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Spatiotemporal Evolution of Land Use in the Weibei Dry Plateau: A Case Study of Heyang County (Postprint)

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Abstract

To investigate the spatiotemporal variation patterns of land use in the Weibei dry plateau region, this study takes Heyang County in Weibei, Shaanxi Province as the research area. With the support of GIS and RS technologies, using Landsat TM images from 1990 and 2000, and SPOT images from 2010 as data sources, the methods of geo-information TUPU analysis and land use transfer matrix were employed to analyze the quantitative changes in land use and the spatial conversion characteristics of land use types during two different periods: 1990–2000 and 2000–2010. The results show that: (1) Over the 20-year period, the cultivated land area in Heyang County decreased by 31.25 km², with cultivated land mainly converted to grassland, forest land, construction land, and water bodies. Orchard land area increased by 21.26 km², with a growth rate of 146.6%, primarily converted from cultivated land, grassland, and forest land. (2) The land use change TUPU in the study area is dominated by stable TUPU and post-change TUPU. Stable TUPU accounts for 86.66% of the total area, while post-change TUPU accounts for 7.32%. This indicates that the overall TUPU change of land use types in the study area is relatively stable, and partial changes mainly occurred during the period of 2000–2010. (3) The land use pattern in the study area exhibits a certain hierarchical structure over the 20-year period. Cultivated land, construction land, and water bodies are mainly distributed in areas with little topographic variation or lower elevations; grassland and forest land are primarily concentrated in medium-high topographic gradients; forest land and unused land show dominant distribution in high topographic gradients. Topography and human activities are the main factors driving land use/cover change (LUCC) in this region, while policy orientation and market economic demand also have significant impacts on LUCC. The research results provide a scientific basis for optimizing the spatial allocation of regional land use and decision-making support for ecological construction planning.

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Land Use Dynamics in Weibei Upland in China—A Case Study of Heyang County

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Abstract

To investigate the spatiotemporal variation patterns of land use in the Weibei dry plateau region, this study took Heyang County in Shaanxi Province as the research area. With the support of GIS and RS technologies, and using Landsat TM images from 1990 and 2000 and SPOT images from 2010 as data sources, the study employed geo-informatics TUPU and land use transfer matrix methods to analyze the quantitative changes and spatial conversion characteristics of land use types during two periods: 1990–2000 and 2000–2010. The results showed that: (1) Over the 20-year period, arable land area in Heyang County decreased by 31.25 km², primarily converting to grassland, forestland, construction land, and water bodies. Orchard area increased by 21.26 km², reaching a growth rate of 146.6%, mainly converted from arable land, grassland, and forestland. (2) The land use change TUPU in the study area was dominated by stable TUPU and anaphase TUPU. Stable TUPU accounted for 86.66% of the total area, while anaphase TUPU accounted for 7.32%. This indicates that land use type changes were generally stable, with partial changes mainly occurring between 2000 and 2010. (3) The land use pattern over the 20-year period showed a certain hierarchical structure. Arable land, construction land, and water bodies were mainly distributed in areas with little terrain variation or lower elevations; grassland and forestland were concentrated in medium to high terrain gradients; forestland and unused land showed dominant distribution in high terrain gradients. Terrain and human activities were the main factors driving land use/cover change (LUCC) in this region, while policy orientation and market economic demand also had significant impacts on LUCC. The study results provide a scientific basis for optimizing the spatial allocation of regional land use patterns and decision-making support for ecological construction planning.

Keywords: Land use change; Remote sensing; Spatial pattern; Change TUPU; Driving factor; Weibei upland

Abstract

Spatial-temporal evolution of land use and landscape pattern has become a core component of research on land use and cover change. In order to understand the spatial and temporal change characteristics of land use of Weibei upland, Heyang County, we used the geo-informatics TUPU, land use transfer matrix and the Markov model to evaluate quantitative characteristics of changes and spatial transfer of the land use types in this area based on interpretation data from TM image in 1990 and 2000 and SPOT image in 2010. The driving forces of land use change were also analyzed in this research. The results showed obviously hierarchical distribution of land use types. Cropland, mining and construction land and water body were distributed in area of terrain relief under 25 m as well as slope of slope (SOS) less than 3°. During the past 20 years, cropland was the dominant land use type. Grassland and forestry land mainly distributed on middle or high terrain gradient. Forest land and unused land were the dominant land use types on the area of high terrain gradient. From 1990 to 2010, the area of arable land decreased continuously, from 893.13 km² in 1990 to 861.88 km² in 2010, and arable land mainly transformed into grass land, forest land, mining and construction land and water body. Area of orchard increased obviously, from 14.54 km² in 1990 to 35.76 km² in 2010, mainly transformed from arable land, grass land and forest land. There had 5 land use change TUPU types: the stable type, anaphase type, prophase type, transform type and constant type. Stable type and anaphase type were the dominant types in the study area from 1990 to 2010. The areas of stable type and anaphase type accounted for more than 86% and 7% of total area, respectively. The other land use change TUPUs occupied low proportions of total area. This indicated that land use changes were gently in this area, land use changes mainly occurred during 2000 to 2010. Landform and anthropogenic activities were the main factors driving land use cover change (LUCC). Moreover, the policy guidance and market demand for LUCC also had a greater impact on LUCC. The study provided scientific theoretical basis for the dynamic optimal configurations of land use pattern and the decision support of construction of eco-environment of Heyang County.

Keywords: Land use change; Remote sensing; Spatial pattern; Change TUPU; Driving factor; Weibei upland

Introduction

Land, as an important resource for human survival and social development, serves as a bridge and link between humans and the environment, making it significant for studying the relationship between humans and the environment [1-2]. Human transformation of the surface environment is reflected in different land use patterns [3]. At the same time, land use/cover change (LUCC) has also

caused many environmental and social problems. Therefore, understanding the evolution process of land use landscapes and their driving factors can reveal the internal laws of land use change and explore its impacts on human-environment relationships, which has important academic value and practical significance [4].

LUCC research examines the evolution process of land use types in a region over a long period, reproducing the spatiotemporal dynamics of terrestrial landscapes [5]. Currently, many scholars use remote sensing technology to monitor regional land use spatial patterns and their changes [6-11]. LUCC is the most significant manifestation of human impact on natural environments and an important entry point for exploring human-land relationships. Numerous studies have shown that LUCC involves all issues related to sustainable development, including regional economic development, biodiversity, environmental quality, soil, hydrology, and water resources, and has become a focus and hotspot of global change research [12-16]. Regional LUCC research includes: information extraction methods using different approaches to process remote sensing imagery for interactive land use change information extraction [17-19]; change analysis using GIS technology for long-term regional land use spatiotemporal dynamic change and driving force analysis [20-23]; and from the perspective of sustainable land use and ecological environment evaluation, scholars have evaluated land use changes or ecological risks of land use at different scales or in different geomorphic regions, providing scientific basis for regional planning [24-27]. Due to location differences, the driving forces of mutual conversion of regional land use types differ, and the impact degree of the same driving factors on land use type conversion varies in different regions.

Heyang County in Shaanxi is located in the Weibei dry plateau region, in the northeastern part of the Guanzhong Plain, and is a major agricultural production base in Shaanxi. Since the 1990s, the region' s economy and society have developed rapidly; however, unreasonable resource utilization has brought tremendous pressure on the environment. This paper takes Heyang County as the study area, and with the support of RS and GIS, selects Landsat TM images from 1990 and 2000 and SPOT 5 remote sensing imagery from 2010. After interpretation, current land use data of the study area were obtained. Using land use transfer matrix and information conversion TUPU methods, the spatiotemporal change characteristics and evolution patterns of county-level LUCC in the study area over the past 20 years were comparatively analyzed, aiming to provide scientific basis and reference for optimizing land use change monitoring, land consolidation, and management in this region.

1. Study Area Overview

Heyang County is located at 109°58 -110°25 E, 34°59 -35°26 N, in the northeastern part of the Guanzhong Plain, eastern Weibei dry plateau, facing Linyi County of Shanxi Province across the Yellow River to the east, adjacent to Chengcheng County across the Dayu River to the west, connected to Huanglong County and Hancheng City by Liangshan Mountain to the north, and border-

ing Dali County and Chengcheng County by Tielian Mountain to the south, as shown in Figure 1 [Figure 1: see original paper]. The average elevation of the study area is 721 m, with an average annual temperature of 11.5°C and rainfall of 553 mm, featuring large diurnal temperature variation. The study area has a stepped terrain, gradually rising from southeast to northwest, with elevations ranging from 335–1,543 m, a north-south length of 41.8 km, an east-west width of 35.6 km, and a total area of 1,328.71 km². The geomorphic types are, in order, valley terraces, loess tablelands, and low-medium mountains.

2.1 Data Sources and Data Processing

The research data included Landsat TM and ETM+ multi-band images from 1990 and 2000, and SPOT5 multi-band satellite imagery from 2010. The spatial resolution of the first two phases was 30 m × 30 m, with bands 4, 3, 2 (RGB) combination. To avoid differences in vegetation types due to different seasons, images from the same season or even the same month were selected. Therefore, this study used two scenes from July 1990, two scenes from May 2000, and two scenes from May 2010. Topographic maps at 1:50,000 scale were purchased, scanned and digitized to generate a DEM for subsequent use. Using ERDAS 9.3 software, the 1990 TM and 2000 ETM+ single-band images were fused to obtain multi-band images, as well as the 2010 SPOT5 multi-band remote sensing imagery. The three-phase images (two scenes each) were mosaicked and projected. Based on 1:10,000 topographic maps, 30 ground control points were collected, and polynomial method was used for spatial correction. Registration error was controlled within half a pixel. The images were clipped using the administrative boundary vector map of Heyang County to obtain three-phase multi-band images of the study area, followed by image enhancement processing for feature factor extraction.

According to the national "Technical Regulations for Land Use Status Survey," using ERDAS and ArcGIS software combined with field surveys, land use types were classified according to national land classification standards. Based on analysis accuracy requirements, land types in the study area were merged and classified from high to low levels. The study area land types were divided into seven categories: arable land, forestland, grassland, construction land, orchard, water body, and unused land. This study used visual interpretation method to interpret the three-phase images. Combined with field investigations, historical statistical data of the study area, and second land survey data, the interpretation results were compared and found to basically conform to reality, with results shown in Figure 2 [Figure 2: see original paper].

2.2.1 Land Use Spatial Conversion

Land use state transition matrix comprehensively and specifically describes the structural characteristics of regional land use changes, reflecting the direction of land use change guided by human activities. This method originates from

the quantitative description of system state and state transition in system analysis, reflecting the process of a metastable system transforming from state T to T+1 within a certain time interval, which can better reveal the spatiotemporal evolution process of land use patterns [28]. Its mathematical expression is:

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix}$$

where S_{ij} represents the land use state at the beginning and end of the study period, and n is the number of land use types.

Currently, common land use state transition matrices can use either land use type area or the conversion probability from initial to final land use types, called the Markov transition probability matrix [29]. This study used the former for land use type transfer analysis in Heyang County.

2.2.2 Land Use Change TUPU Analysis

Through the map algebra function of the geographic information spatial analysis module, the land use change information TUPU of the study area from 1990–2010 was obtained, realizing an effective information collection of land use spatial pattern and its evolution process. According to the change characteristics of land use TUPU units in the study area, they were summarized into five types of TUPU change patterns [30]: land use with no change from initial to final year is called stable TUPU; land use that only changed during 1990–2000 is called prophase TUPU; land use that only changed during 2000–2010 is called anaphase TUPU; land use type that changed from one way to another and then back to the initial way is called transition TUPU; land use type that changed in both periods is called continuous change TUPU.

2.2.3 Land Use Terrain Gradient Analysis

This study comprehensively considered the influence degree of terrain factors on land use in the study area, using landform relief, slope change rate and aspect grading to analyze the influence of terrain on the evolution of land use spatial pattern [31]. Landform relief is an important index describing regional terrain characteristics, which can quantitatively describe regional terrain relief characteristics from a macro perspective. It is the difference between extreme elevation values in a region and affects land use pattern landscape structure in many aspects, such as accessibility, soil type, moisture, temperature, etc. Ground slope change rate is the rate of change of ground slope in differential space, calculated by again calculating the slope of ground slope values, reflecting terrain profile curvature information. Ground slope change rate mainly affects land use patterns by influencing farming methods, water and nutrient element redistribution, etc. Aspect is one of the important factors affecting the

redistribution of sunlight and solar radiation received by micro-terrain surfaces. Different aspects receive different degrees of solar radiation, mainly affecting crop growth suitability from soil type, temperature, and energy redistribution aspects, playing an important role in mountain ecology.

Based on terrain gradient classification, the geoinformatics TUPU of land use spatial pattern evolution process was selected, combined with land use change intensity, to analyze the characteristics of land spatial pattern changes under different terrain gradients in the study area. Based on the actual situation of the study area, terrain factors were classified (Table 1). Using ArcGIS 10.2 raster data reclassification function, each terrain factor was classified and the area of each level was calculated, with raster cells uniformly set to 30 m × 30 m.

Distribution index can reflect the distribution characteristics of land use type structure changes or various TUPU types on different terrain gradients [31], with the formula:

$$DI = \frac{A_{ij}/A_i}{A_j/TA}$$

where DI is distribution index, i is the ith TUPU type, j is the jth terrain level, A_i and A_{ij} represent the total area of the ith land type and its distribution area in the j terrain area respectively, A_j is the total land area of the jth terrain level, and TA is the total area of the study area. If DI value is greater than 1, the land use TUPU shows dominance, with larger DI values indicating higher dominance; if DI value is less than 1, it shows disadvantageous distribution, with smaller values indicating lower dominance.

3.1 Land Use Type Conversion Analysis

As shown in Tables 2 and 3 , from 1990 to 2000, the conversion directions of various land use types in the study area were relatively complex. Arable land area decreased by 23.63 km², a reduction of 2.65% of the original arable land area. With increasing benefits from economic forest planting, orchard area showed the largest increase, adding 8.32 km² over 10 years with a growth rate of 57.22%. The change in orchard area mainly came from conversion of arable land, driven by agricultural structural adjustment and economic interests. Water body area increased by 2.34 km², a growth rate of 2.51%. Unused land area decreased by 11.34 km², a reduction of 38.91%. Construction land area increased by 17.71 km², a growth rate of 26.05%, mainly due to population increase, improved living standards, and development of some industrial sectors, with large amounts of arable land converted to construction land. As some arable land, forestland and unused land were converted to grassland, grassland area increased by 9.89 km², a growth rate of 6.04% of the 1990 grassland area. Forestland decreased by 3.28 km², a reduction of 4.94%.

From 2000–2010, forestland quantity increased by a net 4.16 km² (see Tables 2 and 4), with the increase mainly coming from arable land, grassland, and unused land. There may be two factors: first, government administrative decision-making behavior led to changes in land use methods and degree, such as the Grain for Green Project started in 1998. Second, agricultural industrial structure developed toward high-benefit directions, such as conversion of some sloping arable land to economic forest, leading to increased forestland area. Arable land area slightly decreased from 869.50 km² to 861.88 km², a reduction of 0.88%. Water body area decreased by 6.25 km², a reduction of 6.53%. Orchard area increased by 12.89 km², a growth rate of 56.39%. Unused land decreased by 0.23 km², with little change. Grassland area slightly decreased by 2.76% compared to 2000. Meanwhile, due to increased population pressure, construction land area continued to increase by 1.86 km², a growth rate of 2.17%, related to continuous population and economic growth.

3.2 Land Use Change TUPU Analysis

Land use change TUPU can well reflect the change process of land use at each stage. Using ArcGIS 10.2 software spatial analysis function, land use change TUPU information from 1990–2010 in the study area was extracted (Figure 3 [Figure 3: see original paper]) to analyze the land use change process.

In the study area land use TUPU, stable type area was 1,151.46 km², accounting for 86.66% of the area, mainly showing the “arable–arable–arable”and “grassland–grassland–grassland” land use change patterns. Arable land and grassland were the main land use types in the study area, accounting for nearly 82% of the total area of this pattern. Anaphase TUPU ranked second, with an area of 97.29 km², accounting for 7.32% of the area. Prophase TUPU area was 29.75 km², accounting for 2.24% of the area. Transition TUPU area was 45.67 km², accounting for 3.44% of the area. Continuous change TUPU area was 4.48 km², accounting for 0.34% of the area. These data show that land use changes in the study area were relatively stable over the 20-year period. Compared with 1990–2000, land use changes were relatively more intense during 2000–2010. The results indicate that the land use structure in the study area was mainly agricultural. From 1990–2000, due to regional economic development, the human–land contradiction was prominent, with some grassland converted to arable land and some arable land converted to construction land. The anaphase TUPU area was three times that of prophase TUPU area, indicating that human activities were relatively frequent after 2000. Due to rapid population increase, large amounts of arable land were occupied by construction land, while humans frequently changed land use methods to adapt to market demands.

3.3.1 Terrain Relief Impact

The overall terrain of the study area is relatively flat, with terrain relief <25 m gradient area accounting for more than 57% of the total area. The land use structure in the area showed obvious differences at different terrain relief

levels (as shown in Table 5). Arable land and construction land were mainly concentrated in areas with terrain relief <100 m. In gradients with terrain relief >100 m, forestland and grassland showed dominant distribution. During 1990–2010, the dominance of grassland and forestland on gradients >100 m showed an increasing trend, while on gradients <100 m it remained unchanged or decreased. Arable land and water body area changed little, while unused land showed a decreasing dominance trend on gradients >100 m, indicating that mountainous areas in the study area have been developed and utilized to some extent since 1990. The proportion of arable land, construction land, and water bodies decreased with increasing terrain relief, while the proportion of forestland, grassland, and unused land increased with increasing terrain relief.

3.3.2 Slope Change Rate Impact

Slope change rate has an important influence on regional land use structure. Land use types in the study area varied significantly with slope change rate gradients (Table 6). The study area was mainly dominated by slope change rates of 0°–3°. Except for grassland, forestland, and orchard, other land use types showed dominant distribution within the 0°–3° range, while grassland and forestland showed obvious dominant distribution above 3° slope change rate. Except for grassland, all other land use types showed decreasing area trends with increasing slope change rate. Arable land showed no obvious changes at various gradients during these 20 years, while orchard and water body areas showed increasing trends within the 0°–1° gradient range. Forestland and unused land showed obvious decreasing dominance trends within the 0°–1° range, but obvious increasing distribution above 3° gradients. Larger regional slope change rates pose significant obstacles for human land management, so human activities are mostly concentrated in areas with small slope change rates. On the other hand, since the implementation of the "Beautiful Mountains and Rivers Project," returning farmland to forest has reduced soil erosion and protected the ecological environment, keeping land use patterns on steep slopes basically as forest and grassland, while human activities are concentrated in areas with little slope variation.

3.3.3 Aspect Impact

The study area basically has no flat slopes, with sunny and semi-sunny slopes accounting for over 80% of the total area. The aspect gradient differences of land use structure changes in the area were obvious (Table 7). Arable land and construction land were mainly distributed on sunny or semi-sunny slopes, showing dominant distribution. Grassland, forestland, water bodies, and unused land showed dominant distribution on shady and semi-shady slope gradients. During 1990–2010, arable land and water body area changed little in each aspect gradient. The dominance of orchard and forestland on shady slopes slightly decreased, while grassland slightly increased. The dominance of unused land on sunny slopes decreased, but slightly increased on semi-sunny, semi-shady, and

shady slopes, especially showing obvious increase on shady slope gradients.

4 Discussion and Conclusion

The study area is rich in agricultural resources, with flat terrain and diverse soil types suitable for cultivation. Arable land is the main land use pattern in the entire area. However, due to economic benefits and social development demands, arable land and unused land area have decreased year by year. With population growth and economic development needs, orchard and construction land area have increased significantly. Grassland and water body area have continued to decrease, especially grassland area with a large reduction rate, while water body area decreased with a smaller rate.

Factors affecting land use change mainly include socioeconomic and natural factors. Socioeconomic factors include economic growth, population increase, technological progress, social development, and human activity orientation. Socioeconomic development changes the structure, methods, quantity, and degree of various land uses, representing the driving force behind spatiotemporal evolution of land use patterns [32]. Natural factors include terrain, environment, climate, and natural disasters, but human activity is the most active and important factor causing LUCC [33]. The study area population increased from 398,000 to 436,000 over 20 years, an increase of 9.5%. The decrease of arable land, grassland, and unused land, and the large increase of orchard and construction land indicate that population increase and human activities are inseparable from LUCC. On the other hand, land use structure patterns are formed under certain economic development stages and policy environments, and the role of policy orientation on LUCC cannot be ignored. From the 20-year land use pattern evolution in the study area, policy factors played a direct role in changes of forestland, arable land, orchard, and construction land. Changes in forestland and grassland were mainly driven by national ecological environmental protection policies, especially the Grain for Green Project started in 1998, which encouraged returning unsuitable cultivated land to forest and grass, gradually adjusting the agricultural, forestry, and animal husbandry land use structure, leading to a large increase in forestland in the latter 10 years of the study period. The adjustment of agricultural industrial structure in the study area led to continuous increase in orchard area over 20 years, increasing total agricultural output value.

1) The land use change characteristics in the study area over 20 years were that arable land area decreased year by year from 893.13 km² in 1990 to 861.88 km² in 2010, mainly converting to grassland, forestland, construction land, and water bodies. Orchard area increased year by year with a large rate, from 14.54 km² in 1990 to 35.76 km² in 2010, mainly converted from arable land, grassland, and forestland.

2) The land use information TUPU in the study area was dominated by stable TUPU and anaphase TUPU. Stable TUPU accounted for 86.66%

of the total area, anaphase TUPU accounted for 7.32%, and other TUPU types accounted for very small proportions. This indicates that land use type TUPU changes were generally stable, with partial changes mainly occurring between 2000–2010. Using the geo-informatics TUPU method, the study analyzed the land use pattern and spatiotemporal evolution process in the study area, revealing the conversion trends of various land use types.

3) During 1990–2010, land use type distribution in the study area showed a certain hierarchical pattern within terrain gradients. Arable land, construction land, and water bodies showed dominant distribution in low terrain gradients; grassland and forestland were mainly concentrated in medium to high terrain gradients; forestland and unused land showed dominant distribution in high terrain gradients. The terrain gradient differentiation characteristics in the study area are the result of multiple factors working together, with natural factors being the basis of LUCC and social development and national policies being the main driving forces. This study provides a theoretical basis for future land resource use, management, and rational planning in the study area.

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

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