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Study on the Spatial Differences in Land-Use Change and Driving Factors in Tibet

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Abstract: As the main body of the Qinghai–Tibet Plateau, the Tibet Autonomous Region is an important ecological security barrier for the surrounding areas and even for Asia. However, the ecological environment is very fragile, and slight changes in land use may seriously affect the stability of the ecosystem. Therefore, it is necessary to deeply explore the driving factors of change in the various land-use types to stabilize the ecological structure and function of Tibet. In this paper, the transition matrix, land dynamic degree and Geodetector model are introduced to obtain the land-use change in the whole Tibetan region and its four subregions from 1990 to 2020. Based on the elevation, slope, temperature, precipitation, population and GDP, the driving factors of conversions between land-use types are explored. The results showed that during the study period, farmland, grassland and forest all showed a decreasing trend in area size. The grassland is large in the northwest region and is the main land-use type in Tibet, and its conversion to water area is the largest. The area of construction land has increased significantly, and its occupation of farmland is the largest, especially in the southwest region. The Geodetector results show that there are differences in the driving factors of the conversions between the whole region and each subregion. In the whole region, the increase in precipitation and temperature were the main drivers of unutilized land and grassland-to-water area conversions, whereas the growth of GDP and population were the dominant drivers of built-up land expansion; however, at the subregional scale, the driving effects of topographic and climatic factors in the two conversions were enhanced. In addition, under the implementation of different ecological protection measures, the productivity of vegetation has been improved. Based on the study results, ecological protection and restoration projects can be implemented in a targeted manner by guiding human activities and formulating reasonable plans to achieve the purpose of strengthening the sustainability of land use and protecting the ecological environment regionally.

Keywords: Tibet; land use; Geodetector; climate change; net primary productivity

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1. Introduction

Land resources are the media for the interaction between the various material circles of the earth [1]. When land resources generate material circulation within the socioeconomic system and natural eco-environment system under the influence of human activities, they can be called a land-use system [2], which plays an important role in regional sustainable development [3,4]. Land-use change objectively reflects the temporal and spatial change process on the Earth's surface [5], and it is an important manifestation of the impact of human activities on the natural environment [6]. Rapid urban expansion and continuous economic and population growth have promoted the evolution of land-use patterns [7,8], which has affected regional ecological security [9], such as through the weakening of ecosystems' self-regulation ability and the reduction in biodiversity [10–12]; therefore, research on land-use change is also an inevitable requirement to protect the ecological environment and promote sustainable development [13,14]. Especially since the 1990s, land-use change research has become a key field and core content of global environmental change [3,15,16], and it is one of the frontier and hotspot fields in geography and ecology research [17,18].

The "Land Use and Land Cover Change" plan [19] and the "Land Use and Land Cover Change Research Implementation Strategy" [20], jointly proposed by the International Geosphere and Biosphere Programme and the Global Environmental Change Humanities Program, provide directions for research on land-use change that it is necessary to further explore the mechanisms of land-use change and analyze the natural and human driving factors affecting land-use change [21]. At present, scholars have performed substantial research on the spatial patterns [22], dynamic change [23], driving mechanisms [24], trend predictions and ecological benefits [25] of land use by using land dynamics, the transition matrix, the conversion of land use and its effects (CLUES) model [26], the CA-Markov model [27] and other methods [28,29], forming a relatively mature research paradigm, where the research scale focuses from a global land change to local change [30]. Exploring the driving factors of land-use change is of great significance for realizing green and sustainable development in areas with rapid development, prominent contradictions between humans and land, and fragile ecological environments [31]; thus, the research of Chinese scholars also mainly focuses on ecologically fragile areas in the northwest [32], important urban agglomerations in the east [33] and large river basins [34].

The Qinghai–Tibet Plateau is known as the roof of the world [35], the third pole of the earth [36], and the water tower of Asia [37]. It plays a great role in regulating the surrounding areas and global climate change [38,39]. However, the alpine, dry and hypoxic environment makes the ecological environment of the Qinghai–Tibet Plateau extremely fragile [40], especially in the event of sudden climatic disasters or human disturbance [41], making it prone to land and ecological degradation [42]. The impact of climate change on the Qinghai–Tibet Plateau is gradually emerging, such as the academic discussions on the gradual warming and warm drying of the Qinghai–Tibet Plateau and the threats of degradation to plateau grasslands and glaciers [43,44]. As the main body of the Qinghai–Tibet Plateau, Tibet has all these characteristics. The gradual improvement of Tibet's economic development level and the increase in population in recent years have increased the scope and intensity of human activities [45], and the level of urbanization has also been improved. The way humans use land has also changed dramatically. At present, there are few studies on land-use change in Tibet. Scholars mostly focus on the overall Qinghai–Tibet Plateau [46,47] or key areas of the Qinghai–Tibet Plateau [48], such as the Hehuang Valley, the Yarlung Zangbo River Basin, the Lhasa River Basin and the Sanjiangyuan Region [49]. The research content is mainly based on the analysis of the temporal and spatial evolution characteristics of land use based on long-term data. At present, the research on the relationship with ecosystem services is gradually increasing [50,51], whereas research on the exploration of the driving factors of land-use change is less, and most of the existing studies are based on the entire study area as the object to analyze the driving force. The factors affecting land-use change are often very different in time and space [52,53], especially for such a large area of Tibet, as it has significant spatial and zonal differences in climate and topography. It is inapposite to determine the influencing factors in a unified way, and it is necessary to conduct a difference analysis according to the regional characteristics.

Therefore, this paper takes the Tibet Autonomous Region as the study area, which is then divided into four subregions by natural and social factors, and the land-use changes and their driving factors are obtained for the whole region and subregions to determine the differences in the characteristics of land-use change at different spatial scales. The research results will provide data support for ecological protection and other aspects in Tibet and will provide scientific and technological support for the realization of carbon neutralization and carbon peaking in Tibet.

2. Materials and Methods

2.1. Study Area

The Tibetan Autonomous Region is in Southwest China, and it lies between 78.25° E–99.20° E and 26.50° N–36.53° N (Figure 1), with a total area of approximately 1.2 million km², which accounts for approximately 1/8 of China and approximately 46.53% of the Qinghai–Tibet Plateau. The altitude of Tibet is between 76 and 8848 m, with an average altitude of more than 4000 m. The terrain generally slopes from northwest to southeast, and the landform types are diverse. The climate of Tibet is characterized by low temperatures, strong radiation, and low rainfall. Affected by the topography and monsoons, the climate of Tibet is generally cold and dry in the northwest (the average annual temperature is below 0 °C) and warm and humid in the southeast (the average annual temperature is approximately 8 °C), and the annual rainfall increases from approximately 50 mm in the northwest to more than 2000 mm in the southeast. In 2020, the population of Tibet was approximately 3.65 million, and the population density in Lhasa and surrounding counties was relatively large. Compared with other provinces and cities in China, the economic development of Tibet is relatively backward.

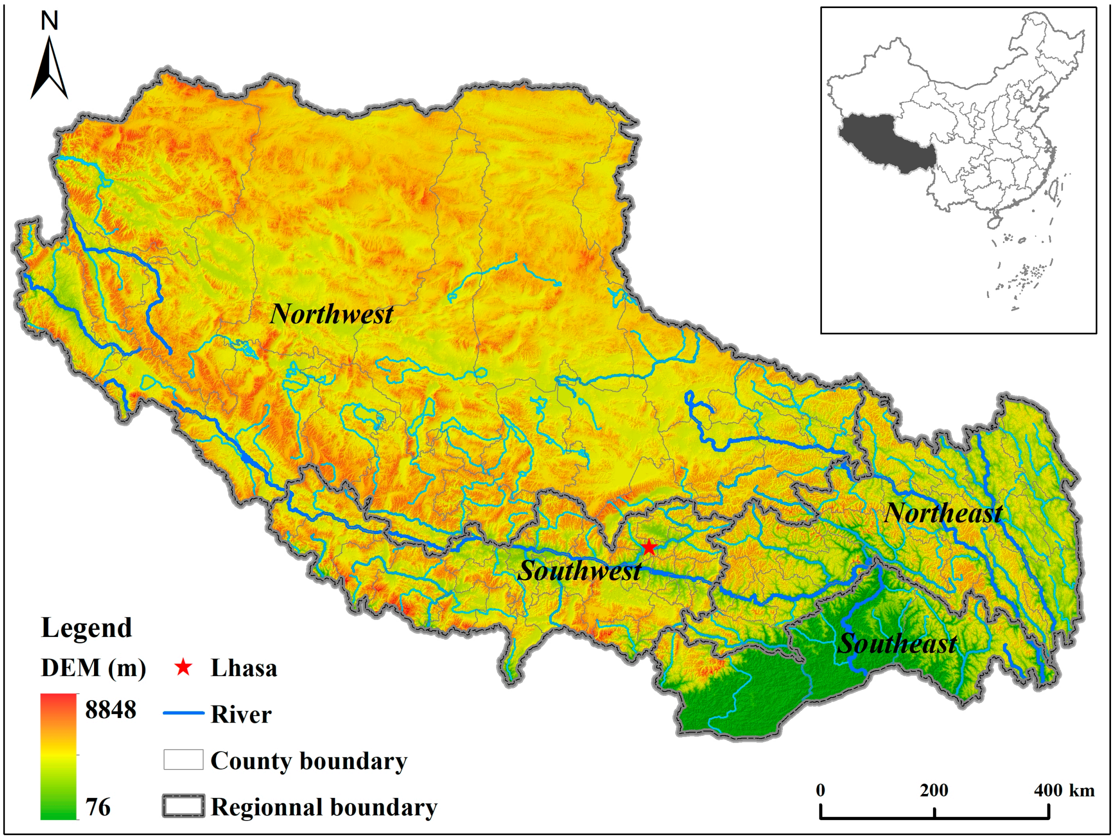

Figure 1. Location of the Tibet Autonomous Region.

2.2. Data source and Processing

Land-use change is the result of the interaction between natural and human factors [54]. Topography and climate play a major role in natural factors [55], whereas human factors are mainly based on economic and social development status, such as population growth, economic development and land policies [19]. Based on the previous research experience of scholars and the requirements of an easy quantification of indicators, the driving factors selected in this study include elevation, slope, temperature, precipitation, population density and gross domestic product.

The data used in this study include land-use status, topography, socioeconomic data, meteorological data and remote sensing data. The land-use data came from the Resource and Environmental Science and Data Center of CAS with a spatial resolution of 30 m and a time span from 1990 to 2020, which is the most used data source for the study of land use in China and the Qinghai–Tibet Plateau with an accuracy more than 95%. In order to reflect the temporal changes, this paper selected land-use data from seven time points (1990, 1995, 2000, 2005, 2010, 2015, 2020). The land-use types include 6 first-class types (farmland (FL), forest (FT), grassland (GL), water area (WA), construction land (CL), and unused land (UL)) and 25 s-class types. Terrain data, including DEM and slope, came from the Geospatial Data Cloud with a spatial resolution of 100 m. The socioeconomic data, including population density and spatialization data of gross domestic product, were obtained from the RESDC with a spatial resolution of 1000 m at two time points (1990 and 2020). Meteorological data, including precipitation and temperature, are all monitoring data from meteorological stations and came from the China Meteorological Data Services Center at two time points (1990 and 2020), and the kriging interpolation model was used to realize the spatialization of the data. In the process of the driving factor analysis, the growth of meteorological data and socioeconomic data from 1990 to 2020 was used as the calculation basis. The data show that the maximum population density has increased from 1037 persons/km^2 in 1990 to 3844 persons/km^2 in 2020, and the increase is no longer limited to Lhasa; the maximum GDP also increased from 20 million yuan/km^2 to 416.43 million yuan/km^2. In addition, the net primary productivity (NPP) data from MODIS were also selected to explore the vegetation quality in the case of land-use change and then assist in analyzing the driving differences between natural and human factors on land-use change; this study only used the existing data (after 2000) for analysis. All data were projected using Krasovsky-1940-Albers, and the evaluation unit size was 10 × 10 km in the driver detection analysis. All data were preprocessed and scaled in ArcGIS software. This study makes an in-depth exploration of land-use change and driving forces in Tibet from different spatial scales. Based on ecological geographic divisions [56], comprehensive land divisions [57] and county-level administrative divisions, Tibet is divided into four subregions, including northwest (NW), northeast (NE), southwest (SW) and southeast (SE) (Figure 1).

2.3. Methodology

2.3.1. Land-Use Change

The transition matrix is used to display the analysis results of land-use change. There is little change between the two adjacent land-use data in Tibet; therefore, this paper only uses the land-use data in 1990 and 2020 to analyze the mutual conversion between different types, and the land-use dynamic degree [58,59] is introduced to obtain the intensity of land-use change.

$$D_i = \left\{ \sum_{j}^{n} \left(\frac{|\Delta S_{ij}|}{S_a} \right) \right\} \times \frac{1}{t} \times 100\%$$

where S_a is the area of Tibet and $|\Delta S_{ij}|$ is the absolute value of the mutual conversion area between the i-th and the j-th land-use types during the study period t.

2.3.2. Driving Factor Analysis of Land-Use Change

A Geodetector is introduced to analyze the driving factors of land-use change in Tibet. The model uses a statistical method to study the spatial heterogeneity of geographical phenomena and reveal the driving force behind them [60]. Its basic assumption is as follows: a study area is divided into several subregions; if the sum of the variances of one variable in the subregions is less than the variance in the whole area, the variable has spatial differentiation; if the spatial distribution areas between two variables are consistent, there is a statistical correlation between the two variables. If the spatial distribution of the two variables tends to be consistent, then the two variables are statistically correlated [61]. The model includes four modules, and three modules are used in this study: factor detection, interaction detection and risk detection; the fourth, ecological detection, was not the focus of this article.

Factor detection is used to quantitatively express the degree to which each independent variable explains the spatial difference of the dependent variable, expressed by the q value:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$$

where h is the classification or partition of the independent variable or dependent variable; N_h and N are the number of units in layer h and the whole region, respectively; and σ_h^2 and σ^2 are the variances of the dependent variable in layer h and the whole region, respectively. The range of q is [0, 1], and the larger the q value is, the stronger the explanatory power of the independent variable.

Interaction detection is used to identify whether the interaction between two independent variables will increase the explanatory power or be independent of each other. Risk detection is used to judge whether there is a significant difference in the value of the dependent variable between different categories or partitions of the independent variable, and it can also detect the appropriate range or category of the dependent variable for different independent variables.

The dependent variable used in this paper is the conversion between land-use types, and the independent variables include DEM, slope, temperature growth (Tem), precipitation growth (Pre), population density growth (Pop) and gross national product growth per square kilometer (GDP). The independent variables are all divided into 6 grades according to the natural breakpoint method. The classification of dependent variables is mainly based on the importance of land-use types and the conversion between land-use types, and reclassifies them as shown in the following tables (Tables 1 and 2).

Table 1. The grades of independent variables.

Grade	Slope (°)	DEM (m)	Pre (mm)	Tem (℃)	GDP (Yuan/km²)	Pop (Persons/km²)
1	<5	<1800	<−150	<0.5	<0	<0
2	[5, 10)	[1800, 3200)	[−150, −80)	[0.5–0.8)	[0, 10)	[0, 0.5)
3	[10, 15)	[3200, 4200)	[−80, −30)	[0.8–1)	[10, 150)	[0.5, 1)
4	[15, 25)	[4200, 4800)	[−30, 20)	[1, 1.2)	[150, 1000)	[1, 2)
5	[25, 35)	[4800, 5300)	[20, 80)	[1.2, 1.5)	[1000, 3000)	[2, 4)
6	≥35	≥5300	≥80	≥1.5	≥3000	≥4

Table 2. The classification of dependent variables.

Codes	Conversions between Land-Use Types	Code	Conversions between Land-Use Types
C1	FL→CL	C6	WA→FT/GL
C2	FT/GL→CL	C7	UL/GL→WA
C3	FT/GL→FL	C8	UL→GL
C4	GL→UL	C9	GL→FT
C5	WA→UL	C0	Others

3. Results

3.1. Land-Use Change

Statistical results show that grassland is the main land-use type in Tibet (Table 3), and its area is larger than other land types, followed by unused land, forest, water area, farmland and construction land. Among the first-class types, the corresponding second-class types with the largest area are low-coverage grassland, bare rock, arbor forest, lake, dry land and urban built-up area. The total area of farmland and construction land accounts for only approximately 0.66% of Tibet, which indicates that the degree of land development is not high.

Table 3. The area of different land-use types from 1990 to 2000 (km²).

Types	1990	1995	2000	2005	2010	2015	2020
FL	7664.82	7691.23	7699.82	7692.62	7692.34	7636.28	7573.29
FT	164,746.60	164,767.38	164,779.42	164,776.50	164,776.36	164,762.25	164,754.27
GL	554,815.51	554,782.79	554,769.66	554,709.54	554,708.42	554,446.39	553,954.63
WA	78,020.98	78,026.86	77,986.37	78,011.70	78,009.96	78,049.47	79,508.35
CL	236.56	244.45	241.72	273.65	275.66	341.86	543.24
UL	395,327.51	395,299.27	395,334.94	395,347.96	395,349.19	395,575.68	394,478.16

Spatially, the farmland is dominated by dry land, which is mainly distributed along the rivers in the southwest and northeast regions. Paddy fields are mainly distributed in the southeastern region, but the total area is small, and there are few farmlands in the northwestern region. In the case of reflecting the spatial characteristics of land-use change, in order to reduce the space, this paper showed the spatial map of land use in four periods (1990, 2000, 2010, 2020) (Figure 2). Forest is mainly distributed in the southeastern and northeastern regions, and the forest in the southeastern region accounts for more than 64% of the total forest area. The total forest area in the two regions accounts for approximately 76% of Tibet, most of which is arbor forests, whereas the northwest and southwest regions have more shrubs. Grassland and unused land are widely distributed throughout the study area, with the largest area in the northwest region. Unused land is also widely distributed in the southeast region, accounting for approximately 9.60% of the region.

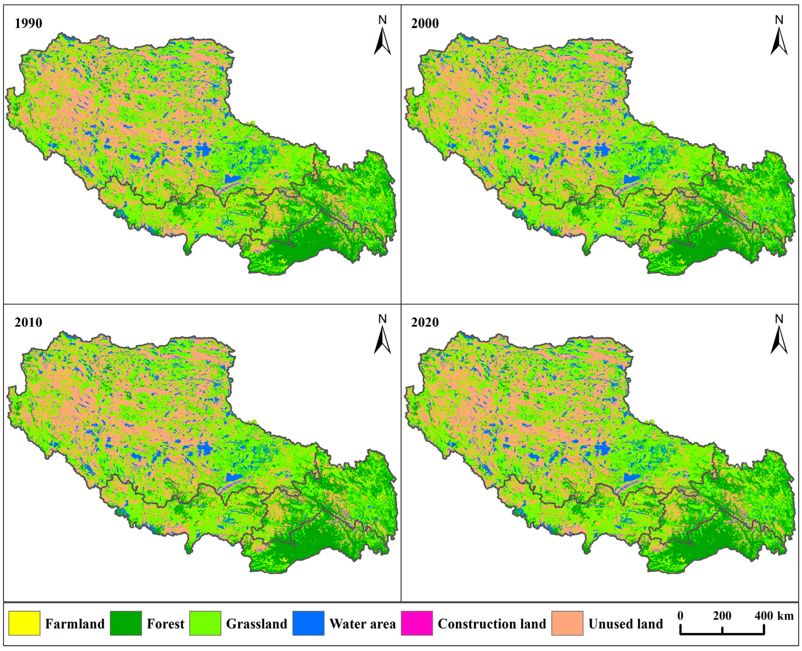

Figure 2. The spatial distribution of different land-use types in four periods.

The land-use change was relatively small over the past 30 years, but each land-use type showed different characteristics (Figure 3). The farmland increased first and then decreased, and the largest area was 7699.65 km² in 2000; overall, it decreased by 91.56 km² from 1990 to 2020. The forest also showed the same trend as farmland, but the overall fluctuation range was only 32.81 km², which was relatively more stable. The grassland has been in a decreasing trend over the past 30 years, with a decreasing area of 860.88 km². The water area increased by 1458.87 km² from a steady state before 2015, and the unused land decreased by 1097.51 km², both of which showed opposite changes. The area of construction land increased by 306.68 km² in 30 years, among which the increase in industrial and mining land and urban built-up area was more obvious. Spatially, the changes in grassland, unused land and water area in the whole region are mainly caused by their changes in the northwestern region. The change in farmland is caused by the change in dry land in the southwestern and northeastern regions, especially that in the southwestern region, which has a greater impact. The continuous increase in construction land is mainly caused by the substantial increase in development activities in the southwestern region.

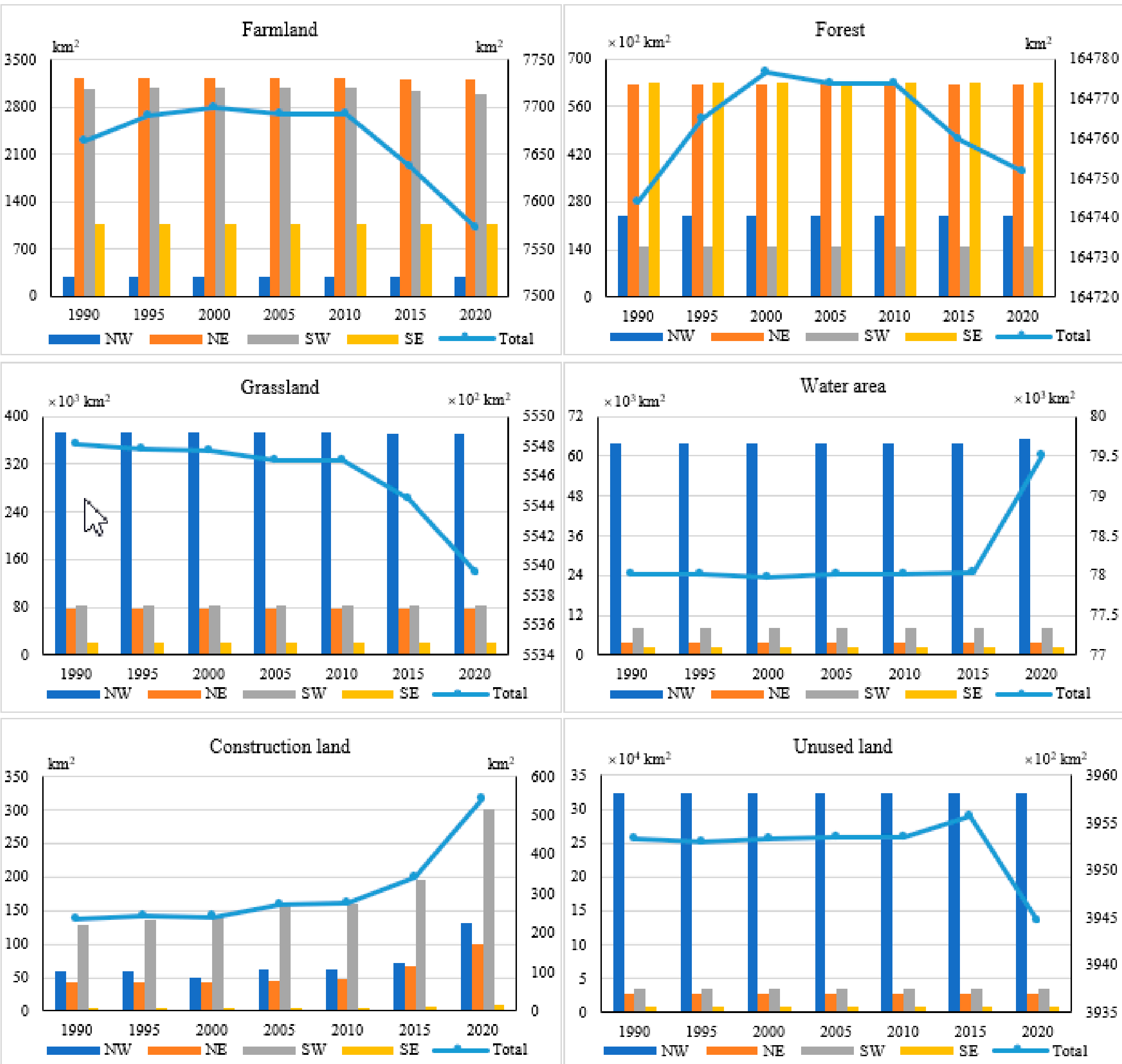

Figure 3. Changes in land-use types in different regions.

To further explore the characteristics of land-use change, this paper constructs the transition matrix of land-use types between 1990 and 2020. Table 4 showed that the main change in the past 30 years was the conversions from unused land and grassland to water area, with areas of 1280.52 km^2 and 689.37 km^2, respectively, and the conversion from water area to unused land was 425.32 km^2; others, such as the conversion of grassland and farmland to construction land, exceeded 100 km^2. Spatially, the conversions between grassland, unused land and water area mainly occurred in the northwest region, and the conversion from grassland to construction land was also large. The dynamic degrees of grassland and unused land in this region are higher than those in other regions. The northeastern region is the main area where water area is converted to forest, and some farmland and grassland in this region are also converted to construction land. The southwestern region is mainly characterized by the conversion of farmland, grassland and forest to construction land with higher dynamic degrees of farmland and construction land than other regions. The land-use types in the southeastern region are relatively stable; in general, the conversion of grassland to forest is the highest, and there is almost no conversion among other types (Figure 4).

Table 4. The transition matrix of land-use types in different regions.

Regions	**2020** / **1990**	**FL**	**FT**	**GL**	**WA**	**CL**	**UL**	**Total**
Whole Tibet	FL	7509.63	0.89	1.62	35.02	117.11	0.37	7664.64
	FT	7.10	164,637.02	23.12	30.32	44.49	1.93	164,743.99
	GL	42.70	46.17	553,867.29	689.37	104.99	62.69	554,813.22
	WA	8.91	64.20	34.42	77,470.48	15.08	425.32	78,018.41
	CL	2.19	0.06	0.91	0.05	233.33	0.01	236.56
	UL	2.54	3.34	25.02	1280.52	28.22	393,984.95	395,324.60
	Total	7573.08	164,751.69	553,952.37	79,505.77	543.24	394,475.27	1,200,801.42
NW	FL	288.24	0.00	0.06		3.36	0.10	291.76
	FT	0.47	24,159.10	0.02	19.11	2.99	1.07	24,182.76
	GL	0.18	2.00	371,474.16	658.23	46.55	36.01	372,217.14
	WA		0.04	10.35	63,535.56	1.85	345.70	63,893.50
	CL			0.00		60.11		60.11
	UL		2.60	22.00	1262.05	16.24	322,880.10	324,182.99
	Total	288.89	24,163.75	371,506.58	65,474.95	131.10	323,262.99	784,828.26
NE	FL	3193.51	0.41	0.65	11.58	25.43		3231.58
	FT		62,399.46	9.43	7.23	9.18	0.86	62,426.15
	GL	2.94	1.29	78,259.31	8.72	20.19	15.23	78,307.69
	WA	0.02	54.05	15.27	3609.20	2.46	4.24	3685.25
	CL	2.12	0.00	0.04	0.05	41.03		43.24
	UL	0.00	0.00		2.32	2.57	27,414.36	27,419.25
	Total	3198.60	62455.21	78284.70	3639.09	100.86	27,434.69	175,113.15
SW	FL	2945.58	0.23	0.91	23.42	87.85	0.27	3058.26
	FT	2.53	14,979.33	0.01	1.60	28.86		15,012.33
	GL	39.58	17.30	81,935.08	22.15	37.21	11.44	82,062.76
	WA	8.89	10.07	8.30	8114.28	10.77	75.37	8227.68
	CL	0.01	0.06	0.86	0.00	127.70	0.01	128.65
	UL	2.54	0.74	3.02	15.66	9.42	34,275.70	34,307.09
	Total	2999.13	15,007.73	81,948.19	8177.12	301.81	34,362.80	142,796.77
SE	FL	1082.30	0.25	0.01	0.02	0.47		1083.05
	FT	4.10	63,099.14	13.66	2.39	3.46		63,122.75
	GL		25.58	22,198.74	0.27	1.04		22,225.63
	WA		0.03	0.49	2211.45			2211.98
	CL	0.06				4.50		4.56
	UL				0.49		9414.79	9415.28
	Total	1086.46	63,125.00	22,212.90	2214.61	9.47	9414.79	98,063.24

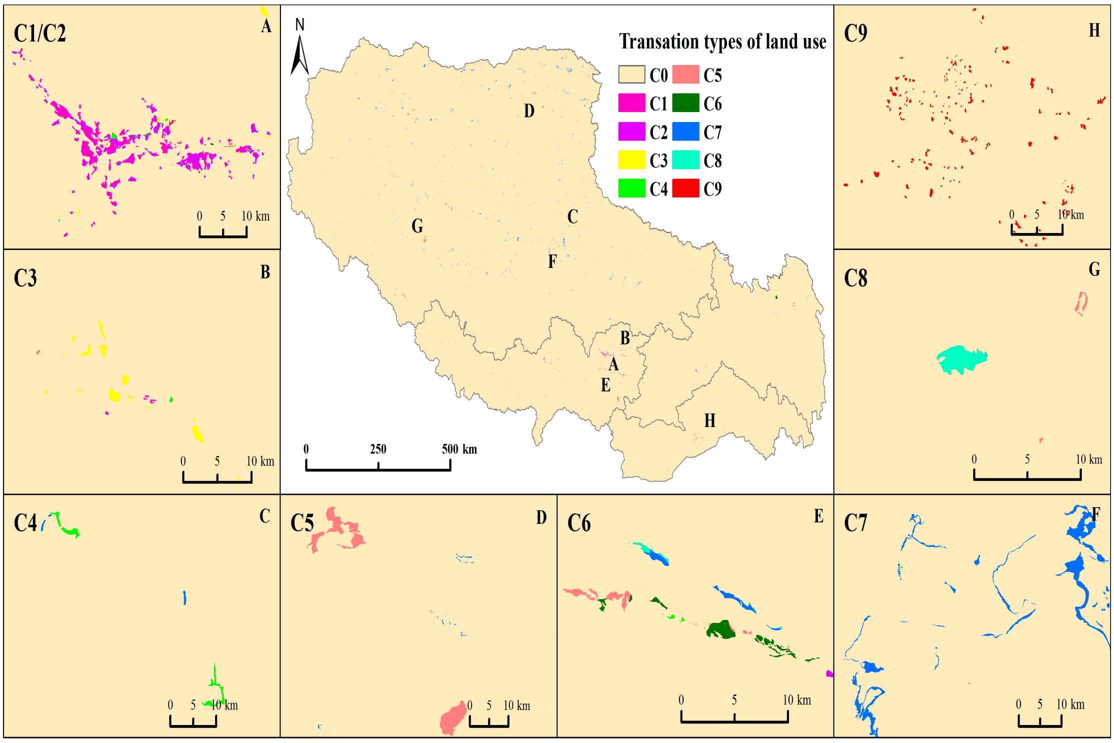

Figure 4. The spatial distribution of main land-use type conversations.

3.2. NPP

The statistical results of NPP show that the total value showed an overall growth trend from 2000 to 2020, but it suddenly decreased to 0.145 Pg C in 2015, which was lower than 0.149 Pg C in 2000, whereas it increased to 0.159 Pg C in 2020 (Figure 5). The trend of the mean value was similar to that of the total value. Although the areas of farmland, forest and grassland have shown a decreasing trend since 2000, the NPP still increased, which indicates that the growth state of vegetation in Tibet is improving, the vegetation coverage and growth force are stronger, and the carbon sequestration ability of vegetation has been enhanced. Spatially, the mean value is the largest in the southeastern region, with a value greater than 700 g·C/m^2, and the maximum value is 732.48 g·C/m^2 in 2000, followed by the northeastern region, southwestern region and northwestern region, where the largest mean values of the three regions are 210.22 g·C/m^2, 109.08 g·C/m^2 and 48.28 g·C/m^2, respectively. The mean value in the southeastern region with forest as the main land-use type is approximately 15 times that in the northwestern region with grassland as the main land-use type, indicating that the productivity of forest is significantly higher than that of grassland. In terms of the total value, affected by the mean value and total area of each region, the southeastern region still has the largest NPP, and the difference between the northwestern and northeastern regions is not too large; however, the total value of the northwestern region exceeds that of the northeastern region in 2020. The southwestern region has the smallest value.

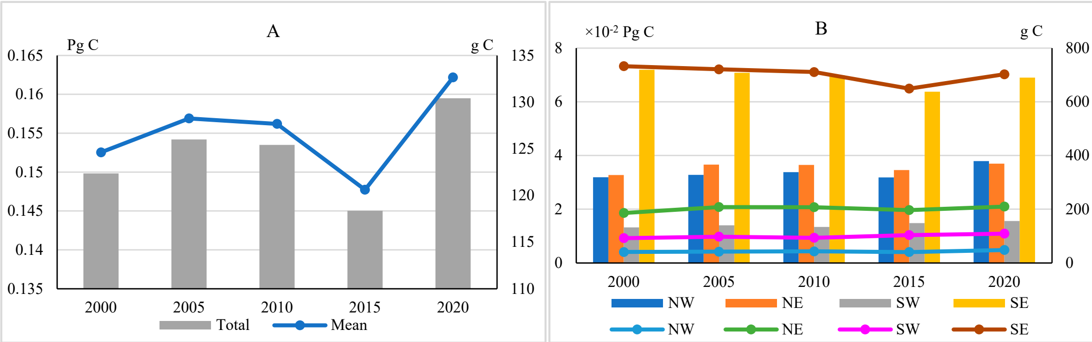

Figure 5. The total and mean values of NPP in different subregions. (Notes: The bar represents the total value, and the line represents the mean value. (**A**) is the value in the whole region, whereas (**B**) is the value in different subregions).

In terms of time, each region also showed different NPP variation characteristics. Although the NPP in the northwestern region decreased to the level of 2000 in 2015, it showed an increasing trend throughout the study period, indicating that although the area of grassland is decreasing, the quality of grassland has improved and productivity has increased. The trend in the northeastern region is similar to that in the northwestern region, but its decrease in 2015 is smaller, and the total value is higher than that in 2000. The southwestern region also showed an increasing trend, although it decreased in 2010, but the total value was still higher than that in 2000. The NPP value showed a decreasing trend in the southeastern region, especially with the greatest decrease that appeared in 2015, but it increased to the level of 2010 again by 2020.

3.3. Driving Force Analysis of Land-Use Type Conversions

3.3.1. At the Whole Region Level

The interaction detection results show that, for all land-use type conversions, the interaction effect between each pair of two factors is bilinearly enhanced or nonlinearly enhanced, indicating that the interaction has a stronger impact on driving land-use type conversions than the separate indicator.

The factor detection results show that, for the conversion of farmland, forest and grassland to construction land (C1 and C2), GDP and Pop are the main driving factors (Table 5), and their q values are significantly higher than other factors. The interaction between the two factors is bilinearly enhanced, that is, their interaction effect is stronger than that of each factor but less than the sum, whereas the interaction between GDP and other factors is a nonlinear enhancement, which means that the interaction between them is stronger than the additive effect of the corresponding two factors, especially the interaction effect between GDP and terrain factors, which is the highest (Table 6). The dominant factors in the conversion of forest and grassland to farmland (C3) are DEM and GDP, and the interaction between all factors is nonlinearly enhanced, among which the interaction of DEM and slope is the strongest (Table 6). The risk detection results show that the greater the increase in GDP and population is, the greater the probability of the three conversions, and the most suitable DEM level is 3200–4200 m with a slope between 10–15°.

GDP, Tem and DEM have similar effects on the conversion of grassland to unused land (C4) with similar q values (Table 5). The interaction between Tem and Pre is the strongest (Table 6), which indicates that the superposition effect of climatic factors is prominent. The probability of C4 is greater when the temperature increases and the precipitation decreases with an elevation between 4200–4800 m. In contrast, the conversion of unused land to grassland (C8) is likely when the elevation with a high probability is within 3200–4200 m. The mutual conversion between water area and unused land (C5 and C7) is mainly affected by topographic and climatic factors, in which the dominant effect of slope is the strongest (Table 5), whereas the interaction between Pre and slope is the strongest (Table 6). Under the condition of reduced human activities, the greater the growth of precipitation and temperature, and the greater the conversion of unused land to water area (C7), then the warmer and more humidified area is conducive to C7; the conversion of grassland to water area is also due to this reason.

Pop is the dominant factor for the conversion of water area to forest and grassland (C6). The interaction between Pop and DEM is the strongest, followed by the interaction between Pop and Tem (Table 6). The greater the increases in temperature, GDP and population are, the greater the probability of C6 when the elevation is within 3200 m and 4200 m and the slope is within 15–25°, which may be related to the river basin greening project in Tibet. The main driving factor for the conversion of grassland to forest (C9) is the DEM, and the interaction between the DEM and other factors is high (Table 6). C9 mainly occurs in areas with an altitude lower than 1800 m and a slope of more than 15 degrees. It can be seen from Table 6 that C9 mainly exists in the southeast and southwest regions.

Table 5. Factor detection of C1–C9 in the whole region.

	DEM	Slope	Pre	Tem	GDP	Pop
C1	0.0172	0.0013	0.0103	0.0078	0.2483	0.0223
C2	0.0096	0.0007	0.0059	0.0100	0.2646	0.0181
C3	0.0061	0.0004	0.0022	0.0012	0.0057	0.0019
C4	0.0029	0.0011	0.0019	0.0029	0.0031	0.0006
C5	0.0023	0.0051	0.0015	0.0007	0.0011	0.0010
C6	0.0032	0.0007	0.0003	0.0037	0.0034	0.0088
C7	0.0057	0.0356	0.0124	0.0011	0.0134	0.0093
C8	0.0002	0.0004	0.0002	0.0008	0.0002	0.0002
C9	0.0309	0.0013	0.0046	0.0025	0.0141	0.0026

Table 6. Intersection detection of different factors of C1–C9 in the whole region.

	DEM	Slop	Pre	Tem	GDP	Pop	DEM	Slop	Pre	Tem	GDP	Pop	DEM	Slop	Pre	Tem	GDP	Pop
	C1						C2						C3					
DEM	0.0172						0.0096						0.0061					
Slop	0.0785	0.0013					0.0458	0.0007					0.0586	0.0004				
Pre	0.0345	0.0592	0.0103				0.0214	0.0423	0.0059				0.0120	0.0145	0.0022			
Tem	0.0364	0.0249	0.0596	0.0078			0.0284	0.0320	0.0557	0.0100			0.0177	0.0052	0.0140	0.0012		
GDP	0.4382	0.4591	0.2783	0.2729	0.2483		0.4279	0.4309	0.2734	0.2732	0.2646		0.0251	0.0150	0.0147	0.0097	0.0057	
Pop	0.0904	0.0745	0.0671	0.0360	0.2499	0.0223	0.0473	0.0651	0.0437	0.0395	0.2678	0.0181	0.0165	0.0140	0.0095	0.0085	0.0121	0.0019
	C4						C5						C6					
DEM	0.0029						0.0023						0.0032					
Slop	0.0057	0.0011					0.0104	0.0051					0.0069	0.0007				
Pre	0.0087	0.0182	0.0019				0.0066	0.0432	0.0015				0.0059	0.0028	0.0003			
Tem	0.0072	0.0068	0.0278	0.0029			0.0058	0.0067	0.0080	0.0007			0.0090	0.0087	0.0132	0.0037		
GDP	0.0086	0.0134	0.0106	0.0105	0.0031		0.0045	0.0112	0.0043	0.0081	0.0011		0.0118	0.0049	0.0049	0.0138	0.0034	
Pop	0.0051	0.0037	0.0048	0.0134	0.0110	0.0006	0.0056	0.0064	0.0041	0.0035	0.0033	0.0010	0.0220	0.0108	0.0126	0.0171	0.0121	0.0088
	C7						C8						C9					
DEM	0.0057						0.0002						0.0309					
Slop	0.0381	0.0356					0.0013	0.0004					0.0772	0.0013				
Pre	0.0224	0.0415	0.0124				0.0009	0.0019	0.0002				0.0438	0.0079	0.0046			
Tem	0.0121	0.0384	0.0156	0.0011			0.0018	0.0023	0.0021	0.0008			0.0615	0.0107	0.0121	0.0025		
GDP	0.0215	0.0412	0.0200	0.0154	0.0134		0.0008	0.0010	0.0011	0.0019	0.0002		0.0793	0.0480	0.0226	0.0212	0.0141	
Pop	0.0220	0.0400	0.0209	0.0136	0.0164	0.0093	0.0012	0.0014	0.0013	0.0020	0.0007	0.0002	0.0497	0.0256	0.0111	0.0087	0.0161	0.0026

3.3.2. In the Subregions

The main land-use type conversions are different in subregions. The dominant driving factors are different, and the driving forces of each factor are stronger than those in the whole region (Table 7). The driving effect of terrain factors in the conversion of land-use types in the northwestern region is significantly enhanced, especially for the conversion between grassland, water area and unused land, and the interaction between the terrain factors and other factors is also at a high level. The risk detection shows that the larger the temperature rises or falls, the more areas are converted between the three types. For example, when the temperature rises by 1.2–1.5 °C, the conversion from unused land to water area is approximately 452 km², accounting for 30% of the total conversion area in the northwest region. In addition, the influence of population density is stronger than that in the whole region for the conversion of grassland to construction land.

The driving force of Pop in the conversion of water area to forest and grassland in the northeastern region is more powerful, with a q value greater than that in the whole region. When population density growth is greater than 4 persons/km², the conversion area exceeds 68 km², which is equivalent to the entire conversion area in this region, indicating that this type of conversion is more heavily affected by human activities. Greening projects at the headwaters and both sides of rivers may be the main driving force.

The most important land-use change in the southwestern region is the conversion of farmland, grassland and forest to construction land. With economic growth, the converted area also increases. Compared to that in the whole region, the driving forces of Tem and terrain factors are stronger than those of Pop. The main reason is that the population density in this region is more homogeneous, and the probability of occurrence at different Pop levels is not significantly different. In addition, the importance of Tem exceeds GDP for the conversion from forest and grassland to farmland in this region, and the interaction between Tem and topographic factors is stronger than that of other factors.

There are few conversions among different land-use types in the southeastern region, and the most important is the conversion from grassland to forestland, but the results of the Geodetector are also different from those in the whole region, which is due to the smaller driving effect of GDP compared to other factors and the significantly improved driving effect of climatic factors, especially when the temperature increases by more than 1 °C; however, the driving force of GDP is more prominent in the southwestern region, which results in its strong driving force in the whole region.

Table 7. Factor detection of C1–C9 in the subregions.

	DEM	Slop	Pre	Tem	GDP	Pop	DEM	Slop	Pre	Tem	GDP	Pop
	NW						NE					
C1	0.0065	0.0007	0.0014	0.0013	0.0078	0.0022	0.0179	0.0050	0.0024	0.0115	0.0068	0.0128
C2	0.0049	0.0003	0.0054	0.0007	0.0217	0.0100	0.0040	0.0033	0.0017	0.0137	0.0053	0.0136
C3	0.0254	0.0003	0.0000	0.0004	0.0003	0.0000	0.0279	0.0003	0.0012	0.0009	0.0010	0.0033
C4	0.0033	0.0018	0.0020	0.0003	0.0000	0.0005	0.0020	0.0014	0.0056	0.0103	0.0125	0.0022
C5	0.0037	0.0039	0.0013	0.0004	0.0012	0.0012	0.0021	0.0979	0.0051	0.0028	0.0016	0.0120
C6	0.0002	0.0003	0.0000	0.0003	0.0001	0.0004	0.0019	0.0012	0.0020	0.0050	0.0036	0.0138
C7	0.0074	0.0282	0.0082	0.0029	0.0089	0.0075	0.0013	0.0002	0.0014	0.0026	0.0007	0.0032
C8	0.0003	0.0002	0.0000	0.0008	0.0001	0.0003	0.0172	0.0013	0.0103	0.0078	0.2483	0.0223
C9	0.0317	0.0006	0.0004	0.0005	0.1209	0.0088	0.0232	0.0002	0.0014	0.0009	0.0003	0.0043
	SW						SE					
C1	0.0722	0.0072	0.0379	0.0830	0.2687	0.0389	0.0022	0.0044	0.0121	0.0304	0.0005	0.0007
C2	0.0550	0.0039	0.0404	0.1304	0.4325	0.0276	0.0023	0.0015	0.0107	0.0273	0.0016	0.0003
C3	0.0407	0.0158	0.0050	0.0300	0.0115	0.0035	0.0087	0.0539	0.0112	0.0099	0.0006	0.0010
C4	0.0045	0.0188	0.0094	0.0157	0.0242	0.0027	0.0172	0.0013	0.0103	0.0078	0.2483	0.0223
C5	0.0033	0.0289	0.0073	0.0130	0.0054	0.0033	0.0172	0.0013	0.0103	0.0078	0.2483	0.0223

C6	0.0646	0.0100	0.0207	0.0213	0.0133	0.0183	0.0302	0.0341	0.0105	0.0158	0.0081	0.0059
C7	0.0034	0.0215	0.0042	0.0038	0.0006	0.0032	0.0074	0.0011	0.0036	0.0023	0.0002	0.0002
C8	0.0274	0.0042	0.0262	0.0149	0.0059	0.0085	0.0172	0.0013	0.0103	0.0078	0.2483	0.0223
C9	0.0733	0.0102	0.0083	0.0158	0.0270	0.0135	0.0322	0.0145	0.0219	0.0255	0.0025	0.0033

4. Discussion

Based on the current situation of increasing human activities and climate change, this paper studies land-use change and deeply explores the differences in natural and human influences on land-use change in Tibet, and then superimposes the spatial division to identify the characteristics and dominant driving factors of land-use change in subregions. Based on the results of this study, more targeted planning and governance policies can be formulated for land management in Tibet, and it is also helpful to resolve the conflict between land development and ecological conservation.

Compared with other provinces in China, the land-use types have not changed much in Tibet over 30 years, and the land dynamic degree is relatively small [58]. Grassland and unused land are widely distributed throughout the whole region, whereas most of the lakes are distributed in the northwest region. The land development intensity is weak around the whole region, but the development activities have accelerated significantly in the past 10 years, and the area of construction land has increased greatly. The results of the Geodetector indicate that it is greatly affected by GDP and Pop in the whole region, and the southwest region has the largest increase in construction land. The growth of GDP and population density in the southwestern region is at the forefront, which has greatly promoted the development activities of the region, but on a subregional scale, the driving forces of climate and topography factors outweigh Pop, indicating that construction in the southwestern region may already be focusing on environmental suitability rather than population pressure. The development of urban construction land mainly occupies the surrounding farmland, whereas industrial and mining land occupies more grassland and forestland, and with the increase in farmland occupation, the conversion of grassland to farmland also occurs in the southwestern region.

The statistical results of climate factors show a trend of warming and humidification in Tibet, and the temperature and precipitation in most areas are increasing. The melting of glaciers, snow and permafrost, combined with precipitation, creates more water surface, and some grasslands and unused land are submerged and converted into water area, which is also an important reason for the reduction of these two land-use areas, especially in the northwest region where the overall elevation is higher than 4200 m; the Geodetector results also fully prove this conclusion. Spatially, the conversion of water area to forest and grassland mainly occurs along the river in the northeast and southwest regions, which has a strong relationship with the greening projects implemented in Tibet [49], and the greening projects in key river basins have produced positive effects. The changes in forests are relatively weak and are mainly distributed in the southeastern and northeastern regions; in addition, there are areas where grasslands have increased in the whole region, which is mainly affected by the implementation of major ecological protection and restoration projects in Tibet.

Although the areas of farmland, grassland and forest have shown a decreasing trend in the past 20 years, under the background of the gradual warming and humidification of the Tibetan Plateau [44], the total NPP in Tibet is increasing. The productivity and quality of vegetation are in an elevated state, and the carbon sequestration capacity of vegetation is enhanced. NPP is heavily affected by the climate [45]. For example, the rainfall decreased compared with previous years in 2015, which caused the NPP to fluctuate greatly in this year. In addition, a series of implemented ecological protection and restoration measures have also made significant contributions to the enhancement of vegetation productivity in Tibet. For example, the enclosure project isolates the negative effects of grazing, which accelerates the recovery of damaged vegetation, increases the coverage of the vegetation community and improves the carbon sequestration potential of soil and vegetation in the enclosure area [62]. Other measures, such as grazing prohibition, rotational grazing and fertilizing, have also played a role in improving vegetation productivity. However, the implementation of these projects is temporarily carried out in a small space and over a short period, and the whole region has not shown obvious improvement effects. In the future, it is necessary to increase the efforts of ecological protection and restoration projects.

According to the characteristics and driving factors of land-use change in different subregions, corresponding management policies can be formulated to promote sustainable land use and protect the regional ecological environment. Land use in the northwest region is mainly affected by natural factors such as climate change; thus, it is possible to positively guide human activities to form a synergistic mechanism with climate change, which includes implementing measures such as grazing prohibition, rotational grazing and ecological relocation to reduce human activities near villages or towns, restoring damaged ecosystems by reseeding, fertilizing and maintaining wild areas, and formulating policies for balancing grass and livestock to coordinate ecological and socioeconomic benefits at the government level. There are more development activities in the southwestern region, especially in areas with warmer temperatures and flat terrain. It is necessary to formulate a reasonable land-space plan to set different development priorities, strengthen the protection of basic farmland in the river valleys, limit the occupation of farmland and grassland, increase the greening of cities and important river banks, and enhance the quality of ecosystem services, all of which will guarantee the ecological benefits of human beings. However, the land-use status of the northeast and southeast regions is relatively stable, and it is possible to excavate and explore the realization path of ecological product value from the perspective of ecosystem services, and then achieve innovative breakthroughs in the coordinated development of ecology and economy.

5. Conclusions

Based on the land-use data of Tibet from 1990 to 2020, this paper divides the study area into four subregions, combines topographic, social and climatic factors, and introduces a Geodetector to explore the driving factors of conversion between land-use types at different spatial scales.

Grassland is the main land-use type in Tibet, followed by unused land, both of which are widely distributed in the whole region. The farmland area is small, and the forest is mainly distributed in the southeast area. With the development of the social economy, some farmland, forests and grassland are occupied by construction land. The degree of development in the past 10 years has been particularly intensified, and the phenomenon of construction land occupying farmland, and farmland encroaching on grassland, has been formed; however, the farmland area is still greatly reduced and the grassland area in the entire study area has decreased the most, especially with the conversion of grassland to water area in the northwest region, which is very large. At the whole-region scale, the growth of GDP and population density is the dominant factor leading to the rapid expansion of construction land and its encroachment on farmland, grassland and forests. Under the background of terrain conditions, the warming and humidification of the Tibetan Plateau caused by the increase in rainfall and temperature leads to the conversion of unused land and grassland to water area. At the subregional scale, the conversion of land-use types and the corresponding dominant driving factors also show strong spatial characteristics. In the northwest region, the driving force of terrain factors in the conversion of unused land and grassland to water area is stronger than that of the whole region, followed by changes in climate warming and humidification. The economic development of the southwestern region has led to the acceleration of urbanization, and the phenomenon of construction land occupying surrounding farmland has gradually increased, but the driving force of population density has been relatively weakened. Due to the implementation of greening projects in the northeast and southwest regions, some wetlands on both sides of the rivers have been converted into forest and grassland, whereas the overall change in the southeast region is small, and the conversion of some grasslands into forest is more likely affected by natural factors.

Although the land-use statistics show that the areas of forests, grassland and farmland have decreased, under the influence of climate change and human-induced ecological protection and restoration activities the growth quality of vegetation has been improved, and the average productivity and carbon sequestration capacity of vegetation have increased, which indicates that a series of ecological projects carried out in Tibet in recent years have played a positive role. Therefore, Tibet needs to strengthen the implementation of ecological protection and restoration projects and rationally design a land-space development plan in the future to ensure that the comprehensive ecological and socioeconomic benefits can be maximized on the premise of ensuring the function of ecological security barriers. In addition, based on the results of this study, Tibet should grasp the overall situation when promulgating and implementing land and ecological protection policies, highlighting spatial differences and giving full play to the advantages of different regions. Under the premise of protecting the ecological environment as the main task, Tibet should focus on optimizing the economic development plan in the southwest region, increasing the investment in ecological management in the northwest region, and innovating and developing the ecological industry economy in the northeast and southeast regions. The method of this study and the positive effect of the research results on the formulation of regional land and ecological policies can provide a good reference for other regions.

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