased in Xinzhuangji and Dahe townships. 5) The sensitivity index of all types of land use types in the Hongsibu ecological resettlement area was less than 1; this indicates that the ESV coefficient is reasonable. (6) The main factors affecting the ecosystem services in Hongsibu District were grassland (0.993), climatic regulation (0.941), soil formation and protection (0.932), and waste disposal (0.924).

References

Bai X X, Zhang A G, 2015. Study on the regional pattern selection of ecological migration in the Loess Plateau. *Open Journal of Social Sciences*, 3(7): 58030. doi: 10.4236/jss.2015.37038

Chen Meiqiu, Zhao Baoping, Luo Zhijun et al., 2013. The ecosystem services value change in the upper reaches of Ganjiang River based on RS and GIS. *Acta Ecologica Sinica*, 33(9): 2761–2767. (in Chinese)

Costanza R, d'Arge R, De Groot R et al., 1998. The value of the world's ecosystem services and natural capital. *Ecological Economics*, 25(1): 3–15. doi: 10.1016/s0921-8009(98)00020-2

Daily G C, 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington DC: Island Press.

Fan Q D, Ding S Y, 2015. Response of ecosystem services to land use change in county scale of Fengqiu, Henan Province, China. *Arabian Journal of Geosciences*, 8(11): 9015–9022. doi: 10.1007/s12517-015-1846-z

Feng Yingbin, He Jian, Yang Qingyuan, 2014. Evaluation of ecological effects in land use planning: a case study of ecological Barrier Zone of Three Gorges Reservoir Area. *Scientia Geographica Sinica*, 34(12): 1504–1510. (in Chinese)

Fu Bojie, Zhang Liwei, 2014. Land-use change and ecosystem services: concepts, methods and progress. *Progress in Geography*, 33(4): 441–446. (in Chinese)

Gao Hongjuan, Luo Xuqiang, Han Huiqing et al., 2016. The change of ecosystem service value along the road in mountainous region—a case study of provincial road 309 in Majiang County, Guizhou Province. *Journal of Nanjing Forestry University (Natural Sciences Edition)*, 40(1): 135–141. (in Chinese)

Guan Yang, Shao Chaofeng, Lu Lei et al., 2014. Carbon source and carbon sinks assessment in the arid and semi-arid regions under the ecological immigration—taking Luanjingtan demonstration area in Inner Mongolia as an example. *Journal of Safety and Environment*, 14(5): 233–237. (in Chinese)

Huang J P, Yu H P, Dai A G et al., 2017. Drylands face potential threat under 2℃ global warming target. *Nature Climate Change*, 7(6): 417–422. doi: 10.1038/nclimate3275

Jia Yaofeng, 2016. Review of benefit evaluation research on ecological migration in China. *Resources Science*, 38(8): 1550–1560. (in Chinese)

Jin Lian, Wang Yongping, Huang Haiyan et al., 2013. Dynamic mechanism of sustainable development of ecological migration in Guizhou Province. *Research of Agricultural Modernization*, 34(4): 403–407. (in Chinese)

Korbeľová L, Kohnová S, 2017. Methods for improvement of the ecosystem services of soil by sustainable land management in the Myjava River Basin. *Slovak Journal of Civil Engineering*, 25(1): 29–36. doi: 10.1515/sjce-2017-0005

Li Yifeng, Luo Yuzhu, Zheng Hua et al., 2013. Standard of payments for ecosystem services in Sanjiangyuan Natural Reserve. *Acta Ecologica Sinica*, 33(3): 764–770. (in Chinese)

Liu Liang, Xu Wei, Yue Qi et al., 2017. Spatio-temporal variations in land use structure and ecosystem service values in coastal zone of Tangshan City. *Ocean Development and Management*, (12): 51–55. (in Chinese)

Li Yonghong, Liu Xiaopeng, Pei Yinbao et al., 2016. Research on the change of urban land use in ecological immigrant settlement region—a case study in Hongsibu Distrct, Ningxia Province. *Journal of Ningxia University (Natural Science Edition)*, 37(3): 372–377. (in Chinese)

Li Y F, Zhan J Y, Liu Y et al., 2017. Response of ecosystem services to land use and cover change: a case study in Chengdu city. *Resources, Conservation and Recycling*. doi. 10.1016/j.resconrec.2017.03.009

Liu Xiaopeng, Wang Yajuan, 2013. Progress in the researches on the relationships between eco-migration and ecological environment in China. *Journal of Ningxia University (Natural Science Edition)*, 34(2): 173–176. (in Chinese)

Liu Xiaopeng, Li Yonghong, Wang Yajuan et al., 2017. Geographical identification of spatial poverty at county scale. *Acta Geographica Sinica*, 72(3): 545–557. (in Chinese)

Liu Yansui, Li Jintao, 2017. Geographic detection and optimizing decision of the differentiation mechanism of rural poverty in China. *Acta Geographica Sinica*, 72(1): 161–173. (in Chinese)

Lu Qingshui, Zhao Zhiping, 2009. Eco-immigration policy for the degraded rangeland and response of herd families: a case study of Maduo County, the source region of Yellow River. *Geographical Research*, 28(1): 143–152. (in Chinese)

MA (Millennium Ecosystem Assessment), 2005. *Ecosystems and Human Well-Being*: *Synthesis*. Washington, DC: Island Press.

Ning Jia, Liu Jiyuan, Zhao Guosong, 2015. Spatio-temporal characteristics of disturbance of land use change on major ecosystem function zones in china. *Chinese Geographical Science*, 25(5): 523–536. doi: 10.1007/s11769-015-0776-8

Palmer M, Bernhardt E, Chornesky E et al., 2004. Ecology for a crowded planet. *Science*, 304(5675): 1251–1252. doi: 10.1126/science.1095780

Patarasuk R, Binford M W, 2012. Longitudinal analysis of the road network development and land cover change in Lop Buri Province, Thailand, 1989–2006. *Applied Geography*, 32(2): 228–239. doi: 10.1016/j.apgeog.2011.05.009

Shi Junhong, 2015. Study on strategy of sustainable development for pastoral ecological migration of the minority. *Ecological Economy*, 31(10): 83–89. (in Chinese)

Shi Junhong, 2015. Selection of livelihoods strategy and influence factors for pastoral ecological migration. *Journal of Arid Land Resources and Environment*, 29(11): 37–42. (in Chinese)

State Statistics Bureau, 1997–2017. *Statistical Bureau of Ningxia Hui Autonomous Region*, 1996–2016. Ningxia statistical yearbook. Beijing: China Statistics Press.

Tang Hong, Yang Degang, Zhang Xinhuan et al., 2011. Respond of farm household to eco-immigration in Sangong River Basin of Xinjiang. *Progress in Geography*, 30(4): 463–469. (in Chinese)

Wang Xiulan, Bao Yuhai, 1999. Study on the methods of land use dynamic change research. *Progress in Geography*, 18(1): 81–87. (in Chinese)

Wang Sufang, Tu Jianjun, Zhang Hongmei et al., 2009. Study on the resettlement pattern of ecological migration based on city and countryside overall plan. *Guizhou Agricultural Sciences*, 37(4): 170–171, 174. (in Chinese)

Wang Yajuan, Liu Xiaopeng, Zhao Dalei, 2010. Environment impact assessment of Guyuan Municipal Districts land use program based on ecosystem services value. *Research of Soil and Water Conservation*, 17(3): 222–226. (in Chinese)

Wang Ya, Meng Jijun, 2017. Effects of land use change on ecosystem services in the Middle Reaches of the Heihe River Basin. *Arid Zone Research*, 34(1): 200–207. (in Chinese)

Wang Yongping, Wu Xiaoqiu, Huang Haiyan et al., 2014. The resettlement mode of ecological migration in the regions of scarce land resources: in case of Guizhou Province. *Ecological Economy*, 30(1): 66–69, 82. (in Chinese)

Wang Fang, Ge Quansheng, Yu Qibiao et al., 2017. Impacts of land-use and land-cover changes on river runoff in Yellow River Basin for period of 1956–2012. *Chinese Geographical Science*, 27(1): 13–24. doi: 10.1007/s11769-017-0843-3

Wang Jinfeng, Xu Chengdong, 2017. Geodetector: principle and prospective. *Acta Geographica Sinica*, 72(1): 116–134. (in

Chinese)

Xiao Yang, Ouyang Zhiyun, Xu Weihua et al., 2016. Optimizing hotspot areas for ecological planning and management based on biodiversity and ecosystem services. *Chinese Geographical Science*, 26(2): 256–269. doi: 10.1007/s11769-016-0803-4

Xie Gaodi, Zhen Lin, Lu Chunxia et al., 2008. Expert knowledge based valuation method of ecosystem services in China. *Journal of Natural Resources*, 23(5): 911–919. (in Chinese)

Xu H G, Tang X P, Liu J Y et al., 2009. China's progress toward the significant reduction of the rate of biodiversity loss. *BioScience*, 59(10): 843–852. doi: 10.1525/bio.2009.59.10.6

Yan Enping, Lin Hui, Wang Guangxing et al., 2014. Analysis of evolution and driving force of ecosystem service values in the Three Gorges Reservoir region during 1990–2011. *Acta Ecologica Sinica*, 34(20): 5962–5973. (in Chinese)

Yang Yue, Hasi Eerdun, Du Huishi et al., 2014. Impacts of land use change on ecosystem service value in Yanchi County of Ningxia Based on RS and GIS. *Research of Soil and Water Conservation*, 21(5): 100–105. (in Chinese)

Yang G T, Liu Z H, Zhou H J, 2015. Evaluation of the effect of ecological migration on rural household development capability. *Journal of Human Resource and Sustainability Studies*, 3(1): 54369. doi: 10.4236/jhrss.2015.31002

Yao Yuan, Ding Jianli, Wang Gang et al., 2014. Response of ecosystem services value to land use change in Murghab-Tejen Oasis, Turkmenistan. *Arid Land Geography*, 37(1): 134–143. (in Chinese)

Ye Yanqiong, Zhang Jiaen, Chen Lili et al., 2016. Agriculture and forestry ecosystem services value in Guangzhou-Foshan Metropolitan Area under the background of urbanization, Southern China. *Chinese Journal of Applied Ecology*, 27(5): 1619–1627. (in Chinese)

Yu Lulu, Zhang Xiaoxiang, Li Yangfan et al., 2016. Coastal ecosystem services and their spatial-temporal variation in Haikou, China. *Acta Ecologica Sinica*, 36(8): 2431–2441. (in Chinese)

Zhang Qian, Gao Ming, Yang Le et al., 2017. Changes in the spatial structure of ecological land and ecosystem service values in nine key districts of Chongqing City over the past 25 years. *Acta Ecologica Sinica*, 37(2): 566–575. (in Chinese)

Zheng Zhenmin, Fu Bojie, Feng Xiaoming, 2016. GIS-based analysis for hotspot identification of tradeoff between ecosystem services: a case study in Yanhe Basin, China. *Chinese Geographical Science*, 26(4): 466–477. doi: 10.1007/s11769-016-0816-z

Zhou Wenxia, Shi Peiji, Wang Yongnan et al., 2017. Effect of ecosystem service values of River Valley City: a case study of Lanzhou. *Arid Zone Research*, 34(1): 232–241. (in Chinese)

Zhu Xiaolei, Zhang Jianjun, Cheng Mingfang et al., 2017. A study on transfer of ecosystem service values in Mining Cities by Meta-analysis. *Journal of Natural Resources*, 32(3): 434–448. (in Chinese)