Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 4, No. 3, 2022

Temporal and Spatial Evolution of Land Use in Gansu Section of The Yellow River Basin and Analysis of Driving Forces

Tong Zhang*

College of Geography and Environmental Science, Northwest Normal University, Lanzhou 730070, China
* Corresponding author:

Abstract: Land use change is an essential representation of the interaction between human activities and the natural environment as well as a vital part of global environmental change and sustainable research. Exemplified by the Gansu section of the Yellow River Basin, land-use transfer matrix, land-use change index and principal component analysis are used to study the spatiotemporal evolution pattern and driving mechanism of land use. The results revealed that during the study period, grassland, plowland and woodland are the primary type of land use in the Gansu section of the Yellow River Basin, land use transition was mainly based on the transfer between plowland, grassland and construction land. The comprehensive land use change index was 0.39%, showing a fluctuation trendency of the first rising, then falling and then rising; the individual land-use change index in different land use types was shown in descending order: Construction land > water > plowland > woodland > grassland > unused land. Population structure, economic level, and industrial structure are the main driving factors affecting the change of construction land and plowland area.

Keywords: Land Use Change, Driving Force, Yellow River Basin.

1. Introduction

The land is an essential spatial carrier of human social and economic activities. Land use change is an important representation of the interaction between human activities and the global environment as well as a vital part of global environmental change and sustainable research [1-2]. As the closest link between humans and nature, human activities consistently influence the evolution of land use on urban, regional, national and even global scales. Therefore, it has become a major research field to discuss the development of the spatiotemporal pattern of land use and its driving mechanism [3-5].

Previous research on land use mainly focused on the evolution and driving mechanism and its effect. In addition, some scholars concentrated on land use scenario simulation and prediction. In terms of research methods, the change in land use structure and quantity is analyzed by the land-use transfer matrix [6], the land-use change index [7] land-use degree [8] and so on. Principal component analysis [9], geographical weighting model [10] and random forest model [8] are widely used to explain the driving mechanisms of land use change. The ecological environmental quality index [11] is often introduced into the study of the ecological effects of land use. GCAM-CA model [12], CLUE-S model [13] and grey prediction model [14] are utilized in predicting the quantity and structure of land use. The scale of research is gradually altering from a global scale to a regional scale [15].

The watershed is an area with a strong interaction between the natural environment and human activities [16], and the balance of the watershed ecosystem is significantly affected by land use change [17]. The Yellow River Basin is an important ecological security barrier and an important area for population and socio-economic development [18], but the fragile ecological environment and extensive land use of the Yellow River Basin seriously restrict the process of socio-economic development. The ecological protection and high-quality development strategy of the Yellow River Basin was first proposed in 2019 and has became a major national development strategy, much attention has been paid to the land use changes in the Yellow River Basin [19-20]. Most of the existing land use studies are bounded by provincial administrative regions, and there is an absence of more specific research on land use in watershed. The Gansu section of the Yellow River Basin has special socio-economic conditions, diverse regional types, and a complex ecological environment, so it is more representative and typical [21]. Therefore, regarding the existing research, 57 counties in the Gansu section of the Yellow River Basin were selected as the study areas to study the spatiotemporal evolution characteristics and driving mechanism of their land use patterns.

2. Study Area and Data Source

The Gansu section of the Yellow River Basin is in the central and eastern part of Gansu Province, spanning three geomorphological units: Longdong Loess Plateau Area, Longzhong Loess Plateau Hilly and Gully Area, and Gannan Plateau Area, which is an important water conservation area and recharge area in the upper reaches of the Yellow River. Referring to related studies [21-22], based on the natural Yellow River Basin and maintains the integrity of the county administrative division unit as much as possible, 57 counties (counties, county-level cities and municipal districts) along the Yellow River in Gansu Province were selected as research samples (Figure 1).

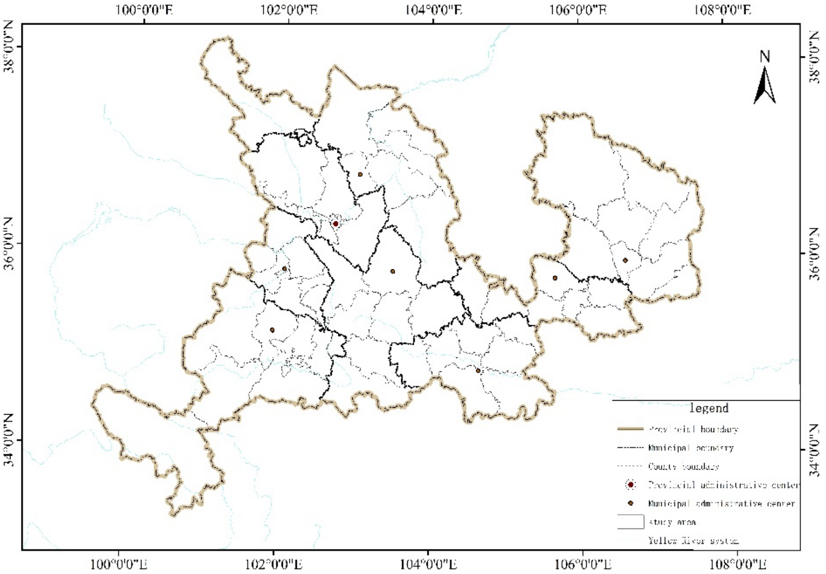

Figure 1. Study area

Land-use data in 2000, 2005, 2010, 2015, and 2020 were from the Data Center for Resources, and Environmental Sciences, Chinese Academy of Sciences; the data set divided land types into 6 primary and 25 secondary categories, the first category contains plowland, woodland, grassland, water, construction land, and unused land. Social and economic data are from the China County Statistical Yearbook, Gansu Development Yearbook, Gansu Rural Statistical Yearbook and statistical bulletins of cities and prefectures of Gansu.

3. Methods

3.1. Land-use transfer matrix

The land-use transfer matrix was used to reflect the change in the number and the conversion process of land types in the Gansu section of the Yellow River Basin during the study period [6].

$$S_{ij} = \begin{Bmatrix} S_{11} S_{12} \dots S_{1n} \\ S_{21} S_{22} \dots S_{2n} \\ \dots \\ S_{n1} S_{n2} \dots S_{nn} \end{Bmatrix} \tag{1}$$

Where S_{ij} represents the area from land type i to type j; n is the number of land types.

3.2. Land-use change index

The individual land-use change index is used to investigate the change speed of one specific type. The comprehensive land-use change index can dynamically analyze the intensity of the whole land use change [7].

$$\text{SLUD} = \frac{LUC_{(i,t_1)} - LUC_{(i,t_2)}}{LUC_{(i,t_2)}} \times \frac{1}{T} \times 100\% \tag{2}$$

$$\text{ILUD} = \left[\frac{\sum_{i=1}^{n} \Delta LUC_{i-j}}{\sum_{i=1}^{n} LUC_{(i,t_1)}} \right] \times \frac{1}{T} \times 100\% \tag{3}$$

Where SLUD is the individual land-use change index, $LUC_{(i,t_1)}$ and $LUC_{(i,t_2)}$ are the area of a particular land type during t_1 and t_2 respectively; ILUD means the comprehensive land-use change index, LUC_{i-j} is the area of land type i transformed into type j; $LUC_{(i,t_1)}$ is type i land use area at t_1 and T is the research period.

3.3. Principal component analysis (PCA)

Principal component analysis (PCA) is a multivariate statistical method that transforms multiple indicators into a few composite indicators and explores the relationship between composite indicators and dependent variables [7]. At present, scholars mainly use principal component analysis to study the driving mechanism of land use, which has produced rich research results [7,9,23].

4. Results and Discussion

4.1. Land-use transition

Table 1 describes the land-use transfer matrix of the Gansu section of the Yellow River Basin from 2000 to 2020. It revealed that grassland, plowland, and woodland are the primary land use types in the Gansu section of the Yellow River Basin. Areas of all land types are increased during the study period except for plowland and unused land. Land use transition was mainly based on the transfer between plowland, grassland and construction land, a total of 3948.61 km² of plowland was transferred, of which 2425.18 km² flowed into grassland, and 983.42 km² flowed into construction land. Grassland and construction land was shifted into 2579.09 km² and 1363.17 km² respectively, and plowland was the most vital transfer source. Which is due to the implementation of the project of returning farmland to forest and grassland and the acceleration of urbanization and industrialization.

From the perspective of space (Figure 2), the transition of plowland to construction land mainly occurs in areas with good geographical locations and high socio-economic development. Lanzhou is the capital of Gansu Province with a high level of industrialization and urbanization, promoting the expansion of construction land. The transfer of plowland to grassland mainly occurs in major ecological function areas such as Linxia and Gannan, mainly due to the implementation of environmental policies. The transfer of grassland to plowland mainly occurs in some counties in Tianshui and Dingxi, which are the main producing areas of agricultural products with a long history of agricultural cultivation, relatively flat land, and good cultivable soil.

Table 1. Land-use transfer Matrix (Km^2)

2020 2000	Grassland	Plowland	Woodland	Construction land	Water	Unused land	Roll-out total
Grassland	76705.49	401.02	532.90	309.66	25.73	76.21	1345.53
Plowland	2425.18	40966.94	413.54	983.42	36.34	90.13	3948.61
Woodland	40.47	30.73	19187.51	48.83	16.97	2.54	139.54
Construction land	16.80	122.10	4.76	2097.78	1.31	0.55	145.51
Water	8.23	14.72	1.05	12.96	904.48	2.08	39.04
Unused land	88.41	26.18	2.33	8.30	47.11	3379.36	172.33
Roll-in total	2579.09	594.76	954.58	1363.17	127.46	171.50	

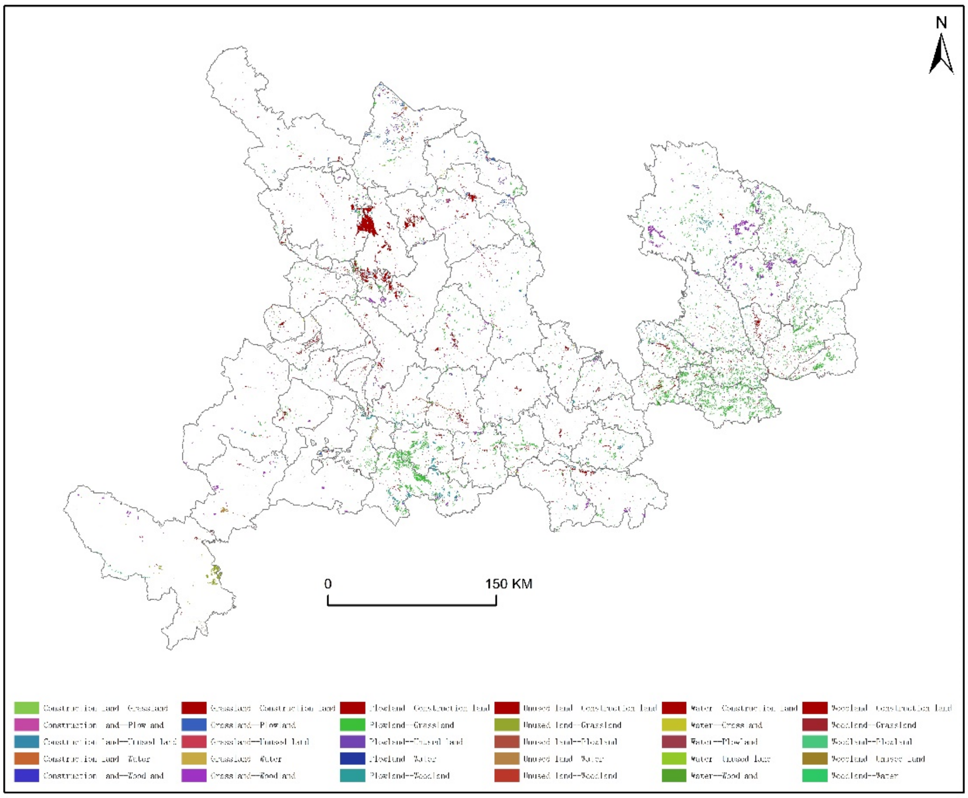

Figure 2. Spatial distribution map of land-use transition

4.2. Change of land-use index

During the study period, the comprehensive land-use change index in the Gansu section of the Yellow River Basin displayed a fluctuate tendency of first rising, then decreasing, and then rising (Table 2). The change index reached its maximum between 2000 and 2005, implying that the land-use change was the most drastic during 2000-2005, and the change index reached its minimum value in 2005-2010, and the index change tended to stabilize. From the perspective of the individual land-use change index, Construction land had the highest change index of 2.71%; will be succeeded by water and plowland, which were 0.47% and 0.37%, respectively; unused land had the lowest change index of close to 0, which mainly because the invariants of unused land accounted for relatively large and the amount of transfer out was small, while the invariants of construction land accounted for relatively small, but the amount of conversion was large.

From 2000 to 2020, the change index of grassland, plowland and water area showed a trendency of first rising and then decreasing, indicating that these land types changed sharply from 2000 to 2005, and were relatively stable after 2005, which may be related to the implementation of the project of returning plowland to grassland. The change index of construction land first decreased and then increased, and the change index changed greatly from 2010 to 2015, indicating that the urbanization process accelerated during this period, which promoted the expansion of construction land. The woodland change index first decreased and then increased, indicating that the amount of woodland transfer in the early stage was less, but large in the later stage. The change index of unused land was relatively small, and its change index increased between 2010 and 2020, which may be due to the implementation of ecological conservation policies that promoted the conversion of a large amount of unused land to grassland.

Table 2. Change of land-use change index

	2000-2005	2005-2010	2010-2015	2015-2020	2000-2020
The comprehensive land-use change index	0.79%	0.83%	0.73%	0.79%	0.39%
Grassland	0.03%	-0.16%	0.11%	0.07%	0.08%
Plowland	-0.20%	0.41%	0.05%	-0.20%	-0.37%
Woodland	0.25%	0.18%	0.01%	-0.02%	0.21%
Construction land	0.74%	0.57%	1.67%	1.64%	2.71%
Water	0.11%	0.23%	0.48%	0.09%	0.47%
Unused land	-0.09%	0.04%	0.43%	-0.37%	0.00%

4.3. Driving mechanism of land-use

Previous studies have shown that the Driving mechanism of land-use is complex, with multiple indicators involving natural and socio-economic factors. Due to the prolonged period of natural factors' influence on land-use change, the impact of human activities has greatly surpassed that of natural elements [23]. Refer to existing studies, this paper selected the total population (X1), urbanization rate (X2) and urban population density (X3) from the perspective of Population structure; per capita GDP (X4), resident savings deposits (X5), fiscal revenue (X6), investment in fixed assets (X7) and total retail sales of consumer goods (X8) were selected from the angle of economic level; the Proportion of primary industry (X9), the proportion of secondary industry (X10) and the proportion of tertiary industry (X11) were selected from the aspect of industrial structure; total power for agricultural machinery (X12) and grain yield (X13)were selected from the agricultural technology level. Plowland (Y1) and construction land (Y2) with most affected by human activities were selected for the analysis of driving mechanism. The principal component analysis method was used to screen the components with characteristic values greater than 1 as the principal components. Three prominent component were picked for construction land and plowland, respectively, and their eigen values and contribution rates are shown in Table 3. It can be observed that the eigen values of constituents for construction land are 4.73, 1.50 and 1.12, respectively, and the cumulative contribution rate of the three members is 73.47%. The eigen values of constituents for plowland were 5.51, 1.43 and 1.25, respectively, and the cumulative contribution rate of the three members was 74.44%.

Will as can be seen from the principal component load matrix (Table 4), the first principal component of construction land is strongly correlated with the total population, urbanization rate, per capita GDP, resident savings deposits, per capita fiscal income, retail sales of consumer goods and the ratio of the primary industry, among which, the proportion of the primary industry showed a significant negative correlation. Population structure, economic level and industrial structure are the main driving factors affecting construction land. The first principal component of plowland is strongly correlated with the total population, urbanization rate, per capita GDP, resident savings deposits, per capita fiscal income, fixed assets investment, retail sales of consumer goods and the proportion of primary industry. Population structure, economic level and industrial structure are the main driving factors affecting plowland.

Table 3. Eigen values and contribution rate of principal component

Land use type	Principal component	Eigen values	Contribution rate/%	Cumulative Contribution rate/%
Construction land	1	4.73	47.30	47.30
	2	1.50	15.02	62.32
	3	1.12	11.15	73.47
Plowland	1	5.51	50.13	50.13
	2	1.43	12.96	63.09
	3	1.25	11.35	74.44

Table 4. Load matrix of principal components

Driving factor	Construction land			Plowland		
	Principal component			Principal component		
	1	2	3	1	2	3
X1	0.61	0.58	0.23	0.63	0.58	0.07
X2	0.76	-0.43	-0.20	0.74	-0.52	-0.03
X3	-	-	-	0.25	0.14	0.70
X4	0.74	-0.45	-0.19	0.74	-0.52	-0.01
X5	0.90	0.35	-0.03	0.91	0.29	-0.19
X6	0.93	0.14	-0.05	0.94	0.08	-0.10
X7	-	-	-	0.92	0.05	0.10
X8	0.88	0.38	-0.08	0.88	0.30	-0.27
X9	-0.66	0.51	0.18	0.63	0.57	-0.12
X10	-	-	-	-	-	-
X11	0.47	0.04	0.33	0.46	0.17	0.04
X12	0.13	-0.17	0.76	0.16	0.04	0.79
X13	0.32	-0.46	0.51	-	-	-

Note: The indicators underlined in the table did not pass the significance test or the Pearson correlation coefficient was small, so these indicators were excluded.

4.4. Discussion

The land-use transfer matrix and land-use change index reflect the response of land use to human activities during spatiotemporal change of land use. In recent years, many scholars have studied the evolution of land use in the Heihe River Basin [25], Huaihe River Basin [9] and Yellow River Basin [26] by using the above methods. The results show that the influence of human activities on land use in different regions gradually increases with the change of time, and most of them show the characteristics of decreasing cultivated land area and increasing construction area, which was similar to the evolution of land use pattern in Gansu section of the Yellow River Basin. This is related to the vigorous implementation of the plan of returning farmland to forest and grassland in the late 90s of the 20th century and the promotion of urbanization and industrialization. Principal component analysis is one of the important methods to study the driving mechanism of land use, and it is also applicable to the watershed scale to a certain extent. For example, Zhang's research on the Southeast River Basin [7] and Deng's research on the Dongjiang River Basin [14], the former discusses the natural and human factors of land-use change, while the latter discusses only anthropogenic drivers of land use, both of which indicate a significant correlation between human activities and land use change. Since 2000, the accelerated urbanization of the study area has led to rapid urban population growth, rapid economic development, and industrial structure changes, all of which have affected construction land and cultivated land to varying degrees. Under the background of ecological protection and high-quality development strategy of the Yellow River Basin rising to a major national development strategy, the Gansu section of the Yellow River Basin, as the pilot area in the upper reaches of the Yellow River Basin, has extreme requirements for land resources, so it is necessary to accurately grasp the characteristics of land use change and its driving mechanism, so as to catch the methods and paths of land use transition on time.

5. Conclusions

(1) Grassland, plowland, and woodland are the primary land use types in the Gansu section of the Yellow River Basin. During the study period, land use transition was mainly based on the transfer between plowland, grassland and construction land. Among them, the transfer of plowland to construction land mostly occurs in areas with better geographical location conditions and higher socio-economic development levels. The transfer of plowland to grassland mainly occurs in Linxia, Gannan and other major ecological function areas. The transfer of grassland to plowland mainly occurred in Tianshui, Dingxi and other major agricultural production areas.

(2) During the study period , The comprehensive land use change index in Gansu section of the Yellow River Basin was 0.39%, which showed a fluctuating trendency of first increasing, then decreasing and then increasing, reached the maximum during 2005-2010, and then gradually levelled off. the individual land-use change index in different land use types was shown in descending order: construction land > water area > plowland > woodland > grassland > unused land.

(3) The construction land and plowland both show obvious socio-economic factors driving type, population structure, economic level and industrial structure are the main driving factors affecting the change of construction land and plowland area.

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