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Spatio-temporal evolution of Ecologically-sustainable land use in China's Loess Plateau and detection of its influencing factors

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Abstract: Ecological land (Eco-land) is a basic resource for human beings to survive, and eco-land use is a strategy, a way to manage the land resource. So, ecologically-sustainable land use is essential for human beings to survive. This paper investigates the spatiotemporal characteristics and mechanisms of urban-rural eco-land using a new and innovative integration way based on eco-land change data in China's Loess Plateau (LP) prefecture level cities and explores factors of eco-land change. The spatial difference characteristic of eco-land among different level cities in the LP is that: small cities > big cities > middle cities. From 2009 to 2016, the eco-land in the LP from the perspective of urban-rural areas has changed significantly. Significant differences of urban-rural eco-land were identified among various urban growth types, and all the cities in the LP were further classified into four types based on eco-land change trend, with type A and B cities identified as the vital zone and major zone. Taking the eco-fragile region Loess Plateau (LP) as an example, our results demonstrated that the migrants to cities in LP could relieve ecological pressures and promote restoration of ecological vegetation. We have demonstrated that urbanization and the influence of government policy can be discerned through the quantification of the spatial-temporal change of eco-land and suggest that combining both urban and rural eco-land can support more effective land use decisions and provide theoretical basis for the practical application of urban planning, policy -making and sustainable development. What's more, governments should strive to population mobility and restore vegetation to sustain this fragile ecological environment.

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Introduction

Since the enactment of social and economic reforms in 1978, China has experienced dramatic and rapid development as urbanization levels increased from 17.9% in 1978 to 52.6% in 2012 (Bai et al. 2014). The rapid urbanization is accompanied by high levels of concentration of the urban population and expansion of the built-up areas in many countries (Liu and Yang 2015), and the loss of ecological land in city (Han et al. 2018).

Accelerated urbanization associated with significant political, economic and cultural developments not only has profoundly altered land use patterns and structure (Li et al. 2018), but also changed environmental and ecosystem services (Liu et al. 2015). The expansion of the city makes the original natural ecological system into nature-society coupling system, which affects air quality, water use, energy consumption, human health and urban sustainability (Liu et al. 2011; Zhou et al. 2015; Xie et al. 2017).

China's urbanization growth was directed and controlled by the national government that urban biased policy was implemented, and that national investment like heavy industries was mainly concentrated in cities (Li et al. 2018). It is precisely because, as a vast country with spatial heterogeneity in different regions, the development within cities is extremely unbalanced in the process of rapid urbanization. Therefore, it is vital to explore the characteristics of eco-land use contrast and change in the urban-rural areas.

Specially, the recent rise and development of geographical statistical analysis (Xu et al. 2018), such as Mann-Kendall trend analysis (Cao et al. 2018), variance analysis (Perry et al. 2002), pixel-based residual analysis (Liu et al. 2018), and spatial detection analysis (Wang et al. 2019), are help to analyze eco-land dynamics. Actually, previous studies of urbanization and Ecologically-sustainable land use mainly focused on land use change patterns (Chen et al. 2009; Liu et al. 2014), sustainable mechanisms and influence factors (Long et al. 2007; Liu et al. 2016), eco-environment benefits (Liu et al. 2018), and optimization on region land allocation (Li et al. 2015; Yang et al. 2016). The methods mostly based on modeling, statistical data analysis and remote sensing (Li et al. 2016; Gong et al. 2018). All above are particularly true for studies focusing on the spatial and temporal heterogeneity of eco-land. What’s more, the ecological civilization characterized by the settlement ecological land rational and sustainable utilization (ERS) has been a new long-term national development strategy in China.

In this study, we integrated time series analysis with spatial sequence analysis to characterize urban-rural eco-land patterns quantitatively during 2009-2016 in China’s Loess Plateau. The China’s Loess Plateau, located in the middle and upper reaches of the Yellow River, is the largest and deepest loess deposit in the world and has the most serious soil erosion problems in China having received much attention from both the government and academic spheres (Liu et al. 2015; Fu et al. 2017). With the implementation of the Great Western Development Strategy, this region is experiencing rural-urban transformation development (Chen et al. 2019). As an ecologically fragile area, it is also recognized as significant for the ecological security of the whole of China (Zhao et al. 2013).

Therefore, it is necessary to detect the highly sensitive region and investigate the mechanisms behind these effects. We aimed to analyse the urban eco-land of China’s Loess Plateau in urban and rural perspective. Specifically, we aimed to determine: (1) Identify and quantify eco-land from the perspective of the urban and rural areas. (2) Measure the status of eco-land and analyze the change of eco-land between 2009 and 2016 at China’s Loess Plateau prefecture-level cities. (3) Illustrate the spatial variation difference of urban eco-land through a detailed comparison analysis in the Loess Plateau. (4) Identify distinct factors influencing the status and dynamics of eco-land.

1 Data and Methods

1.1 Study area and data sources

The Loess Plateau of China (33°43′7″–41°16′7″N, 100°54′7″–114°33′7″E) is the world’s deepest and largest loess deposit. It has a depth of over 300 meters and covers an area of some 6.4×10^5 km^2 in the upper and middle reaches of China’s Yellow River including portions of seven provinces (Shanxi, central-southern Ningxia, northern Shaanxi, western Henan, central Inner Mongolia, eastern Gansu and northeastern Qinghai). The Loess Plateau is also home to more than 50 million people (Wang et al. 2017). As an area that accounts for 6.67% of China land, the Loess Plateau feeds 8.5% of the Chinese population. Prefecture is a specific unit in China’s administrative division, which is an administrative division ranking between province and county. In this study, the unit of our analysis is prefecture.

The original data was obtained from Land survey results sharing application service platform of China land survey and planning institute that is the institute of ministry of Natural Resources of the

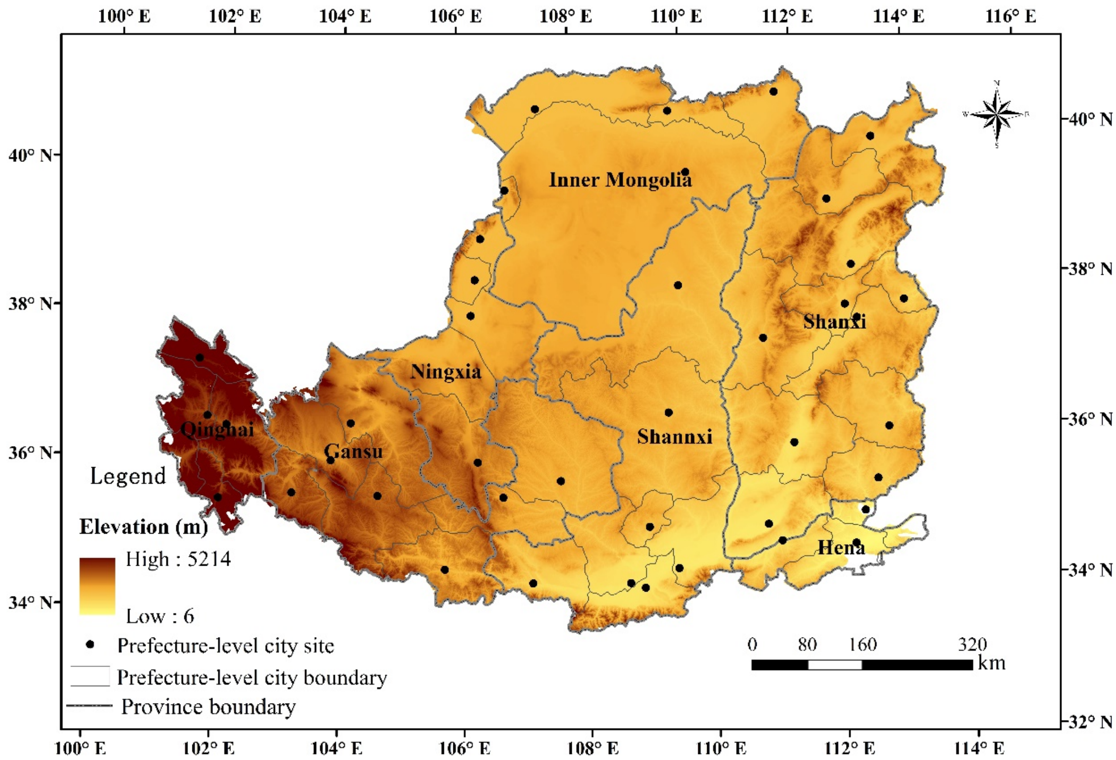

Figure 1 Locations of the observed city point sites in China's Loess Plateau.

People's Republic of China. The data covers from 2009 to 2016, it includes eco-land, residential land and built-up land three categories. Combined with data from the China Statistical Yearbook of 2017 and the city administrative center location data from China's 1:4 million basic geography dataset.

According to the integrity and consistency of data, this study removes lacking data cities, and selects 38 prefecture-level cities as the research object, and the 38 prefecture-level cities are divided into three statistical levels: city, urban and rural. The total ecological land mainly includes fundamental eco-land and recreational eco-land. Since cities of various sizes gained steady growth in China in the post-reform era, especially in recent years. Thus, in this paper, we choose the latest year of 2016 as the criterion. According to the statistic in 2017 (National Bureau of Statistics of China 2017), the cities in China's Loess Plateau were divided into three types: large city, middle city and small city. The locations of city point sites at prefecture-level in Loess Plateau of China were extracted (Figure 1).

An urban-rural gradient approach to gathering suggests a more holistic perspective on the tendencies of subject investigated within and across urban, suburban, and the countryside (McDonnell et al. 1997). City is defined broadly as a permanent large settlement compared with the countryside, but this definition is an abstract concept without spatial identification. According to China land survey and planning institute, the rural area was the urban-rural fringe. The identification of urban and rural areas was made as the Figure 2.

1.2 Study methods

1.2.1 Comparison analysis

The comparison analysis mainly includes that of the changes of eco-land, residential land and built-up land in urban areas and rural areas. The change of residential land is a reflection of city population immigration, while the change of built-up land is a reflection of the overall city expansion and development. The types of eco-land change can be divided into six types based on the growth area rate in the urban (U) and rural (S). Urban growth type -UGT represents the eco-land of U and S are both growth, and the growth of urban areas is larger than that of rural areas (U>0, S>0, R (U/S) >1). Likewise, rural growth type -SGT is

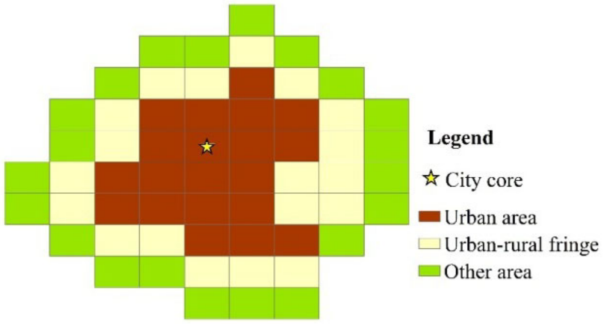

Figure 2 Graphical representation of urban-rural areas identification.

(*U*>0, *S*>0, *R* (*U/S*) <1); urban growth & rural reduce type -UGT&SRT (*U*>0, *S*<0), urban reduce & rural growth type-URT&SGT (*U*<0, *S*>0), urban reduce type-URT (*U*<0, *S*<0, *R* (*U/S*) >1), and rural reduce type-SRT (*U*<0, *S*<0, *R* (*U/S*) >1).

1.2.2 Analyzing interactions between eco-land change

ΔECL was defined as the difference between ECL_u and ECLs to quantify the urban and rural eco-land (ECL) of each city. The Slope of ECL change was measured using linear regression analysis. Then ΔSlope was deemed as the difference between the Slope for ECL_u and ECLs, as described by Eq. (1).

$$Slope = \frac{n \times \sum_{t=1}^{n} t \times ECL_t - (\sum_{t=1}^{n} t)(\sum_{t=1}^{n} ECL_t)}{n \times \sum_{t=1}^{n} t^2 - (\sum_{t=1}^{n} t)^2} \quad (1)$$

where, *n* is the length of time series in years, *t* is one research time node, ECL_t is the eco-land at the year *t*. To analyze the ECL change tendency, spatial pattern of ECL variation was contrast analyzed according to the absolute value of Slope, and the mean Slope of each city's urban and rural area was calculated using the tool of Zonal Statistics as Tables in ArcGIS 10.2.

1.2.3 Other statistical analysis methods

In this study, we also used Pearson parametric correlation analysis to identify synergies between eco-land change and its influencing factors in 2000 and 2010. Synergies indicate interactions between two variable values respectively that could reveal their associations.

2 Results

2.1 Temporal evolution analysis of eco-land use change

With the acceleration of urbanization in prefecture-level cities, the change of urban and rural eco-land in Loess Plateau is relatively obvious (Figure 3). As shown in Figure 3, the change of urban eco-land is positive expect for the periods of Ⅰ and Ⅴ, and the largest change is in the period of Ⅱ; that is positive in the rural area, expect for the period of Ⅳ, with the largest change in the period of Ⅰ. The change rate of eco-land in urban and rural areas is polygonal line, and the change rate in rural areas is higher than that in urban areas except the period of Ⅳ.

On the composition of eco-land, it can be concluded that the change of recreational ecological land in both urban and rural area is

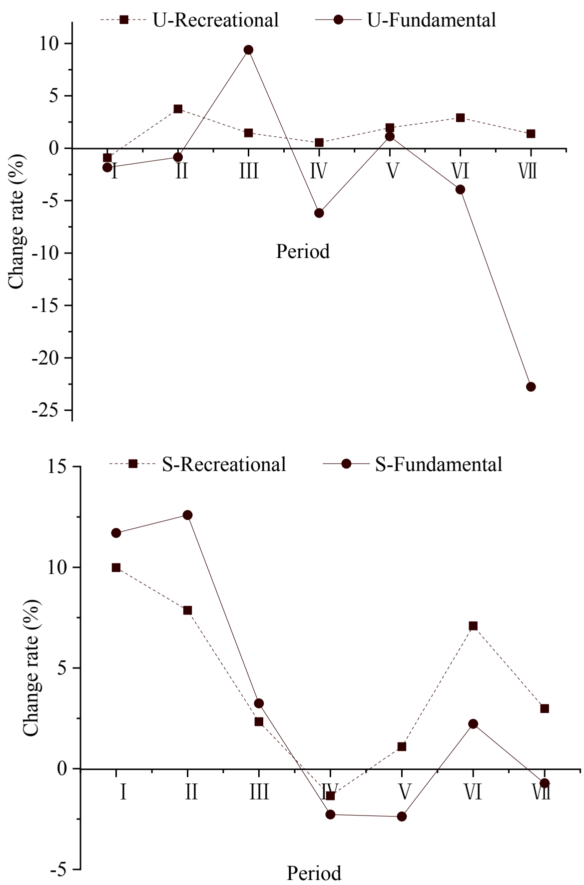

Figure 3 The eco-land change rate of cities in China's Loess Plateau during 2009-2016. (U represents urban; S represents rural).

positive, expect for Ⅰ and Ⅳ, that of fundamental ecological land in urban area Ⅱ has the largest positive change, and the change of recreational ecological land in rural is larger than urban expect for the periods of Ⅶ. The change rate of recreational ecological land and fundamental ecological land is shown in Figure 3. The change rate of rural recreational ecological land is larger than that of urban; except the period of Ⅴ, the change rate of rural fundamental ecological land is also larger than that of urban; except the period of Ⅳ.

2.2 Spatial evolution analysis of eco-land use change in prefecture-level city

2.2.1 Evolution of the eco-land analysis

There is an obviously difference between urban and rural areas in the change of eco-land in China's Loess Plateau prefecture-level cities (Figure 4). The biggest change of urban eco-land is in the southeast, and the least is in the central and the west. The cities with rural growth mainly focus on the cities of Shanxi province and Guanzhong city cluster. Cities with urban growth are mainly concentrated in Inner Mongolia autonomous region, Gansu Province and Henan Province.

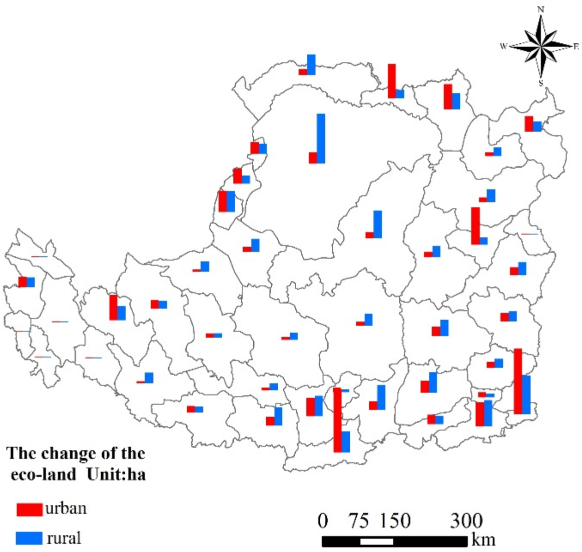

Figure 4 The eco-land change of cities in China’s Loess Plateau during 2009 - 2016.

2.2.2 Distribution types of the eco-land

As we can see from Figure 5, there is a significant difference in the distribution of eco-land growth types in China's Loess Plateau prefecture-level cities. The cities with the biggest growth rate were Xian, Wuzhong and Hohhot. The top three growth ones are Dingxi, Lvliang and Datong. Those with the most significant difference in urban-rural areas are Tianshui, Yinchuan and Taiyuan. Among the six growth types cities of urban-rural eco-land, the urban growth type (UGT) accounts for 30%, urban reduce & rural growth type (URT&SGT) for 23% and the top three are Erdos, Yulin city and Bayan Nur respectively, rural growth type (SGT) for 18%, urban growth & rural reduce type (UGT&SRT) for 16%, rural reduce type (SRT) account for 10%, urban reduce type (URT) for 3%, rural reduce type (SRT) for 10% and the top three cities were Yan'an city, Sanmenxia city and Shizuishan city.

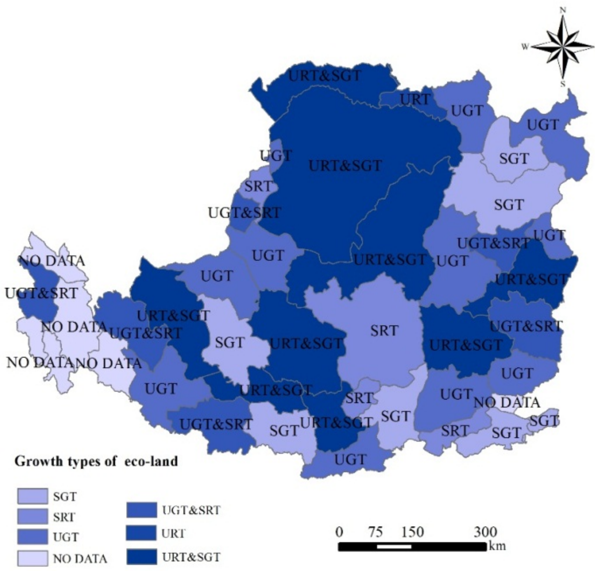

Figure 5 The growth types of cities in China’s Loess Plateau during 2009-2016.

2.3 Comparison analysis of eco-land use change

2.3.1 Overall comparison analysis

The changes of built-up land and residential land both in the urban and rural areas show a stable positive growth while the change of eco-land shows unstable (Figure 6). It also can be seen the difference in the change of built-up land and residential land is less significant than that in rural areas whether in large cities, middle cities or small cities.

The overall change of eco-land is relatively less than that of residential land and built-up land in the period of 2009-2016, with an average proportion of 6.36% and 4.24% in urban and rural respectively. Compared with that residential land and built-up land, that of eco-land accounted for 7.56% and 3.29% in urban，while rural eco-land change accounted for 5.82% and 2.13% respectively. The overall change of rural residential areas and built-up areas is obviously greater than that of urban.

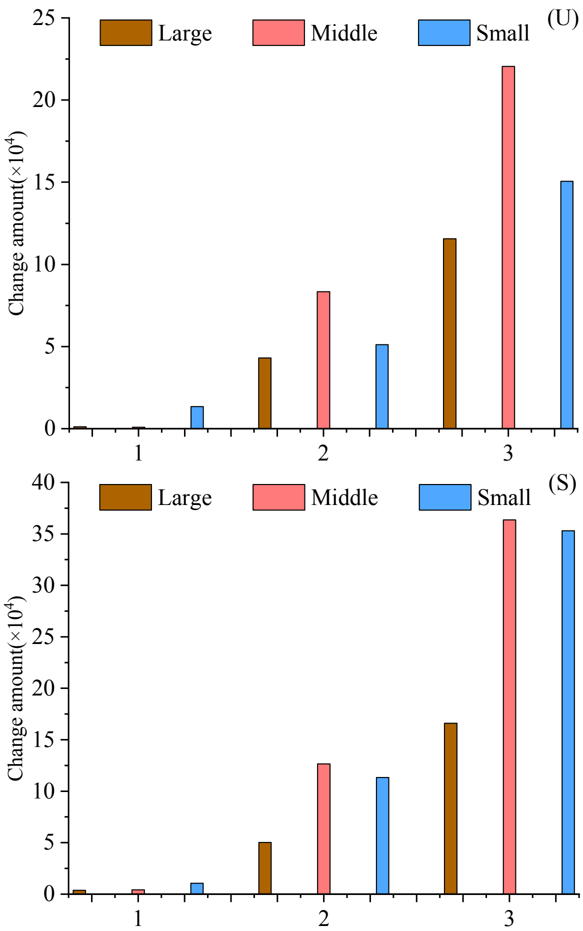

Figure 6 Three types of overall land use changes among the three types of city in China's Loess Plateau during 2009-2016.

2.3.2 City classification based on eco-land change trend

Based on eco-land (ECL) change in urban and rural areas, cities were divided into four types (designated as type A, type B, type C and type D) using the ArcGIS 10.2 (ESRI Inc., Redlands, CA, USA) (Figure 7). Furthermore, considering that the Δ Slope could substantially indicate the change trend of ECL change effect, the major zones and key temporal periods for eco-land management were identified through ECL change analysis.

Cities classified as Type A (*N*=34) experienced ECL high growth rate in rural. These cities were generally large such as Erdos, Shizuishan, Taiyuan and other megalopolises, as well as other big cities in Inner Mongolia and shanxi Province with rich natural resources. Type B (*N*=137) cities were centrally situated in the arid area of northwestern Loess Platea. Especially the cities in the provinces of Gansu and Ningxia, which had small urban size because of the restricted natural resources, these cities had slow rate in the eco-land both in the urban and rural. Type C (*N*=244) cities were mainly distributed in the earth-rock mountain region and Central Plain Urban Agglomeration,

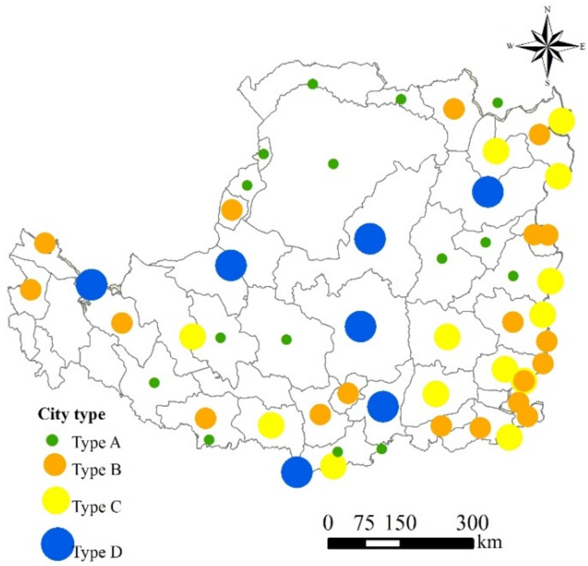

Figure 7 City classification based on eco-land (ECL) change trend in China's Loess Plateau during 2009-2016.

which were characterized by large urban size and high-level urbanization stage, and would continue to be the core area of China's urbanization in the near future. These cities exhibited that ECL_u increased faster than ECL_r, on the whole, the growth rate of eco-land in the city is small. Hence, eco-land (especially in urban) was expected to exacerbate in the future. Type D (*N*=439) cities were quite different from other types. Cities in Type D had a high and increasing speed rate of the eco-land, especially in rural. In the future, Type D cities should be alleviated by controlling the intensity of human activities.

2.4 Analysis the factors influencing eco-land change in Loess Plateau region

2.4.1 Land-cover and Land-use change transitions

Land cover of the LP changed dramatically over the 20 years, both in spatial pattern and area. The land-use pattern conversion occurred mainly from farmland to grassland and forest, as well as from grassland and shrub to forest. The land cover area distribution change was characterized by a decrease in farmland (by 1.4%) and water-bodies, and an expansion of forest vegetation cover (by 0.71%) and built-up areas (Table 1).

Table 1 The conversion of land use during 1990–2010 (unit: 10 km^2)

Land-use types	FL	Forest	GL	Water-bodies	Built-up areas
FL	17147.37	957.76	3762.94	140.21	382.62
Forest	702.90	6322.91	1440.25	14.09	26.22
GL	3931.79	1633.84	19220.24	116.55	122.86
Shrub	151.08	12.39	115.74	174.91	9.85
UL	117.40	8.24	41.07	4.90	190.96
Variation	-240.34	438.18	-213.44	-22.10	383.11

Notes: The vertical row of land use is the year of 1990, and the horizontal row is 2010. FL= Farmland; GL= Grassland; UL= Urban land.

Most of the areas with growth forest coverage were mainly located in the southeast, northeast and middle parts of the Loess Plateau, especially in the earth-rock mountain region. Because farmland is the critical area for soil erosion, abandoning sloping farmlands for revegetation is a primary measurement for revegetation effectiveness. After the 2000s, a large amount of sloped farmlands were transferred to grassland or forest. The shrinkage of farmland and expansion of non-agricultural vegetation and built-up area occurred at a greater rate during 2000–2010 than before (Wang et al. 2017). From 2000 to 2010, the area of farmlands decreased by 1.8%. There has a significant greater rate decline in farmland compared with the period before 2000. Farmland converted to forest and grassland areas of 9577.6km^2 and 37629.4 km^2, accounting for farmland converted to other land types of 18.27% and 71.76%. In contrary, farmland area was slightly increasing during 1990–2000. Farmlands and barren area were the main contributors for increased grassland area. However, after 2000, due to the implementation of Green for Grain project, grassland expansion gained the largest proportion of transferred farmlands through natural succession and reforestation being forest, and this proportion of grassland that converted to forest increased dramatically after 2000 as result of managed reforestation.

2.4.2 Population migration size and changes

The total population in the Loess Plateau increased from 1.21 $\times10^8$ in 2000 to 1.42 $\times10^8$ in 2010 according to the fifth and sixth China Population Census. From the spatial distribution of the average population migration rate, the high population immigration rate concentrated in the relative better geographic location such as the valley plain region, Loess Gully region, some irrigation region and several capital cities Xi'an, Taiyuan, Yinchuan and Lanzhou in the Loess Plateau. We calculated population migration rate changes between 2000 and 2010. The regions where the population density decreased were primarily in the east of Loess gully region and in the earth-rock mountain region. Owing to the constraints of natural geography and the rapid urbanization development, the local rural residents leave off the farmland migrating to economically developed areas.

In order to analyze the effect of population immigration and emigration on ecological vegetation coverage, we divided the average population migration rate into six groups which named M1, M2, M3, M4, M5 and M6. Meanwhile, we calculated the change of rate in population migration during 2000 – 2010 and separated the change of rate in population migration into six groups RC1, RC2, RC3, RC4, RC5 and RC6 (Table 2). The average eco-land and residual eco-land in each group of total population migration rate were to compare. The annual eco-land change trends for the six groups all were > 0. When the population migration rate was at the range of >0.1, the

Table 2 Grouping of average and variation values of population migration rate

Group	Average population migration rate	Changes of the rate	Group
M1	<-0.1	<-0.2	RC1
M2	-0.1 to -0.03	-0.2 to -0.1	RC2
M3	-0.03 to -0	-0.1 to -0.05	RC3
M4	0 to 0.03	-0.05 to 0	RC4
M5	0.03 to 0.1	0 to 0.1	RC5
M6	>0.1	>0.1	RC6

environment condition would be effected obviously, and the annual eco-land trends peaked when the population migration rate was within a 0.03-0.1 range. Residual eco-land trends displayed the inverted V curve and it peaked within the range of -0.1-0.03 range, as well. This showed that appropriate population migration could reduce the destruction of vegetation. While it was necessary to keep a certain population density including immigration and emigration that maintained the vegetation growth stable. According to the change of rate in population migration, trends in annual eco-land increased from the first group to the third group and the residual eco-land achieved a peak when the population migration rate was induced by 0.1-0.2. This showed that in some higher migration of population areas, the greening rate human-induced factors were larger, and the migration of population promoted vegetation condition and alleviated the pressure of the ecosystem to a certain degree.

The result of the spearman correlation analysis between eco-land indicators (annual eco-land and eco-land change) and population migration indicators (population migration rate and change rate in population migration) at country scale during 2000-2010 in the Loess Plateau are shown in Table 3. The population migration rate was positively with annual eco-land (r=0.024), but changes rate in population migration was negatively (r=-0.159). The main reason was that the attraction of ecological environment to human migration was increasing, especially the people in the ecologically fragile areas tended to move to relatively good vegetation zone. Meanwhile, the areas where population migration rates were higher, the original ecological environment was usually terrible or the urbanization develops faster, characterized by the degradation of vegetation.

Moreover, the population migration rate was positively (r=0.0473) significantly (P< 0.01) with the eco-land change, but the changes rate in population migration was negative (r=-0.1056) with the eco-land change no significantly. Especially, when the change rate in population migration within the range of <-0.2 and -0.1-0, the population migration reduced the people's interference with ecological vegetation restoration.

3 Discussion

The innovative urban and rural areas perspective is integrated to study the spatial-temporal evolution of eco-land at China's Loess Plateau in the past decade and then to detect the factors influencing the eco-land in LP. Five new development concepts — innovation, coordination, green development, openness, and sharing — are proposed as the heart of the country's development strategy. Among them, green development demonstrates that the nation holds ecological civilization, which is supportive of environment improvement and efficient resource utilization, in very high regard (Liu et al. 2018). The understanding of variation of ecological land is essential for cities management adaptation and ecological civilization implementation (Zhang et al. 2016). We have demonstrated that urbanization and the influence of government policy can be discerned through the quantification of spatial-temporal change of eco-land. Studies of eco-land types on regional and urban scales can lead to promote the optimization of eco-land patterns (Xie et al. 2017). The LP regional studies of eco-land patterns and spatial variation difference will provide evidence to facilitate the ecological civilization and sustainable development for the whole of China. Overall, the urban and rural land use in LP experienced tremendous changes during the research period. Eco-land as a kind of significant natural resource is fundamental to

Table 3 Relationships between two eco-land datasets and population migration indicators

Group	Annual eco-land	Eco-land change	Group	Annual eco-land	Eco-land change
M1	0.1469	0.1577*	RC1	0.0123	-0.1953*
M2	0.0443**	0.1673	RC2	-0.1441**	-0.2644
M3	-0.0023	0.0871	RC3	0.0203	-0.0417
M4	0.1748*	0.2611	RC4	0.036*	-0.0336**
M5	-0.1317	-0.0901	RC5	-0.387	-0.2901
M6	0.2717**	0.3013*	RC6	0.1212**	0.3255**
M	0.024**	0.0473**	RC	-0.159*	-0.1056

Notes: *, **, *** mean correlated significantly at P<0.05, P<0.01, P< 0.001 respectively.

maintaining ecological security, and the relative insufficiency of eco-land use has become a realistic dilemma faced by cities of different scales (Hunter et al. 2011). How to coordinate the development of production-life-ecological space, especially in the ecologically-fragile areas, balance the city ecological function and the surroundings, maintain the eco-land redline, and make the city to better live in the urban ecological environment, has become an urgent subject needed to be studied. As an integral part of urban ecological space, the change of urban and its surrounding rural eco-land has become an indispensable part of measuring the demand for urban eco-land. Studies of eco-land with the perspective of urban-rural areas help to optimize landscape pattern (Yuan et al. 2019). However, in the process of specific demarcation eco-land, there are great difficulties in the spatial identification and the administrative management of eco-land. How to develop in a low-carbon way, manage eco-land effectively and enhance the adaptability to urban sustainability, how to mutually unify economic, social and ecological benefit of eco-land, how to alleviate the contradiction between eco-land supply and demand and guarantee the sustained and stable development of social economy in the new normal, how to relate these ecological entities with densely or less densely populated settlements, are all the next steps to explore. What's more, as for the PL, the population migration reduced the negative disturbance to forestland, and promoted the restoration of ecological vegetation by facilitating abandonment of slope farmland in the LP. From the perspectives of social-economic-ecological functions, we will focus on the mechanism of emigration environmental action in the future studies.

4 Conclusions

This paper analyzed the eco-land in the LP from the perspective of urban-rural areas from 2009 to 2016, and identified distinct factors influencing dynamics of eco-land in the LP. The study innovatively used comparative method to explore the change process and mechanisms of urban-rural eco-land. Given the preceding discussion, the results show as follow. The spatial difference characteristic of eco-land among different level cities in the LP is that: small cities > big cities > middle cities. The eco-land in the LP during 2009-2016 from the perspective of urban-rural areas has changed significantly. Significant differences of urban-rural eco-land were identified among various urban growth types. All the cities in the LP were further classified into four types based on ECL change trend, with type A and B cities identified as the vital zone and major zone of ECL. The purpose is to improve the city's adaptability to ecological civilization and provide more effective approaches for cities sustainability. Factors detection for China's Loess Plateau, our results demonstrated that the migrants to cities in LP could relieve the ecological pressures and promote the restoration of ecological vegetation.

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