Land Cover Change and Eco-Environmental Quality Response of Different Geomorphic Units on the Chinese Loess Plateau Postprint

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Abstract

Land cover in the Chinese Loess Plateau has undergone dramatic changes since the late 1980s. Revealing the trend in land cover change and eco-environmental quality response of different geomorphic units in this stage is a realistic requirement for promoting sustainable development of the Chinese Loess Plateau. Based on the data of geomorphic units and land cover in 1990, 2000, 2010 and 2018 of the Chinese Loess Plateau, we studied the trend of land cover change and eco-environmental quality response of different geomorphic units by using a significance index of land cover change, a proportion index of land cover change and an eco-environmental response model. The results indicated that from 1990 to 2018, the areas of forestland and construction land substantially increased, whereas those of cropland, grassland, wetland and unused land considerably decreased. Land cover change exhibited large geomorphic differences, and the main conversion of land cover was from cropland into other land types. Unstable trend of land cover change in the loess tablelands and sandy loess hills declined, whereas the unstable trends in the other geomorphic units enhanced. Eco-environmental quality varied among different geomorphic units. The expansion of construction land and degradation of forestland, grassland and wetland resulted in the deterioration of eco-environmental quality. The conversion of cropland and unused land into forestland and grassland, and the conversion of grassland into forestland were the main factors that drove the improvement of eco-environmental quality. The findings of this study may provide theoretical reference and support decision making for the optimization of land use structure and the improvement of eco-environmental quality on the Chinese Loess Plateau.

Full Text

Land Cover Change and Eco-Environmental Quality Response of Different Geomorphic Units on the Chinese Loess Plateau

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Abstract

Land cover on the Chinese Loess Plateau has undergone dramatic changes since the late 1980s. Revealing the trends in land cover change and eco-environmental quality response across different geomorphic units during this period is essential for promoting sustainable development of the region. Based on geomorphic unit and land cover data from 1990, 2000, 2010, and 2018 for the Chinese Loess Plateau, we analyzed land cover change trends and eco-environmental quality responses using a significance index of land cover change, a proportion index of land cover change, and an eco-environmental response model. Results indicated that from 1990 to 2018, forestland and construction land areas increased substantially, while cropland, grassland, wetland, and unused land areas decreased considerably. Land cover change exhibited significant geomorphic differences, with the primary conversion being from cropland to other land types. The unstable trend of land cover change in loess tablelands and sandy loess hills declined, while unstable trends in other geomorphic units intensified. Eco-environmental quality varied among different geomorphic units. Expansion of construction land and degradation of forestland, grassland, and wetland resulted in deteriorating eco-environmental quality. Conversely, conversion of cropland and unused land into forestland and grassland, and conversion of grassland into forestland, were the main factors driving improvement in eco-environmental quality. These findings provide theoretical reference and decision-making support for optimizing land use structure and improving eco-environmental quality on the Chinese Loess Plateau.

Keywords: cropland; degradation; eco-environmental quality index; grassland; human activity; unused land; relative ecological value

1. Introduction

Land use/cover change (LUCC) represents a critical link among the four spheres of the Earth' s system—atmosphere, hydrosphere, biosphere, and lithosphere—and constitutes the most direct manifestation of human activity' s impact on the Earth system. It also serves as an important indicator of human activity' s response to global land cover change. Since the 1950s, rapid population growth and socioeconomic development have dramatically altered global land cover patterns, eliciting widespread concern. In China, sustained socioeconomic development, accelerated industrialization and urbanization, and implementation of national and regional development and ecological protection strategies have significantly affected land cover spatial patterns since the late 20th century. Consequently, LUCC, with its coupled human–natural system at the core, has become a crucial factor in studies of global climate and environmental changes.

Extensive research has examined land cover changes, their driving factors, and effects on ecological environments. For instance, Waisanen et al. (2002) analyzed spatio-temporal variations in arable land in the United States from 1790 to 1997 using cropland-related data. Ge et al. (2008) examined land use change variations in China over the past 300 years using historical land data. Liu et al. (2014) described China's land cover change spatial distribution pattern using the LUCC transfer matrix and land dynamic degree model. Land cover change is driven by numerous factors. At large regional scales, natural environmental factors such as climate, hydrology, soil, and topography play important roles, exerting long-term and stable impacts. At smaller regional scales where climatic differences are minimal, topography and geomorphology become key factors restricting human activity and influencing land cover changes. Previous studies have explored relationships between topographical factors (elevation, slope, slope direction) and land use changes. However, the data used to illuminate these relationships are based on macroscopic geomorphic units, which cannot reflect geomorphic structures at regional scales.

The Chinese Loess Plateau features complex geomorphic units with typical and unique loess landforms such as tablelands, beams, and mounds. Influenced by global climate changes and long-term human disturbances, the region has become one of the world' s most severely eroded areas. Since the late 1980s, the Chinese government has promoted regional vegetation restoration and ecological reconstruction projects. However, implementation of China' s Western Region Development Strategy and National Energy Security Strategy has exerted tremendous pressure on the local ecological environment through rapid urbanization and high-intensity energy resource development, resulting in environmental pollution, vegetation destruction, and soil erosion. Geomorphology, as the fundamental factor affecting human activities, directly influences land cover and land carrying capacity, controls the distribution of water, heat, and sunlight resources, and determines the direction of land cover change. Therefore, studying regional ecological environment change processes is necessary to reveal land cover change direction and ecological environment responses across different geomorphic units.

Using the significance index of land cover change, proportion index of land cover change, and eco-environmental response model, this study aims to: (1) reveal land cover change and its dynamic conversion process before and after implementing the cropland-to-forest and grassland conversion program; (2) discuss land cover change processes and possible causes across different geomorphic units; and (3) examine eco-environmental quality evolution and its driving factors across different geomorphic units. The findings will elucidate relationships among geomorphology, land cover change, and eco-environmental quality, providing theoretical reference for ecological restoration improvement and sustainable development on the Chinese Loess Plateau.

2.1 Study Area

The Loess Plateau is located in the upper and middle reaches of the Yellow River in northern China (32°-41°N, 101°-114°E). It extends to the Yinshan Mountains in the north, the Qinling Mountains in the south, the Taihang Mountains in the east, and the Wushaoling–Sun Moon Mountain in the west, covering a total area of 62.46×10 km^2. The plateau is approximately 1300 km long from east to west and 800 km wide from north to south, with an average elevation of 1500–2000 m a.s.l. It encompasses Shanxi Province and Ningxia Hui Autonomous Region, as well as parts of Shaanxi, Henan, Gansu, Qinghai provinces and Inner Mongolia Autonomous Region. This sub-humid and semi-arid zone has a temperate monsoon climate, with mean annual precipitation of 200–700 mm and annual mean temperature of 9°C–12°C. Under long-term disturbances from climate change and human activities, severe soil erosion occurs across the Loess Plateau. The soil erosion area reaches 4.72×10 km^2, with water erosion exceeding 8000 $t/(km^2 \cdot a)$ across 9.12×10 km^2, resulting in severe sedimentation in the lower Yellow River reaches.

2.2 Data Sources

Loess Plateau area data were obtained from a Chinese Academy of Sciences investigation. Major river data were obtained from the national geographical database (http://www.webmap.cn). Digital elevation model data with 90 m spatial resolution were provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn).

Geomorphic unit data were referenced from Yang (1995; http://loess.geodata.cn) and divided into ten types: loess tableland (LT), river alluvial plain (RAP), loess beam hill (LBH), loess mound hill (LMH), loess valley hill (LVH), loess hills of intermountain basin (LHIB), sandy loess hill (SLH), sand blown hill (SBH), soil stone hill (SSH), and soil stone mountain (SSM) [Figure 1: see original paper]. Among these, SSM had the largest area (25.37% of the total), while SLH had the smallest (3.12%) [Figure 1: see original paper].

Land cover data were obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Landsat TM/ETM images from 1990, 2000, 2010, and 2018 with 30 m spatial resolution served as the primary data source, combined with field investigations. Following the land cover classification system, the study area was classified into six land cover types: cropland, forestland, grassland, wetland, construction land, and unused land [Figure 2: see original paper]. To evaluate data applicability for the Loess Plateau, we superimposed land cover maps from each period, extracted unaltered areas, randomly collected 500 points by computer, and superimposed them with high-resolution Google Earth satellite images for accuracy testing. The interpretation accuracy of 87.6% met mapping accuracy requirements.

2.3.1 Significance Index of Land Cover Change

The significance index of land cover change measures the degree of importance of regional land cover change and identifies main change types. It is calculated as follows:

$$C_i = \frac{A_i}{A} \times 100\%$$

where C_i is the significance index of land cover change (%) ranging from 0% to 100%, A_i is the change area of land type i (km²), and A is the total land cover change area (km²). Larger C_i values indicate more dominant land cover changes of type i. In analysis, C_i values are sorted in descending order, and land cover change types with cumulative C_i values exceeding 70% are statistically plotted to identify main change types in the study area.

2.3.2 Proportion Index of Land Cover Change

The proportion index of land cover change represents the percentage of land cover change area relative to the total regional area, depicting change intensity. It is calculated as:

$$D = \frac{A}{S} \times 100\%$$

where D is the proportion index of land cover change (%) ranging from 0% to 100%, A is the land cover change area of different land types (km²), and S is the total regional area (km²). Larger D values indicate more drastic land cover changes.

2.3.3 Eco-Environmental Quality Index (EQI)

The EQI quantitatively expresses the overall state of regional environmental quality:

$$EV_t = \frac{\sum_{i=1}^{n} LU_i \times V_i}{TA}$$

where EV_t is the eco-environmental quality index, LU_i is the area of land cover type i (km²), V_i is the relative ecological value of type i (representing the proportional relationship of ecosystem service value per unit area among different ecosystems), TA is the total regional area (km²), and n is the number of land cover types. Based on ecosystem service value coefficients for China' s terrestrial ecosystems established by Xie et al. (2003), this study calculated relative ecological values for different land cover types on the Loess Plateau .

The change index of eco-environmental quality expresses regional eco-environmental quality change trends:

$$EI = EV_t - EV_{t-1}$$

where EI is the change index, and EV_t and EV_{t-1} are EQI values for periods t and $t-1$, respectively. $EI > 0$ indicates improving quality, $EI = 0$ indicates stability, and $EI < 0$ indicates deterioration.

3.1 Characteristics of Land Cover Change

From 1990 to 2018, forestland and construction land areas on the Loess Plateau increased considerably, while cropland, grassland, wetland, and unused land areas decreased significantly. The 28-year period was divided into three subperiods: 1990–2000, 2000–2010, and 2010–2018. Forestland area increased continuously at an average annual rate of 0.12%, while construction land expanded continuously at 2.45% annually. Wetland area decreased then increased but showed an overall declining trend. Cropland area increased then decreased, showing an overall declining tendency. Unused land areas decreased continuously, while grassland fluctuated downward. Land cover changes were notable in Ningxia, Shaanxi, Shanxi, and Henan, but minimal in Qinghai, Gansu, and Inner Mongolia [Figure 3: see original paper].

Thirty land cover change types were observed from 1990 to 2018, with a total change area of 95,151.90 km² (15.17% of the Loess Plateau total area) . From 1990 to 2000, change area was small (2.14% of total regional area), with mutual conversions between grassland and cropland and between grassland and unused land as the main change types. From 2000 to 2010, change area increased to 7.47% of the total regional area, dominated by conversions from cropland to grassland, construction land, and forestland, plus mutual conversion between cropland and grassland. From 2010 to 2018, change area reached 9.30% of the total regional area, primarily showing significant construction land expansion. Overall, land cover change mainly converted cropland to other land types during the 28-year study period.

3.2.1 Significance Index of Land Cover Change

From 1990 to 2018, the significance index of land cover change varied remarkably among different geomorphic units on the Loess Plateau, exhibiting six trend types: stable, smoothly descending, quickly descending, quickly descending followed by stable, stable followed by quickly descending, and stable followed by quickly descending then stable [Figure 4: see original paper]. Over the 28-year period, the dominant land cover change in five geomorphic units (LT, LBH, LMH, SLH, and SSH) was conversion from cropland to grassland, with significance indices of 37.12%, 41.79%, 36.61%, 34.05%, and 25.81%, respectively. In contrast, the three geomorphic units of LVH, LHIB, and SSM showed dominant conversion from grassland to cropland, with indices of 38.29%, 20.46%, and 18.16%, respectively. Meanwhile, RAP and SBH showed dominant conversions from cropland to construction land and from unused land to grassland, with indices of 23.97% and 25.12%, respectively.

From 1990 to 2000, significance indices for LT, RAP, LHIB, and SBH showed smoothly descending trends, while LMH, LVH, and SSH showed quickly descending trends, and LBH, SLH, and SSM displayed quickly descending followed by stable trends. From 2000 to 2010, indices for LHIB, SBH, and SSM showed smoothly descending trends, while LT, LBH, SLH, and SSH showed quickly descending followed by stable trends, LMH and LVH showed rapidly descending trends, and RAP showed stable then rapidly descending then stable trends. From 2010 to 2018, indices for LBH, LMH, and LVH were stable, while RAP, SBH, and SSH showed smoothly descending trends, SLH and SSM showed stable followed by quickly descending trends, and LT and LHIB showed stable followed by quickly descending then stable trends.

Overall, during the 28-year study period, significance indices for LBH and LVH were stable, while LT, RAP, SBH, SSH, and SSM showed smoothly descending trends. LMH showed a quickly descending trend, LHIB showed stable followed by quickly descending then stable trends, and SLH showed quickly descending followed by stable trends.

3.2.2 Proportion Index of Land Cover Change

From 1990 to 2018, proportion indices of land cover change varied significantly across the ten geomorphic units on the Loess Plateau [Figure 5: see original paper]. LVH had the largest proportion index (D=23.32%), while SSM had the smallest (D=10.50%), with an average of 15.83% over the 28-year period. From 1990 to 2000, land cover types changed gently across the ten geomorphic units, with proportion indices successively declining for LT (4.29%), SBH (3.49%), SSH (1.88%), LBH (1.82%), LHIB (1.66%), RAP (1.21%), SSM (1.00%), LMH (0.83%), SLH (0.76%), and LVH (0.68%). The average proportion index was 1.76% [Figure 5a: see original paper].

From 2000 to 2010, proportion indices increased remarkably: LT (11.89%), SLH (10.70%), LMH (8.76%), SBH (7.78%), RAP (7.09%), LBH (7.01%), LVH (6.45%), LHIB (5.90%), SSM (4.69%), and SSH (4.53%). The average proportion index was 7.48%, 5.72% higher than the previous decade [Figure 5b: see original paper]. From 2010 to 2018, proportion indices for LT and SLH decreased markedly to 8.13% and 8.12%, respectively, while the other eight geomorphic units showed increasing trends: LVH (19.50%), LHIB (12.75%), RAP (12.48%), LBH (9.59%), LMH (9.57%), SBH (7.87%), SSH (7.68%), and SSM (6.98%). The average proportion index was 10.27%, 2.79% higher than the previous decade [Figure 5c: see original paper].

3.3 Eco-Environmental Quality Index (EQI)

EQI values for the Loess Plateau were 0.1506, 0.1503, 0.1504, and 0.1505 in 1990, 2000, 2010, and 2018, respectively, with considerable variation among geomorphic units . EQI values increased slightly in LBH, LMH, LVH, and SBH, but decreased considerably in LT, RAP, and SLH. Values decreased slightly in LHIB, SSH, and SSM. SSH had the highest EQI, followed by SSM, while SBH had the lowest.

During the study period, the Loess Plateau' s EQI showed apparent geomorphic differences, with three evolution types: deterioration, stability, and improvement [Figure 6: see original paper]. From 1990 to 2000, stable, deteriorated, and improved areas accounted for 97.86%, 1.30%, and 0.83% of the total area, respectively [Figure 6a: see original paper]. Among the ten geomorphic units, RAP had the largest proportions of deterioration and improvement (2.56% and 1.73%), followed by SBH (1.69% and 1.80%). LBH was most stable, with deterioration and improvement proportions of only 0.51% and 0.17%.

From 2000 to 2010, stable, deteriorated, and improved areas accounted for 92.53%, 3.65%, and 3.81% of the total area, respectively [Figure 6b: see original paper]. RAP had the largest deteriorated area proportion (7.46%), followed by LHIB (5.69%), while SSH had the smallest (1.58%). LMH had the largest improved area proportion (5.57%), followed by LHIB and SLH (5.01% and 4.99%), while SSM had the smallest (2.29%).

From 2010 to 2018, stable, deteriorated, and improved areas accounted for 90.69%, 4.81%, and 4.49% of the total area, respectively [Figure 6c: see original paper]. LBH had the largest deteriorated area proportion (9.50%), followed by LVH (6.31%), while SSM had the smallest (3.50%). Correspondingly, LBH had the largest improved area proportion

Note: Figure translations are in progress. See original paper for figures.

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