Impact Analysis of Landscape Pattern Evolution on Runoff Variation in the Yellow River Basin of Qinghai Province based on LUCC

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Abstract: The Yellow River Basin in Qinghai Province is the practice area of national environmental protection priority. In recent years, with the influence of climate change and human activities, the landscape pattern and runoff in the region have changed significantly. This paper conducts the following research to explore the influence of regional landscape pattern variation on runoff change. Firstly, the average sliding method is used to analyze the interannual variation trend of runoff in the study area. Secondly, the landscape pattern change is analyzed by land-use transfer matrix and landscape pattern index. Finally, the Pearson correlation coefficient method is used to analyze the influence of landscape pattern changes on runoff change. The results show that, unused land and grassland are the main conversion objects. The dominant role of grassland as the dominant type of landscape is gradually increasing, and each patch type tends to gather, which plays a certain role in promoting the formation of surface runoff. In 1995-2005, the extent of land desertification increased, and the area of grassland degraded to unused land was 3704.63 km^2. The patch types were continuously dispersed and fragmented, and the blocking effect on surface runoff was enhanced. During 2005-2018, unused land was substantially converted into grassland due to the implementation of environmental protection projects. Shannon diversity index decreased from 0.9946 to 0.9278. The decrease of landscape heterogeneity played a certain role in promoting the formation of surface runoff.

1 INTRODUCTION

With the increase of human activity impacts, the land-use types of the Yellow River Basin (YRB) in Qinghai Province have undergone major changes in the late 1990s (Chen et al., 2020). Watershed runoff no longer shows typical temporal characteristics with climate change, and to a certain extent, the influence of human activities is superimposed (Xu et al., 2020; Liu et al., 2020). Human activities transformed the regional landscape pattern (Wang et al., 2021). The change of landscape pattern in the basin can transform the soil infiltration and surface evaporation of runoff, thereby affecting the runoff yield and confluence mechanism of the basin (Liu et al., 2019). The landscape index is a quantitative index reflecting the information structure and spatial configuration of landscape patterns (Ma et al., 2019). Many scholars use it to quantify the response relationship between landscape patterns and runoff (Zhang et al., 2021; Bin et al., 2021). Luo et al. (2020) analyzed the changes in land use and runoff in the upper and middle reaches of the Huaihe River and concluded a specific correlation between the two aspects. Li et al. (2020) found that runoff in Yihe River Basin was significantly correlated with the Landscape shape index and Contagion Index. Xiao et al. (2017) found that the landscape of the Fuzhou urban area gradually developed to high fragmentation and complex shape, and the retention effect of landscape pattern on surface runoff gradually increased. These previous studies have achieved plentiful results, which provides an essential basis for the study of this paper. But these studies mainly focus on small-scale areas and are not representative. At present, the change analysis of land-use types and landscape pattern in the YRB in Qinghai Province is mostly based on municipal and county administrative units (Zhu et al., 2020). There is a lack of quantitative data comparison in analyzing the impact of human activities on the basin's runoff. Given this, based on previous studies, this paper analyzes the water resources bulletin data

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of the study area from 1995 to 2018 and obtains the variation trend of precipitation and runoff in a long time series. The change characteristics of landscape patterns in the study area are obtained using the land-use transfer matrix and landscape pattern index. Then Pearson correlation coefficient method is used to quantitatively evaluate the impact of landscape pattern change on runoff change.

2 OVERVIEW OF THE STUDY AREA AND DATA SOURCES

2.1 Overview of the Study Area

The YRB in Qinghai Province is located in eastern Qinghai Province of China, which is located at 32°N–39°N and 95°E–103°E. The range from the Yellow River (YR) source to the Jishixia, including the YR source area above the Longyangxia and the mainstream area from the Longyangxia to the Jishixia (Figure 1). The area is about 152,000km^2, accounting for 20% of the total area of the YRB. The region is located in the ' roof of the world ' of the Qinghai-Tibet Plateau, and is the upper YR ecological key construction area, and is an essential part of the Chinese water tower. There are 35 county-level administrative regions in this region. The regional ecological system structure is relatively simple, mainly alpine meadow and alpine grassland meadow. Permafrost developed, weak ability to resist external interference, poor self-regulation. The climate belongs to the plateau continental alpine climate. The average annual precipitation is 250-800mm.

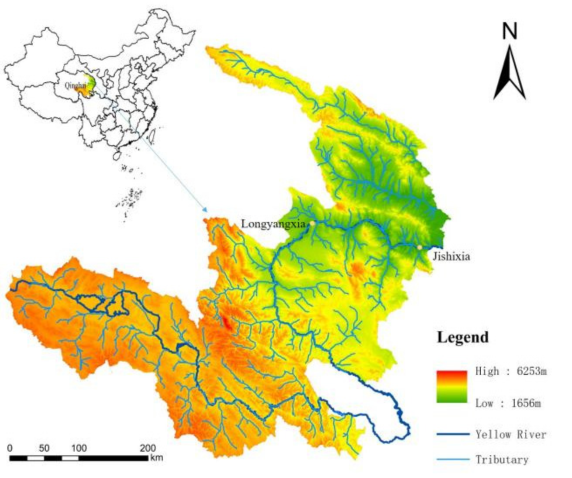

Figure 1: The YRB range and elevation map of Qinghai Province.

2.2 Data Sources

This study obtained the area's 30m grid land-use data in 1995, 2000, 2005, 2010, 2015, and 2018 through the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences. It includes six primary types of unused land, grassland, water area, cultivated land, forest land, construction land, and 25 secondary types of paddy fields, dry land, high, medium, and low coverage grassland, lakes, and towns. Combined with the boundary map of the YRB in Qinghai Province, the land-use status of the YRB in Qinghai Province in each year was extracted by ARCGIS10.8.1 software and the landscape pattern was analyzed by Fragstats4.2 software. Precipitation and runoff data are derived from the water resources bulletin of Qinghai Province from 1995 to 2018, and the annual average runoff depth represents the size of annual runoff.

3 RESEARCH METHODS

Based on the research content, this paper firstly analyzes the change trend of runoff in the study area. In order to eliminate the influence of mutation factors on runoff change, this paper mainly uses the average sliding method to process the runoff data. Secondly, based on the raster data of land-use in the study area, the transfer matrix is selected to analyze the change rules of land-use. Then based on the land-use data, the landscape index is used to quantitatively analyze the characteristics of landscape pattern change. Finally, the Pearson correlation coefficient method is used to explore the influence of landscape pattern change on runoff change. The main research methods are as follows:

3.1 Analysis of Land-use Change

Considering the mutual transformation of various land types, in order to analyze the spatial transformation of land types from 1995 to 2018, the spatial change of land-use types is analyzed based on the area transfer matrix method. The expression is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \cdots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \tag{1}$$

In the formula S represents the area of land-use type, n represents the number of land-use types, i, j represents the early and late land-use types of the study.

3.2 Analysis of Dynamic Change Parameters of Landscape Pattern

In this study, with the help of Fragstats4.2, combined with the ecological significance of each landscape index and the purpose of this study, seven indexes were selected, including Patch Density (PD), Landscape Shape Index (LSI), Largest Patch Index (LPI), Contagion Index (CONTAG), Shannon Diversity Index (SHDI), Shannon Evenness Index (SHEI) and Landscape Division Index (DIVISION). Thus, the change characteristics of landscape pattern in the study area were quantitatively analyzed.

3.3 Influence of Landscape Pattern Evolution on Runoff Variation

Pearson correlation coefficient is a statistical method that can quantitatively measure the correlation between variables. In this paper, R is used to characterize the correlation between landscape pattern index and annual runoff. The calculation method of Pearson correlation coefficient R is as follows:

$$R = \frac{\sum_{i=1}^{n}(x_i-\overline{X})(y_i-\overline{Y})}{\left(\sum_{i=1}^{n}(x_i-\overline{X})^2\right)^{1/2}\left(\sum_{i=1}^{n}(y_i-\overline{Y})^2\right)^{1/2}} \quad (2)$$

4 RESULTS

4.1 Variation Characteristics of Runoff and Precipitation

According to the statistical data of runoff and precipitation in the YRB in Qinghai Province from 1995 to 2018, the trend diagram of yearly runoff and annual precipitation in the YRB in Qinghai Province is drawn, as shown in Figure 2. Because the original data fluctuates violently, the moving average method investigates the diversification bent of rainfall and runoff in long time series. Yearly precipitation and annual flow variation trend are roughly the same, are first slightly decreased and then gradually increased. Precipitation is the chief reason for runoff variety. The variation characteristics of precipitation and runoff can be analyzed by calculating the anomaly percentage of annual precipitation and annual runoff.

As shown in Figure 3, the fluctuation trends of annual runoff and annual precipitation are the same, showing positive and negative alternations. The maximum and minimum annual precipitation anomaly percentages are 30.13% (2018) and -22.93% (2002), respectively. The maximum and minimum annual runoff anomaly percentages are 54.24% (2018) and -37.33% (2002). The changing trend of year-long precipitation and annual runoff in the YRB in Qinghai Province is roughly the same. Compared with annual precipitation, the change range of annual runoff is more significant. This shows that precipitation is not the only factor affecting runoff variation. The annual runoff change in the basin has a certain relationship with human activities such as land-use change. It is essential to analyze further the influence of landscape pattern changes on runoff changes.

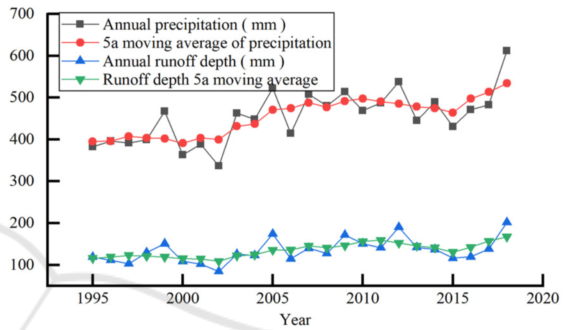

Figure 2: Trends of annual runoff and annual precipitation depth in the YRB in Qinghai Province from 1995 to 2018.

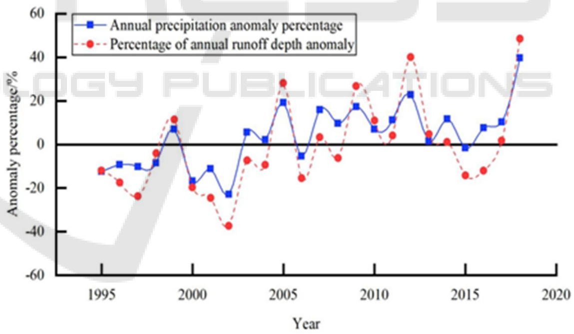

Figure 3: Variation characteristics of annual runoff and annual precipitation depth anomaly percentage in the YRB of Qinghai Province from 1995 to 2018.

4.2 Analysis of Land-use Change Characteristics

As shown in Figure 4, the land-use structure of the YRB in Qinghai Province is generally dominated by grassland, which is widely distributed entirely in the study area. Forest land is located in the mainstream of the YRB, the relatively high southeast and north, and unused land is mainly distributed in the source area.

Cultivated land and construction land are located in the central part of the study area with relatively flat terrain, close to the rivers in the area.

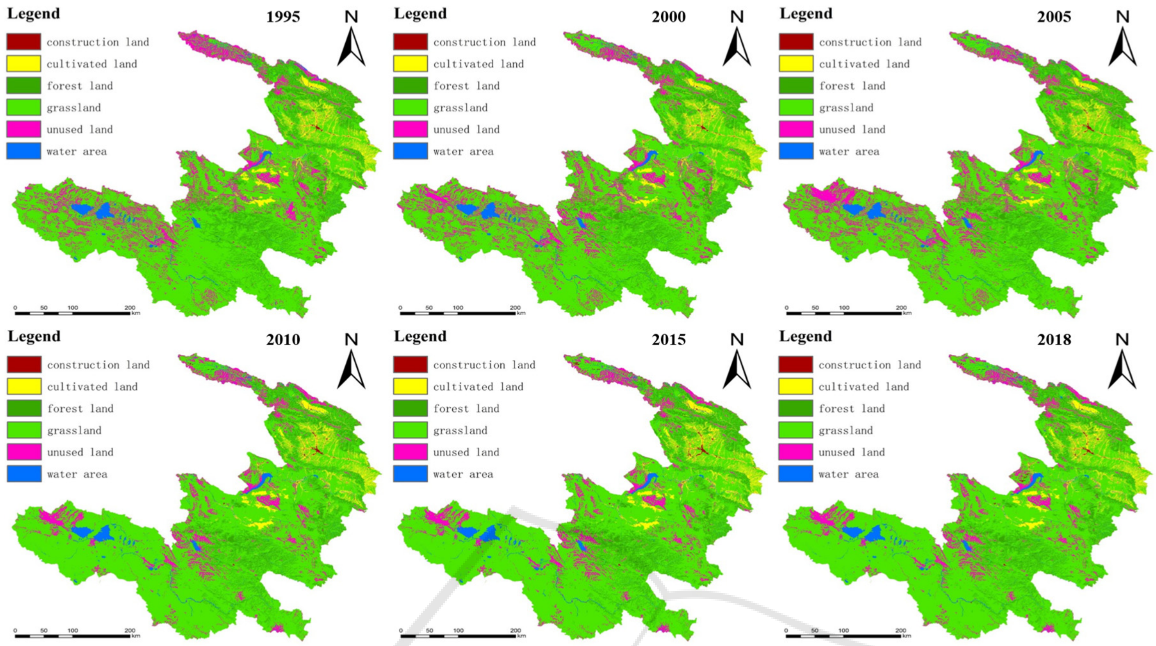

Figure 4: Land-use change of the YRB in Qinghai Province from 1995 to 2018.

As shown in Table 1, grassland and cultivated land dimension decreased first and then increased overall. The proportion decreased from 69.46% and 4.39% in 1995 to 68.60% and 4.22% in 2005 and then increased to 73.44% and 4.41% in 2018. The proportion of unused land and forest land is similar. Unutilized land increases first and then decrease and then maintains a stable trend. The proportion of forest land has little change, which is maintained at about 10.50% on the whole. The proportion of water area and construction land is small, and the overall trend is rising year by year. Based on the above analysis, the land-use types in the research area changed significantly in 2005 and 2015. Therefore, this study obtains the land-use transfer matrix of the YRB in Qinghai Province from 1995 to 2005, 2005 to 2015, and 2015 to 2018 by format conversion, matrix operation, spatial superposition, and statistical analysis in ArcGIS10.8.1. Analysis of their mutual transformation of actual situation, as follows table 2.

During 1995-2005, due to the improvement of regional urbanization and the construction of large-scale water conservancy facilities, construction land and water area explicated an increasing bent, while grassland and cultivated land revealed a downward trend. The cultivated land area converted into construction land is 71.36km^2, accounting for 83.04% of the area transferred into construction land. The grassland area converted to water was 189.45km^2, accounting for 60.25% of the area converted to water. At the same time, under the influence of overgrazing and climate warming, the phenomenon of desertification in the study area is intensified. The area of grassland degradation to unused land is 3704.63km^2, accounting for 97.72% of the area transferred from unused land.

From 2005 to 2015, with the implementation of the westward growth strategy, the conversion of farmland to the forest (grassland), and the ecological protection construction project of the Sanjiangyuan, on the one hand, the pace of urban construction in the study area was further accelerated, and the construction land increased from 602.41km^2 to 747.74km^2. On the other hand, due to the ecological protection and governance, the governance of land degradation has been significantly strengthened, and the degree of desertification has generally shown a weakening trend. The regional grassland degradation has been curbed, and the unused land has been dramatically transformed into grassland, accounting for 95.62% of the transferred grassland area.

Table 1: Land-use type change in the YRB in Qinghai Province from 1995 to 2018.

Land-use type	Area ratio of land-use type to total study area					
	1995	2000	2005	2010	2015	2018
Cultivated land	4.39%	4.26%	4.22%	4.41%	4.37%	4.41%
Forest land	10.47%	10.51%	10.51%	10.50%	10.50%	10.50%
Grassland	69.46%	69.07%	68.60%	73.49%	73.48%	73.44%
Water area	2.14%	2.23%	2.25%	2.38%	2.39%	2.40%
Construction land	0.37%	0.38%	0.41%	0.45%	0.50%	0.48%
Unused land	13.17%	13.55%	14.02%	8.77%	8.76%	8.77%

Table 2-1: Land-use transfer matrix in the YRB in Qinghai Province from 1995 to 2005.

Land-use type	Conversion area of land-use type (km^2)						
	Grassland	Construction land	Cultivated land	Forest land	Water area	Unused land	Total 2005
Grassland	100499.83	2.48	380.30	354.70	70.50	2426.83	103734.65
Construction land	10.89	516.49	71.36	1.18	1.01	1.49	602.42
Cultivated land	178.62	28.39	6010.07	10.55	14.32	14.27	6256.22
Forest land	424.06	1.64	7.55	15645.05	1.99	12.90	16093.19
Water area	189.45	1.59	33.40	9.07	3050.91	80.93	3365.35
Unused land	3704.63	0.26	10.01	16.77	59.34	17213.62	21004.63
Total 1995	105007.47	550.86	6512.69	16037.32	3198.08	19750.04	151056.45

Table 2-2: Land-use transfer matrix in the YRB in Qinghai Province from 2005 to 2015.

Land-use type	Conversion area of land-use type (km^2)						
	Grassland	Construction land	Cultivated land	Forest land	Water area	Unused land	Total 2015
Grassland	101767.71	5.54	109.81	258.53	30.93	8829.93	111002.46
Construction land	68.17	580.91	85.34	2.07	6.24	5.00	747.74
Cultivated land	420.08	13.56	6023.62	12.32	12.22	3.50	6485.30
Forest land	244.45	0.42	8.12	15804.58	3.24	11.48	16072.29
Water area	84.68	1.92	28.23	5.59	3294.13	152.09	3566.64
Unused land	1142.66	0.04	0.91	9.31	18.27	11999.49	13170.69
Total 2005	103727.75	602.41	6256.04	16092.39	3365.03	21001.49	151045.12

Table 2-3: Land-use transfer matrix in the YRB in Qinghai Province from 2015 to 2018.

Land-use type	Conversion area of land-use type (km^2)						
	Grassland	Construction land	Cultivated land	Forest land	Water area	Unused land	Total 2018
Grassland	109549.15	49.30	196.41	667.13	100.33	353.11	110915.44
Construction land	67.55	590.52	42.85	1.66	1.69	4.67	708.94
Cultivated land	195.43	101.03	6204.23	21.57	18.51	2.64	6543.41
Forest land	675.95	1.48	20.33	15352.27	12.11	14.09	16076.24
Water area	112.04	3.70	16.84	13.36	3413.22	23.31	3582.48
Unused land	380.97	1.65	2.65	12.63	17.70	12761.82	13177.43
Total 2015	110981.09	747.68	6483.32	16068.64	3563.57	13159.65	151003.94

From 2015 to 2018, the overall land-use types were in a stable trend. Some construction land was converted into cultivated land, and the transferred area was 101.03km^2, accounting for 64.28% of the transferred area of construction land. This is due to the 2015 Qinghai Province promulgated the "Opinions on Further Strengthening Land Management and Strictly Saving and Intensive Land Use". It is proposed to strengthen land management of whole province, strictly save and intensive land use, and promote cultivated land protection.

4.3 Dynamic Change Analysis of Landscape Pattern

The land-use data of the YRB in Qinghai Province from 1995 to 2018 were processed by ArcGIS10.8.1. Then the landscape index of the study area was calculated by Fragstats4.2. As shown in Table 3, the Landscape Shape Index and Landscape Division Index show a trend of first increase and then decrease, indicating that the overall landscape pattern has experienced a change from dispersion to concentration. This is related to the interference of human activities on the landscape from enhancement to weakening, and the initially dispersed patch space gradually gathers. Contagion Index first decreased and then increased, from 62.4932% in 1995 to 61.9373% in 2005, indicating that the aggregation degree of various landscape types in the study area decreased. However, the Contagion Index increased from 61.9373% to 65.7323% in 2005-2018, indicating a significant increase in the aggregation of landscape types. Shannon Diversity Index and Shannon Evenness Index decreased from 0.9946 and 0.4861 to 0.9278 and 0.4391, respectively, indicating that the control effect of a single component on the landscape was enhanced, reflecting the weakening of landscape heterogeneity during the study period. The dominant role of grassland as a dominant type of landscape increased gradually, mainly due to the implementation of ecological, environmental protection projects in recent years. The distribution of various plaque types in the YRB in Qinghai Province tends to gather in the landscape.

Table 3: Landscape index of the YRB in Qinghai Province from 1995 to 2018.

Year	PD (piece/km^2)	LSI	LPI/%	CONTAG/%	DIVISION	SHDI	SHEI
1995	0.2084	169.8907	61.0481	62.4932	0.6266	0.9946	0.4861
2000	0.2076	171.1873	61.6805	62.2275	0.6190	1.0013	0.4903
2005	0.2083	172.1802	58.9134	61.9373	0.6519	1.0098	0.4956
2010	0.1703	140.4520	64.5149	65.8093	0.5830	0.9258	0.4384
2015	0.1693	139.7512	64.5957	65.7861	0.5820	0.9276	0.4387
2018	0.1720	140.9121	64.3829	65.7323	0.5845	0.9278	0.4391

4.4 Influence Analysis of Landscape Pattern Evolution on Runoff Variation

From the landscape level analysis, the Person correlation coefficients between seven landscape indices and annual runoff were calculated by SPSS software, and the results were shown in Figure 5. Annual runoff variation was negatively correlated with PD, LSI, and DIVISION, indicating that with the increase of landscape fragmentation, the landscape types of the basin tend to be complex, and the hindrance to surface runoff is enhanced. The LPI and CONTAG were positively correlated with the change of annual runoff, indicating that the dominant role of landscape patches and the improvement of aggregation between patches contribute to the formation of surface runoff. In addition, the SHDI and SHEI were negatively connected with annual runoff, indicating that the types of landscape patches were complicated, and the spatial distribution was gradually uniform, delaying the formation of surface runoff. In summary, from 1995 to 2005, due to the improvement of urbanization level, overgrazing, climate, and other factors, the interference of human activities on landscape patterns was enhanced. The types of patches were continuously dispersed and fragmented, which enhanced the hindering effect on surface runoff. During 2005–2018, due to the implementation of environmental protection projects, the fragmentation and heterogeneity of landscape patterns in the YRB in Qinghai Province decreased, and the dominance and polymerization degree increased. Which played a certain role in promoting surface runoff.

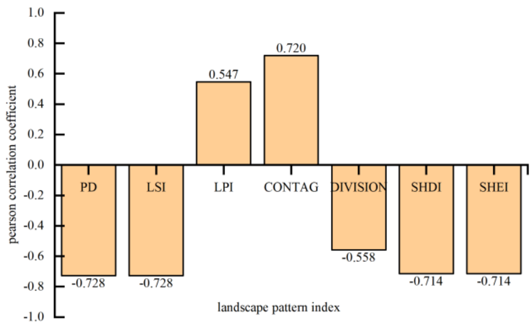

Figure 5: Influence of landscape index on runoff in the YRB in Qinghai Province.

From the analysis of patch types, the impact of land-use change on the runoff process is mainly reflected in the direct and indirect aspects. The direct impact is reflected in the continued addition of water area in the study area. Since 1980, the lake area of the YRB in Qinghai Province began to turn and continue to grow. At the same time, large hydropower stations such as Longyangxia and Lijiaxia have been built. The area of the reservoir area increases, and the water conservation improves, which plays a certain role in promoting surface runoff. The indirect effect is mainly reflected in that the change of surface structure will affect soil moisture storage, thereby affecting the water cycle processes such as infiltration and evaporation and ultimately affecting the runoff in the study area. Grassland is the primary land type in the YRB in Qinghai Province. After 2005, with the project of returning farmland to the forest (grass) and ecological protection of Three River Sources, the grassland area has gradually increased. The increase of grassland area promoted surface evapotranspiration, increased the retention of precipitation in the wet season, and played a role in reducing runoff. Secondly, through the surface evapotranspiration cycle, the increase of grassland area is conducive to the formation of regional precipitation. Since implementing the environmental protection project, the change in atmospheric circulation has caused an increase in precipitation. The rainfall in the YRB in Qinghai Province has developed year by year, which increases the runoff and offsets the decrease of runoff caused by ecological engineering. Therefore, the runoff in the study area is still showing an increasing trend.

5 CONCLUSIONS AND DISCUSSIONS

YRB in Qinghai Province is the core area of the ecological barrier of the Qinghai-Tibet Plateau. The ecological environment is fragile, and the influence of human activities has gradually intensified in recent years. Human activities drive landscape pattern change by changing land-use types, and the change of landscape pattern directly impacts the hydrological process of the whole basin. Therefore, the analysis of land-use and landscape pattern change and its impact on runoff has essential reference value for the regional ecological environment protection, rational land development, and water resources management. The variation trend of precipitation-runoff was calculated in this study. The land-use transfer matrix was used to analyze the land-use situation and the landscape pattern index was used to analyze the landscape pattern change. Finally, the influence of landscape pattern change on runoff change was analyzed by Pearson correlation coefficient method. Through the above research and analysis, the conclusions can be drawn as follows:

From 1995 to 2018, the overall change trends of rainfall and runoff in the YRB in Qinghai Province were similar, showing a slight decline and then a gradual increase. Precipitation was not the only factor affecting runoff variation. The annual runoff variation was much more significant than the yearly precipitation change.

Land desertification intensified and grasslands gradually degraded into unused land in 1995-2005. After 2005, unused land gradually transformed into grassland. The overall trend of grassland decreased firstly, and then increased, and unused land was the opposite. The area of water area and construction land was small and in an overall growth trend.

The analysis of landscape pattern evolutions in the YRB in Qinghai Province from 1995 to 2018 showed that the LSI, DIVISION, SHDI, and SHEI increased at first and then decreased, and the CONTAG firstly decreased and then increased. The landscape heterogeneity was weakened, and the dominant role of grassland as a landscape dominant type was gradually increasing.

The annual runoff variation was negatively correlated with the LSI and SHDI. The CONTAG was positively correlated with the annual runoff variation. The increase of water area and grassland promoted the evaporation cycle of surface water, which was contributory to the organization of regional precipitation and played a certain role in promoting runoff.

This study mainly analyzes the impact of landscape pattern changes on runoff changes in the YRB in Qinghai Province from a macro perspective. It has not yet analyzed the mechanism from a micro perspective. In future studies, the combined effects of climate change and landscape patterns will be considered. The simulation prediction model will be used to explore the mechanism and influence of landscape pattern evolution on surface runoff.

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