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Analysis of the Evolution of Land-Use Types in the Qilian Mountains from 1980 to 2020

Miao Wang [1,2] and Meixue Yang [1,*]

[1] State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
[2] The School of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: mxyang@lzb.ac.cn

Abstract: The Qilian Mountains (QMs), located in the northeast part of the Qinghai–Tibetan Plateau in China, have a fragile ecological environment, complex and sensitive climate, and diverse land-cover types. It plays an important role in the "Qinghai–Tibetan Plateau Ecological Barrier" and "Northern Sand Control Belt" in China's "two screens and three belts" ecological security strategy. Based on land use data of 1980, 1990, 1995, 2000, 2005, 2010, 2015, and 2020, we utilized GIS technology, land use dynamic degree, and land use transition matrixes to analyze the spatial and temporal evolution of land use in the QMs from 1980 to 2020. The results showed the following: (1) From 1980 to 2020, grassland, forest land, and unused land were the main land-use types in the QMs, and the proportion of construction land accounted for only 0.31% of all land-use types. (2) The single land use dynamic degree showed that the dynamic degree of construction land was the highest and the fastest change rate from 2010 to 2015. The comprehensive land use dynamic degree showed that the intensity of land-use change was relatively drastic in the three time periods of 1990–1995, 1995–2000, and 2015–2020. (3) The land-use types in the study area switched infrequently during 2000–2005, 2005–2010, and 2010–2015. (4) The main transition directions of land-use types were grassland and unused land to other land-use types. These changes altered the spatial distributions of different land-use types. The study is critical for understanding the spatial and temporal change patterns of land-use change in the QMs and providing guidance for the optimization of land use in the study area and the improvement of regional eco-environmental protection.

Keywords: Qinghai–Tibetan Plateau; Qilian Mountains; land use; land cover; dynamic degree analysis; transition matrix; temporal and spatial variation

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1. Introduction

Land is an important link between humans and nature [1–3], and it is the basis for human survival and development. In recent years, with the acceleration of global climate change, the increase in the frequency and expansion of the scope of human activities, such as the growing population and rapid urbanization, have led to great changes in land-use types [4–6]. Land use/cover change (LUCC) is an important component in the study of global climate and environmental changes [7–9] and has an important role in the Earth's system [10]. It is also the most direct expression of the interaction between human activities and the natural environment [9] and can directly reflect the way to make use of land resources in a region [4,11]. LUCC is caused by land use, which is the result of a combination of multiple driving forces in the human–land relationship [5,12–14]. Human activities, such as overgrazing, deforestation, grassland reclamation, indiscriminate misuse of mineral resources and other irrational land use practices, have significantly altered the surface environment [15,16] impacting food production, freshwater resources, forest resources, regional climate, and air quality [7]; human-induced LUCC is the most direct human disturbance to terrestrial ecosystems [12,17,18].

LUCC is considered to be one of the most paramount environmental issues in the world [19,20]. The Land Use and Land Cover Change (LUCC) core research program were jointly launched in 1995 by the International Geosphere-Biosphere Program (IGBP) [21,22] of the International Council for Science (ICSU) and the International Human Dimensions Program (IHDP) [23] of the International Social Science Council (ISSC). Two programmatic documents, titled "the LUCC Research Program" [24] and "the LUCC Implementation Strategy" [25], were also published. LUCC has become one of the world's research hot spots and is becoming a focus of attention for the public and management decision-makers [26–29]. It has also triggered a wave of research on LUCC by scholars at home and abroad [6,19,30].

The Qilian Mountains (QMs) rise along the northeastern rim of the Qinghai–Tibetan Plateau, in the northwestern arid zone of China, which is a climatically sensitive and ecologically fragile area in China [31]. With the increase in human activities, land-use types have changed accordingly in the QMs. Land-use change is an important factor reflecting the degree of human activities, and analyzing the spatial and temporal land-use-change pattern is an effective way to reveal the degree of human activities [32]. Previous studies on LUCC in the QMs have focused on the analysis of individual areas within the QMs, especially for the Qilian Mountains National Nature Reserve [33,34]. In addition, studies have also analyzed land-use change and its driving force on the southern slope of the QMs [35] and the Shiyang River Basin of the QMs [9]. Studies on the QMs as a whole region are lacking, and it is unable to reflect the overall LUCC characteristics of the QMs in a comprehensive manner. Therefore, based on the ArcGIS spatial analysis technology, this study analyzed the structural characteristics, spatial distribution patterns, change characteristics, change rates, and their transfer directions of land-use types in the QMs for a long time series from 1980 to 2020 by using a series of indicators of the comprehensive land use dynamic degree (CLUDD), the single land use dynamic degree (SLUDD) and land use transfer matrix to provide direction for the optimization of land-use patterns and regional eco-environmental conservation and improvement in the research area, as well as to better understand the patterns of spatial and temporal land-use changes in the QMs.

2. Materials and Methods

2.1. Study Area

The QMs (35~40° N, 93~104° E) is located on the northeastern edge of the Qinghai-Tibetan Plateau in China, which spans Gansu and Qinghai provinces. The length is about 1000 km from east to west, and it is about 300 km wide from north to south (Figure 1). It is made up of parallel mountains that are part of the northwest-to-southeast-oriented Qilian fold belt [36]. The mountain is higher in the northwest and lower in the southeast and the average elevation is 3523 m [37]. One-third of the mountain range is higher than 4000 m. The highest peak is Unity Peak at 5828.6 m [38]. The QMs belongs to a typical plateau continental climate [39], and the regional ecological environment is fragile, climatically complex, and sensitive. It is important to the "Qinghai–Tibet Plateau Ecological Barrier" and "Northern Sand Control Belt" in China's "two screens and three belts" ecological security strategy [40]. The east is influenced by the southeast and southwest monsoons and has a relatively humid climate [37], the west is controlled by the westerly circulation [41], and the central part is at the intersection of the two circulation systems [42]. Different circulation systems cause regional differences in climate, especially precipitation [43], and the annual average precipitation in the region is about 301.9 mm; precipitation is mainly concentrated in May–September [44].

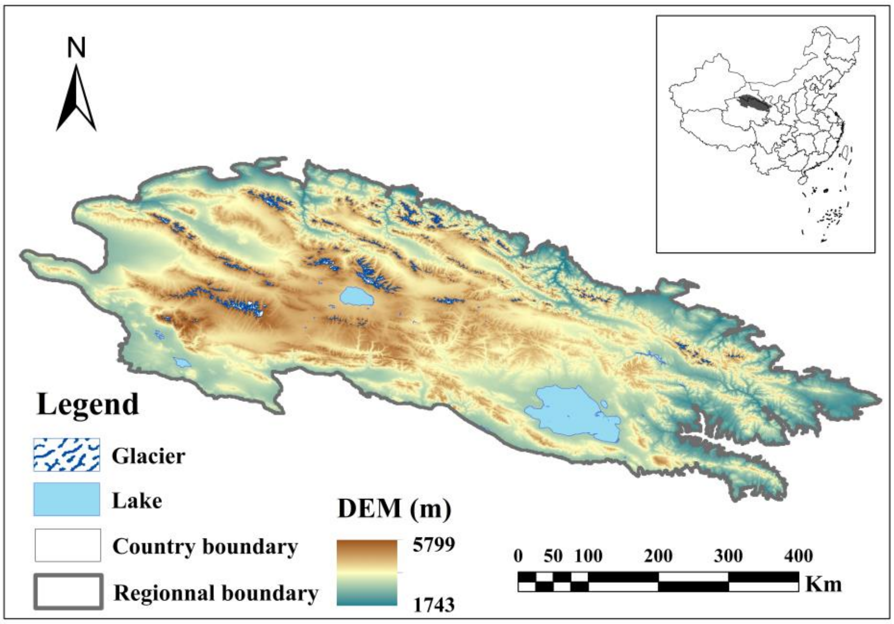

Figure 1. The location of the study area.

2.2. Data Sources and Processing

The LUCC data were obtained from the Resource and Environment Science Data Registration and Publication System. Led by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, in collaboration with the Institute of Remote Sensing Applications, the Northeast Institute of Geography and Agroecology, the Institute of Geodesy and Geophysics, the Xinjiang Institute of Ecology and Geography, the Northwest Institute of Eco-Environmental and Resources, the Institute of Mountain Hazards and Environment, and so on, jointly completed the "Multi-period Land Use Land Cover Change Monitoring Dataset in China" [45]. The spatial resolution of the data was 30 m and contains 11 periods: 1980, 1990, 1995, 2000, 2005, 2008, 2010, 2013, 2015, 2018, and 2020. The dataset is a 1:10 scale multi-period land use/cover thematic database of China built by using Landsat remote sensing images of the United States as the main information source, through pre-processing processes, such as band extraction, false color synthesis, geometric refinement, and sub-county image stitching, mosaic, and human–computer interactive visual interpretation. The remote sensing interpretation of the data is based on 1980 Landsat MSS remote sensing images, 1990, 1995, 2000, 2005, 2010 Landsat TM/ETM remote sensing images, and 2020 Landsat 8 remote sensing images, respectively. Landsat data is also often used as a data source in the production of other LUCC datasets. Landsat data are publicly available through USGS Earth Explorer (https://gisgeography.com/usgs-earth-explorer-download-free-landsat-imagery/, accessed on 26 May 2022). The data are classified using a two-level classification system, with the first level divided into 6 types, including arable land, forest land, grassland, waters, construction land, and unused land. The second level is further divided into 25 types based on the first level types [45]. The decoded classification dataset has been tested for accuracy and has been widely used in the study of spatial and temporal patterns related to land use cover [46], and the comprehensive evaluation accuracy of the primary type of land use in China reached more than 94.3%, and the comprehensive accuracy of the secondary-type classification reached more than 91.2% [47].

In this study, a total of eight periods of data from 1980, 1990, 1995, 2000, 2005, 2010, 2015, and 2020 were selected to process and analyze the QMs with ArcGIS. By using Raster to Polygon in the Conversion Tools, Extract by Mask and Reclassify in the Spatial Analyst Tools, Dissolve in the Data Management tools and Intersect in the Analysis tools under ArcToolbox. The land-use types number six class I types and 23 class II types in the QMs (Table 1) [45]. This is because the QMs is deeply inland and does not include paddy fields and oceans in this classification system. Additionally, Excel was employed in this study to calculate the dynamic attitude degree, and Origin was used for the cartographic analysis.

Table 1. Classification systems of LUCC in the Qilian Mountains [45].

Class I Type		Class II Type		
Number	**Name**	**Number**	**Name**	**Definition**
1	Arable land ($6065\ km^2$)			Refers to land planted with crops, including ripe cultivated land, newly opened land, recreational land, rotational rest land, grass field rotation cropland; land planted mainly with crops, agricultural fruit, agricultural mulberry, agricultural forestry; cultivated for more than three years of the beach and sea shoals.
		12	Dryland	Refers to arable land without irrigation water source and facilities, growing crops by natural will water; dry crop arable land with water source and water facilities, which can be irrigated normally in normal years; arable land mainly for growing vegetables; recreational land and rotational rest land with normal crop rotation.
2	Forest land ($16,454\ km^2$)			Refers to forestry land for growing trees, shrubs, bamboos, and coastal mangrove land.
		21	With forest land	Refers to natural forests and plantations with a denseness of >30%. Including timber forests, economic forests, protective forests, and other mature forest lands.
		22	Shrubland	Refers to short forest land and scrub sparse forest land with densities >40% and heights below 2 m.
		23	Sparse forest land	Refers to forest land with 10–30% tree densities.
		24	Other forest lands	Refers to unestablished afforestation land, trails, nurseries, and various types of gardens (orchards, mulberry gardens, tea gardens, hot crop forestry gardens, etc.).
3	Grassland ($85,839\ km^2$)			Refers to all kinds of grasslands with herbaceous plants growing mainly and covering more than 5%, including scrub grasslands with mainly grazing and open forest grasslands with less than 10% depression.
		31	High cover Grassland	Refers to natural grassland, improved grassland, and mowed grassland with >50% cover. Such grasslands generally have good moisture conditions and dense grass cover growth.
		32	Medium Cover Grassland	Refers to natural and improved grasslands with >20–50% cover, which generally has insufficient moisture and sparse grass cover.
		33	Low cover Grassland	Refers to natural grasslands with a cover of 5–20%. This type of grassland is moisture deficient, with sparse grass cover and poor conditions for grazing use.
4	Waters ($9199\ km^2$)			Refers to the land of natural land waters and water facilities.
		41	Rivers and canals	Refers to naturally formed or artificially excavated rivers and the land below the perennial water level of the main stem. Artificial canals include embankments.
		42	Lakes	Refers to the land below the perennial water level in naturally occurring waterlogged areas.
		43	Reservoir ponds	Refers to the land below the perennial water level in the artificially constructed water storage area.
		44	Permanent Glacial Snow	Refers to land covered by glaciers and snow all year round.

Table 1. *Cont.*

Class I Type		Class II Type		
		46	Beach land	Refers to the land between the level of the river and lake waters during the flat water period and the level of the flood period.
5	Construction Land (601 km^2)			Refers to urban and rural settlements and the land for industry, mining, and transportation beyond them.
		51	Urban land	Refers to the land in large, medium, and small cities and built-up areas above the county town.
		52	Rural settlements	Refers to rural settlements that are independent of towns.
		53	Other Construction Land	Refers to land for factories and mines, large industrial areas, oil fields, salt fields, quarries, etc., and transportation roads, airports, and special land.
6	Unused land (74,504 km^2)			Land that is currently unused, including hard-to-use land.
		61	Sandy	Refers to the land with the surface covered by sand and the vegetation cover of less than 5%, including desert, excluding the desert in the water system.
		62	Gobi	Refers to the land where the surface is dominated by gravel and the vegetation cover is less than 5%.
		63	Saline land	Refers to land where salinity collects on the surface and vegetation is sparse, and only strong salinity-tolerant plants can grow.
		64	Marshland	Refers to land that is flat and low-lying, poorly drained, chronically wet, seasonally waterlogged or perennially waterlogged, and with wet growing plants on the surface.
		65	Bare land	Refers to land with surface soil cover and vegetation cover is less than 5%.
		66	Bare rock texture	Refers to land with a rocky or gravelly surface that covers >5% of the area.
		67	Others	Refers to other unused lands, including the alpine desert steppe, tundra, etc.

2.3. Research Methodology

The research methodology involved a land resource quantity change model (the single land use dynamic degree and the comprehensive land use dynamic degree) and a land use transfer matrix.

2.3.1. Dynamic Degree

The land use dynamic degree can be divided into single land use dynamic degree and comprehensive land use dynamic degree. The model can quantitatively describe the dynamic changes of land-use types, and then truly reflect the rate and extent of land-use type changes in the study area [48,49].

(1) Single land use type dynamic degree.

The single land use type dynamic degree reflects the change in the quantity of a certain land-use type in a study area within a certain time frame [48]. The formula is as follows:

$$K = \frac{(U_b - U_a)}{U_a} \times \left(\frac{1}{T}\right) \times 100\% \quad (1)$$

In this formula, K is the dynamic degree of a certain land-use type during the study period, U_a is the number of land-use types at the beginning of the study period, U_b is the number of land-use types at the ending of the study period, T is the length of the study period, and K is the annual rate of change of a certain land-use type in the study area.

(2) Comprehensive land use dynamic degree

The comprehensive land use dynamic degree reflects the overall degree of change in land-use types in the study area throughout the study period [49]. Its expression is [50]:

$$LC = \left[\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \right] \times \frac{1}{T} \times 100\% \quad (2)$$

In the formula, LU_i is the area of class-i land use at the beginning of monitoring; $\Delta LU_{i\text{-}j}$ is the absolute value of the area converted from type-i land use to non-type-i land use in the monitoring period; and T is the length of the study period. The value of LC is the annual rate of land-use change in the study area.

2.3.2. Transfer Matrix

The land-use type transfer matrix can comprehensively and specifically explain the quantitative structural characteristics of land-use type changes and the direction of each land type change in each region in any time period, as well as reflecting the interconversion relationship between each category [2,51,52]. Its mathematical expression is:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \quad (3)$$

In the formula, S_{ij} is the area transformed from the i-th land type to the j-th land type during the study period; n is the total number of land types of land use in the study area; and i and j are the land-use types at the beginning and end of the study period, respectively.

3. Results and Analysis

3.1. Land Use Structure Characteristics

The spatial patterns of the distribution of land-use types in the QMs in 1980, 1990, 1995, 2000, 2005, 2010, 2015, and 2020 are shown in Figure 2.

The top three land-use types in the study area from 1980 to 2020 were grassland, unused land, and forest land (Figures 3 and 4). Table 2 shows the structural characteristics of land-use types in the QMs from 1980 to 2020. Compared with 1980, the dominant increase was grassland, by 3621 km^2 by 2020, mainly located in the central-eastern part of the study area. The area of unused land decreased by 4820 km^2, mainly in the central and western parts of the study area. Despite the decrease in the area of unused land, the area of unused land was still dominant in 2020, accounting for 38.67% of the total area of the QMs. The area of forest land decreased by 87 km^2, mainly in the northeastern part of the study area. In addition, a small amount of arable land was distributed at the eastern boundary of the QMs, and the waters were dominated by Qinghai Lake and Hala Lake (Figure 2).

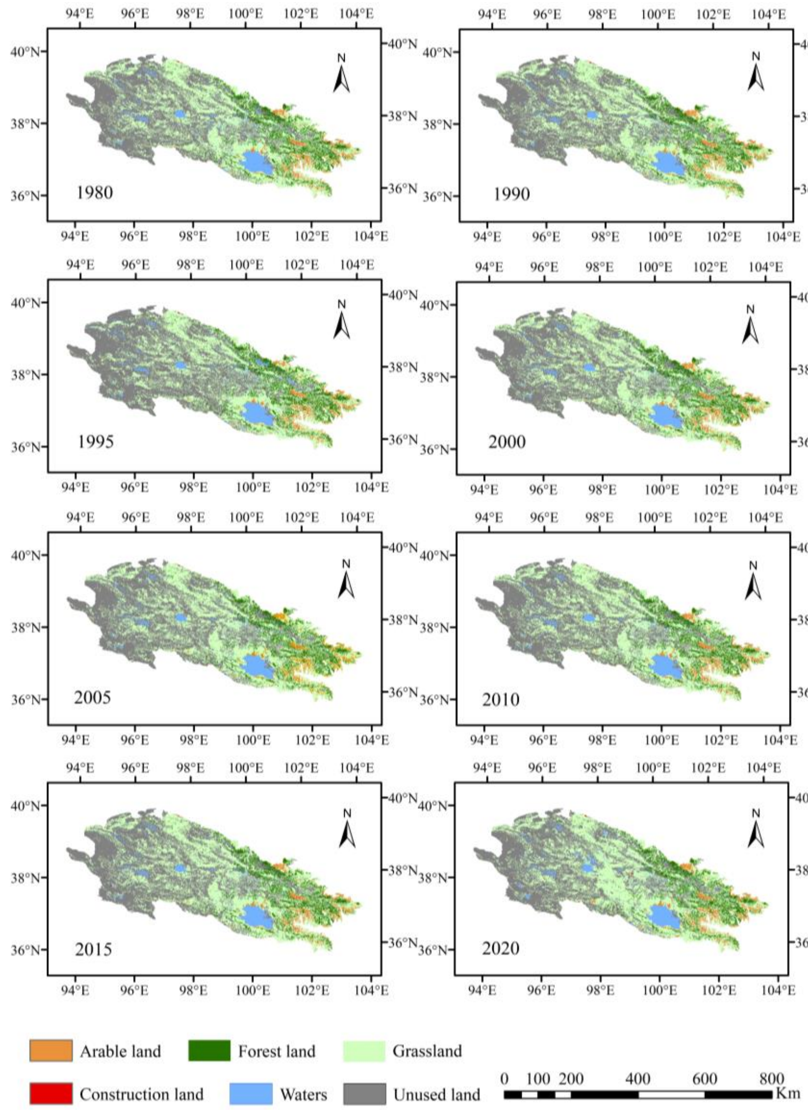

Figure 2. Spatial pattern of land use in the Qilian Mountains.

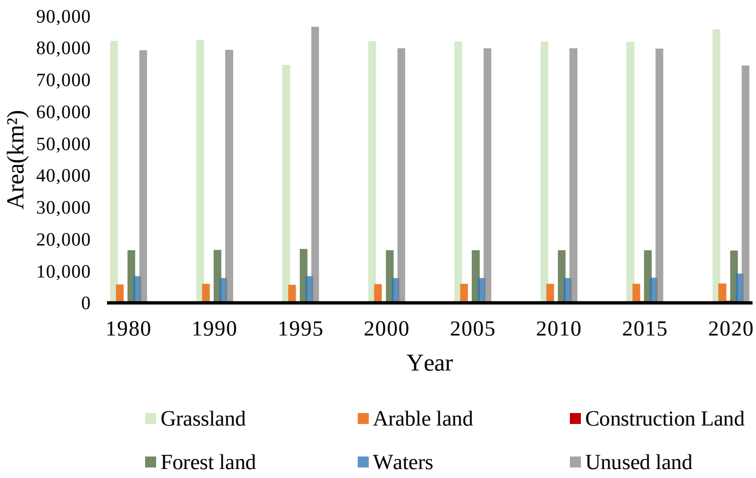

Figure 3. Area of land-use types in the Qilian Mountains.

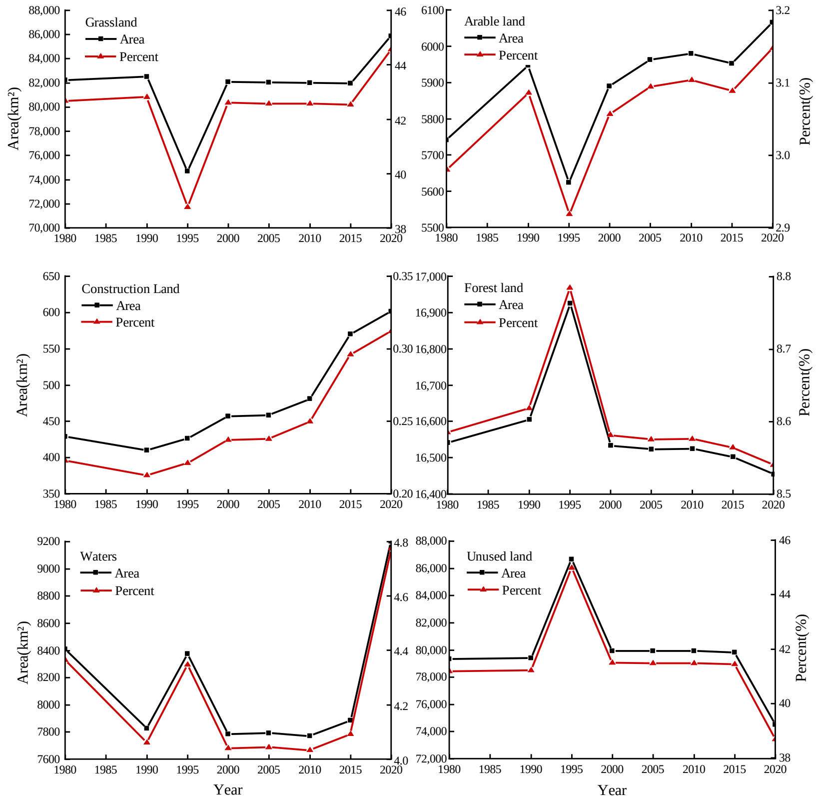

Figure 4. Characteristics of land use structure in the Qilian Mountains.

Table 2. Structural characteristics of land use in the Qilian Mountains from 1980 to 2020.

Year	Land-Use Types	Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land
1980	Area/km^2	82,218	5741	429	16,541	8409	79,324
	Percent/%	42.67	2.98	0.22	8.59	4.36	41.17
1990	Area/km^2	82,481	5946	410	16,604	7825	79,396
	Percent/%	42.81	3.09	0.21	8.62	4.06	41.21
1995	Area/km^2	74,671	5624	426	16,924	8374	86,643
	Percent/%	38.76	2.92	0.22	8.78	4.35	44.97
2000	Area/km^2	82,076	5889	457	16,533	7785	79,922
	Percent/%	42.60	3.06	0.24	8.58	4.04	41.48
2005	Area/km^2	82,014	5962	458	16,522	7791	79,915
	Percent/%	42.57	3.09	0.24	8.58	4.04	41.48
2010	Area/km^2	81,996	5979	481	16,523	7771	79,912
	Percent/%	42.56	3.10	0.25	8.58	4.03	41.48
2015	Area/km^2	81,941	5951	570	16,501	7884	79,815
	Percent/%	42.53	3.09	0.30	8.56	4.09	41.43
2020	Area/km^2	85,839	6065	601	16,454	9199	74,504
	Percent/%	44.55	3.15	0.31	8.54	4.77	38.67

The changes in land use area in the QMs from 1980 to 2020 (Table 3) showed that the change in grassland area experienced an increase from 1980 to 1990, a decrease from 1990 to 1995, an increase from 1995 to 2000, and then a continuous decrease until the increase in grassland area from 2015 to 2020. Overall, the grassland increased the most during 1980–2020, at 3621 km^2 (4.40% increase), followed by the waters increased with 790 km^2 (9.39% increase); arable land and construction land increased with 324 km^2 (5.64% increase) and 172 km^2 (40.09% increase), respectively. Unused land and forest land decreased by 4820 km^2 (6.08% decrease) and 87 km^2 (0.53% decrease), respectively. The changes in each type of land use were 40.09% (construction land), 9.39% (waters), −6.08% (unused land), 5.64% (arable land), 4.40% (grassland), and −0.53% (forest land). It can be seen that among the increased land-use type areas, the largest increase was in construction land; among the decreased land-use type areas, the largest decrease was the unused land.

Table 3. Land use area changes in the Qilian Mountains from 1980 to 2020.

Year and Land Type		Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land
1980–1990	Area change/km^2	263	205	−19	63	−584	72
	Range of change/%	0.32	3.57	−4.43	0.38	−6.94	0.09
1990–1995	Area change/km^2	−7810	−322	16	320	549	7247
	Range of change/%	−9.47	−5.42	3.90	1.93	7.02	9.13
1995–2000	Area change/km^2	7405	265	31	−391	−589	−6721
	Range of change/%	9.92	4.71	7.28	−2.31	−7.03	−7.76
2000–2005	Area change/km^2	−62	73	1	−11	6	−7
	Range of change/%	−0.08	1.24	0.22	−0.07	0.08	−0.008
2005–2010	Area change/km^2	−18	17	23	1	−20	−3
	Range of change/%	−0.02	0.29	5.02	0.006	−0.26	−0.003
2010–2015	Area change/km^2	−55	−28	89	−22	113	−97
	Range of change/%	−0.07	−0.47	18.50	−0.13	1.45	−0.12
2015–2020	Area change/km^2	3898	114	31	−47	1315	−5311
	Range of change/%	4.76	1.92	5.44	−0.28	16.68	−6.65
1980–2020	Area change/km^2	3621	324	172	−87	790	−4820
	Range of change/%	4.40	5.64	40.09	−0.53	9.39	−6.08

Figure 5 intuitively shows the rates of area change of land-use types in the QMs. It can be seen that during the period of 1980–1990, arable land increased the most (3.57%) and waters decreased the most (−6.94%); during the period of 1990–1995, unused land increased the most (9.12%) and grassland decreased the most (−9.47%); during the period of 1995–2000, grassland increased the most (9.92%) and unused land decreased the most (−7.76%); arable land increased the most (1.24%) and forest land decreased the most (−0.07%) between 2000 and 2005; construction land increased the most (5.02%) and waters decreased the most (−0.25%) between 2005 and 2010; between 2010 and 2015, the largest increase was in construction land (18.50%) and the largest decrease was in arable land (−0.47%); and between 2015 and 2020, the largest increase was in waters (16.68%) and the largest decrease was in unused land (−6.65%).

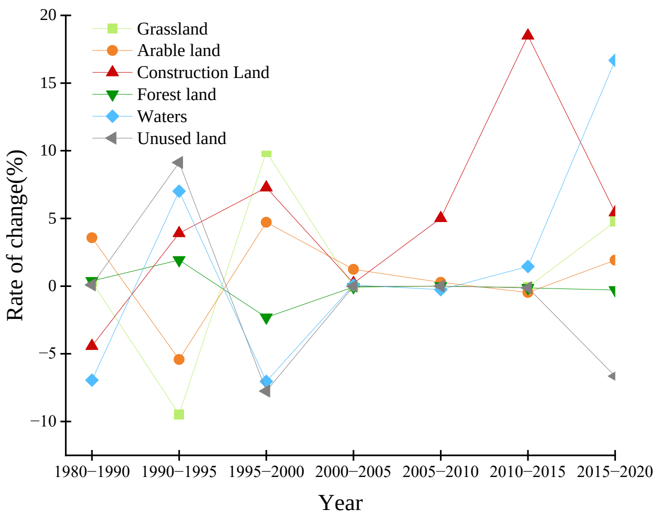

Figure 5. Area change rates of land-use types in the Qilian Mountains.

3.2. Land Use Dynamic Degree

In terms of the single land use dynamic degree (Table 4), different land-use types saw varying rates of change throughout the course of the 40-year period. In 1980–1990, the dynamic degrees of waters, construction land, and arable land in the study area changed faster; the rates of change of other land types were relatively slow. In 1990–1995 and 1995–2000, except for forest land, the rates of change of the dynamic degrees of grassland, arable land, construction land, waters, and unused land in the study area were faster than those in 1980–1990. In 2000–2005, 2005–2010, and 2010–2015, the rate of change of the dynamic degree of each land type in the study area was slower than the same in 1980–1990, but the dynamic degree of construction land showed an increasing trend. The rates of change of the dynamic degrees of land use in the study area from 2015 to 2020 increased, among which the dynamic degrees of waters, construction land, and grassland ranked in the top three. From the changes in each land-use type, reflected by the comprehensive land use dynamic degree (Table 4), the comprehensive land use dynamic degree of the study area in 1980–1990, 1990–1995, 1995–2000, 2000–2005, 2005–2010, 2010–2015, and 2015–2020 was 0.03%, 0.84%, 0.80%, 0.008%, 0.004%, 0.02%, and 0.56%, respectively.

Table 4. Dynamic degrees of land-use types moving in the Qilian Mountains at different times (%).

Year	Single Land Use Dynamic Degree						Comprehensive Land Use Dynamic Degree
	Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land	
1980–1990	0.03	0.36	−0.44	0.04	0.69	0.01	0.03
1990–1995	−1.89	−1.08	0.78	0.39	1.40	1.83	0.84
1995–2000	1.98	0.94	1.46	−0.46	1.41	−1.55	0.80
2000–2005	−0.02	0.25	0.04	−0.01	0.02	0.00	0.008
2005–2010	0.00	0.06	1.00	0.00	−0.05	0.00	0.004
2010–2015	−0.01	−0.09	3.70	−0.03	0.29	−0.02	0.02
2015–2020	0.95	0.38	1.09	−0.06	3.34	−1.33	0.56

3.3. Land Use Transfer Matrix

According to the land use transfer matrix of the QMs in 1980–1990, 1990–1995, and 1995–2000 (Table 5), it can be seen that all land-use types in the study area have undergone different degrees of interconversion.

Table 5. Land use transfer matrix in the Qilian Mountains in 1980–1990, 1990–1995, 1995–2000 (km^2).

Year	Land Types	Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land	Sum
				1990				
1980	Grassland	56,781	2045	159	5982	769	16,482	82,218
	Arable land	1936	3181	153	348	67	56	5741
	Construction land	152	180	49	18	8	22	429
	Forest land	6062	428	20	8924	167	940	16,541
	Waters	811	62	14	153	5881	1488	8409
	Unused land	16,739	50	15	1179	933	60,408	79,324
	Sum	82,481	5946	410	16,604	7825	79,396	192,662
				1995				
1990	Grassland	50,639	1942	141	6192	695	22,872	82,481
	Arable land	2190	3093	178	379	50	56	5946
	Construction land	147	155	59	16	10	23	410
	Forest land	5829	337	27	9095	225	1091	16,604
	Waters	725	53	6	148	5899	994	7825
	Unused land	15,141	44	15	1094	1495	61,607	79,396
	Sum	74,671	5624	426	16,924	8374	86,643	192,662
				2000				
1995	Grassland	53,143	1964	119	5217	622	13,606	74,671
	Arable land	1655	3384	193	307	57	28	5624
	Construction land	137	163	95	18	4	9	426
	Forest land	5530	282	20	9928	166	998	16,924
	Waters	626	43	10	178	6109	1408	8374
	Unused land	20,985	53	20	885	827	63,873	86,643
	Sum	82,076	5889	457	16,533	7785	79,922	192,662

From 1980 to 1990, 57,438 km^2 of land-use types were transformed. Grassland was converted into other land-use types in the largest amount, 25,437 km^2, of which 64.80% was converted into unused land (16,482 km^2). 23.52% and 8.04% of grassland were converted into forest land and arable land, respectively. The conversion of unused land to other land-use types was the second largest, 18,916 km^2, with 88.49% converted to grassland (16,739 km^2). The final area of grassland increased by 263 km^2 and the area of unused land increased by 72 km^2. Overall, the area of grassland, arable land, forest land, and unused land increased, and the area of construction land and waters decreased in 1980–1990.

In 1990–1995, 62,270 km^2 of land-use types were transformed, of which the area of construction land, forest land, waters, and unused land increased, and the area of grassland and arable land decreased. Compared with 1980–1990, the transfer of land-use types is still dominated by the interconversion of unused land and grassland. The area of grassland converted to other land-use types was 31,842 km^2, of which 71.83% was converted to unused land, and the transferred area amounted to 22,872 km^2. The area of unused land converted to other land-use types was 18,916 km^2, and the largest transfer out was 16,739 km^2 of grassland, with a contribution rate of 88.49%. The largest increase in the area of unused land ended up being 7247 km^2. Grassland decreased the most with 7810 km^2.

In 1995–2000, 56,130 km^2 of land-use types were converted. Compared with the conversion of land-use types in 1980–1990 and 1990–1995, the interconversion of unused land and grassland is still dominant. The conversion of unused land to other land-use types was the largest, with 22,770 km^2, and the largest conversions were 20,985 km^2 of grassland (92.16%), 885 km^2 of forest land (3.89%), and 827 km^2 of waters (3.63%), respectively. The conversion of grassland to other land-use types was in the next largest area at 21,528 km^2. Of this, 63.20% was converted to unused land at 13,606 km^2, 24.23% to forest land, and 9.12% to grassland. The final area of grassland increased by 7405 km^2 and the area of unused land decreased by 6721 km^2. Overall, the area of grassland, arable land, and construction land increased, and the area of forest land, waters and unused land decreased from 1995 to 2000.

The land-use types in the study area were infrequently converted in 2000–2005, 2005–2010, and 2010–2015 (Table 6).

Table 6. Land use transfer matrix in the Qilian Mountains in 2000–2005, 2005–2010, 2010–2015 (km^2).

Year	Land Types	Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land	Sum
				2005				
2000	Grassland	81,987	84		2	1	2	82,076
	Arable land	14	5870	1		4		5889
	Construction land			457				457
	Forest land	6	6		16,520	1		16,533
	Waters	1	2			7781	1	7785
	Unused land	6				4	79,912	79,922
	Sum	82,014	5962	458	16,522	7791	79,915	192,662
				2010				
2005	Grassland	81,949	35	5	5	4	16	82,014
	Arable land	15	5938	7	1		1	5962
	Construction land			458				458
	Forest land	1	4		16,517			16,522
	Waters			7		7761	23	7791
	Unused land	31	2	4		6	79,872	79,915
	Sum	81,996	5979	481	16,523	7771	79,912	192,662
				2015				
2010	Grassland	81,886	7	47	1	41	14	81,996
	Arable land	6	5942	27	1	3		5979
	Construction land		1	480				481
	Forest land	2	1		16,499	21		16,523
	Waters					7731	40	7771
	Unused land	47		16		88	79,761	79,912
	Sum	81,941	5951	570	16,501	7884	79,815	192,662

In 2000–2005, 135 km^2 of land-use types were transformed. Grassland was converted into other land-use types in the largest amount, 89 km^2, of which 94.38% was converted into arable land, 84 km^2. There was a 62 km^2 drop in grassland, a 73 km^2 gain in arable land, a 1 km^2 increase in construction land, an 11 km^2 decrease in forest land, a 6 km^2 increase in waters, and a 7 km^2 loss in unused land. From 2005 to 2010, 167 km^2 of land-use types were transformed. Grassland was converted into other land-use types in the largest amount, 65 km^2, of which 53.85% was converted into arable land, 35 km^2. There was an 18 km^2 drop in grassland, a 17 km^2 increase in arable land, a 23 km^2 gain in construction land, a 1 km^2 increase in forest land, a 20 km^2 decrease in waters, and a 3 km^2 decrease in unused land. From 2010 to 2015, the largest amount of unused land was converted to other land-use types at 151 km^2, of which 58.28% was converted to waters at 88 km^2. 31.13% and 10.60% of unused land were converted to grassland and construction land with 47 km^2 and 16 km^2 transferred out, respectively. Grassland was converted to other land-use types in the next largest area, 110 km^2. Of these, 42.73% was converted to construction land with a transfer out area of 47 km^2 and 37.27% was converted to waters with a transfer out area of 41 km^2. The area of grassland dropped by 55 km^2, the amount of arable land dropped by 28 km^2, the area of construction land increased by 89 km^2, the area of forest land dropped by 22 km^2, the area of waters increased by 113 km^2, and the area of unused land reduced by 97 km^2. It can be seen that the areas of arable land, waters, and construction land increased, and the areas of unused land, forest land, and grassland decreased from 2000 to 2005. The areas of construction land, arable land, and forest land increased, and the areas of unused land, grassland, and waters decreased from 2005 to 2010. The areas of construction land and waters increased, and the areas of forest land, arable land, grassland, and unused land decreased from 2010 to 2015.

The conversion of each land-use type in the study area during 2015–2020 was as follows (Table 7).

Table 7. Land use transfer matrix in the Qilian Mountains from 2015 to 2020 (km^2).

Year		2020						
	Land Types	**Grassland**	**Arable Land**	**Construction Land**	**Forest Land**	**Waters**	**Unused Land**	**Sum**
2015	Grassland	58,413	2046	234	5763	992	14,493	81,941
	Arable land	1985	3356	184	331	54	41	5951
	Construction land	176	201	108	22	32	31	570
	Forest land	5933	345	23	9175	161	864	16,501
	Waters	711	63	12	148	6119	831	7884
	Unused land	18,621	54	40	1015	1841	58,244	79,815
	Sum	85,839	6065	601	16,454	9199	74,504	192,662

In 2015–2020, 57,247 km^2 of land-use types were converted. The largest area of grassland was converted to other land-use types with 23,528 km^2. Of this amount, 61.60% was converted to unused land at 14,493 km^2, 24.49% to forest land, and 8.70% to arable land, with 5763 km^2 and 2046 km^2 transferred out, respectively. The area of unused land converted to other land-use types was in the second place with 21,571 km^2, and the largest transfer out was 18,621 km^2 of grassland, 1841 km^2 of waters, and 1015 km^2 of forest land, with a contribution of 86.32%, 8.53%, and 4.71% respectively. The final area of grassland increased by 3898 km^2, and the area of unused land decreased by 5311 km^2. Overall, the area of grassland, arable land, construction land, and waters increased, and the area of forest land and unused land decreased from 2015 to 2020.

Overall, the conversion of each land use type in the study area during the period 1980–2020 was as follows (Table 8).

Table 8. Land use transfer matrix in the Qilian Mountains from 1980 to 2020 (km^2).

Year	2020							
	Land Types	**Grassland**	**Arable Land**	**Construction Land**	**Forest Land**	**Waters**	**Unused Land**	**Sum**
1980	Grassland	58,451	2241	254	5774	1017	14,481	82,218
	Arable land	1936	3185	193	327	62	38	5741
	Construction land	141	174	78	18	5	13	429
	Forest land	5948	352	23	9171	175	872	16,541
	Waters	874	60	11	150	6127	1187	8409
	Unused land	18,489	53	42	1014	1813	57,913	79,324
	Sum	85,839	6065	601	16,454	9199	74,504	192,662

(1) Grassland

From 1980 to 2020, 58,451 km^2 of grassland remained unchanged, and 27,388 km^2 was converted from other land-use types to grassland, of which 18,489 km^2 of unused land, 5948 km^2 of forest land, and 1936 km^2 of arable land made the largest contributions, accounting for 67.51%, 21.72%, and 7.07%, respectively. The area of grassland converted to other land-use types was 23,767 km^2, and the largest amount was transferred from unused land, with an area of 14,481 km^2 and a contribution of 60.93%, followed by forest land and arable land, with an area of 5774 km^2 and 2241 km^2, contributing 24.29% and 9.43%, respectively. The final grassland area increased by 3621 km^2.

(2) Arable land

From 1980 to 2020, 3185 km^2 of arable land remained unchanged, and the area converted from other land-use types to arable land was 2880 km^2, of which 2241 km^2 of grassland made the largest contribution, accounting for 77.81%. The area of arable land converted to other land-use types was 2556 km^2, and the largest transfer was from grassland at 1936 km^2, with a contribution of 75.74%. The final arable land area increased by 324 km^2.

(3) Construction land

From 1980 to 2020, 78 km^2 of construction land remained unchanged, and 523 km^2 was converted from other land-use types to construction land, of which 254 km^2 of grassland was the main amount transferred in, accounting for 48.57%, followed by 193 km^2 of arable land, accounting for 36.90%. The area of construction land converted to other land-use types was 351 km^2, with 174 km^2 of arable land and 141 km^2 of grassland being the main amounts transferred out, with contributions of 49.57% and 40.17%, respectively. The final construction land area increased by 172 km^2.

(4) Forest land

From 1980 to 2020, 9171 km^2 of forest land remained unchanged and 7283 km^2 was converted from other land-use types to forest land, of which 5774 km^2 of grassland and 1014 km^2 of unused land made the largest contributions, accounting for 79.28% and 13.92%, respectively. The area of forest land converted to other land-use types was 7370 km^2, with the largest transfer being 5948 km^2 of grassland and 872 km^2 of unused land, with contributions of 80.71% and 11.83%, respectively. The final forest land area decreased by 87 km^2.

(5) Waters

From 1980 to 2020, 6127 km^2 of waters remained unchanged, and the area converted from other land-use types to waters was 3072 km^2, of which 1813 km^2 of unused land and 1017 km^2 of grassland made the largest contributions, accounting for 59.02% and 33.11%, respectively. The area of waters converted to other land-use types was 2282 km^2, with the largest transfer out of 1187 km^2 of unused land and 874 km^2 of grassland, with contributions of 52.02% and 38.30%, respectively. The final waters area increased by 790 km^2.

(6) Unused land

From 1980 to 2020, there was 57,913 km^2 of unused land without change, and the area converted from other land-use types to unused land was 16,591 km^2, among which

14,481 km^2 of grassland, 1187 km^2 of waters, and 872 km^2 of forest land made the largest contributions, accounting for 87.28%, 7.15%, and 5.26% respectively. The area of unused land converted to other land-use types was 21,411 km^2, with the largest transfer out of 18,489 km^2 of grassland, 1813 km^2 of waters, and 1014 km^2 of forest land, with contributions of 86.35%, 8.47%, and 4.74% respectively. The final unused land area decreased by 4820 km^2.

It can be seen that the area of grassland, arable land, construction land, and waters increased, and the area of forest land and unused land decreased from 1980 to 2020.

4. Discussion and Conclusions

4.1. Discussion

It is a more scientific means to conduce the comprehensive analysis of the structural characteristics of land use, dynamic degree and transfer matrix in the QMs combined with spatial information to reflect the response of human activities to land use change. From 1980 to 2020, various land-use types in the study area changed to different degrees (Table 9). The area of the QMs LUCC changed dramatically before 2000, and the change from 2000 to 2015 was small. In 2000–2015, the area of arable land decreased, the area of grassland and forest land decreased significantly compared with that before 2000, which may be related to the implementation of the "Returning Cultivated Land to Forests and Grasses Project" in 1999. From 2015 to 2020, the area of grassland increased significantly, and the areas of arable land and forest land changed slightly, which may be related to the "14th Five-Year Plan" for Ecological Protection.

Table 9. The changes in the area of various land types in the Qilian Mountains from 1980 to 2020 (km^2).

Year	Grassland	Arable Land	Construction Land	Forest Land	Waters	Unused Land
1980–1990	263	205	−19	63	−584	72
1990–1995	−7810	−322	16	320	549	7247
1995–2000	7405	265	31	−391	−589	−6721
2000–2005	−62	73	1	−11	6	−7
2005–2010	−18	17	23	1	−20	−3
2010–2015	−55	−28	89	−22	113	−97
2015–2020	3898	114	31	−47	1315	−5311
1980–2020	3621	324	172	−87	790	−4820

From the structural characteristics of land use, the proportions of grassland, unused land, and forest land in the QMs are large; the proportions of arable land and construction land are small, especially the proportion of construction land, which may be related to the sparse population and slow economic development in the QMs. The increases in construction land and arable land and the decreases in unused land and forest land between 1980 and 2020 show that human activities have affected the ecological environment of the region during the study period. On the one hand, the increases in construction land and arable land and the decreases in unused land are closely related to the rapid development and construction of the QMs and economic development [53], which have a positive impact on the economy of the region, but the decrease in forest land will have a negative impact on the ecological and environmental security of the region. Moreover, the ecological environment in the QMs is sensitive and fragile, and slight changes in land use can have a significant impact on the region. Unreasonable development and utilization could lead to serious deterioration of the ecological environment in the QMs [54]. For example, there will be a significant impact on the physical and chemical properties of the soil: unreasonable land use can cause damage to the soil ecosystem and make it difficult to recover under natural conditions [55].

In terms of land use dynamic degree, land use dynamic degree can intuitively reflect the magnitude of change and rate of a certain LUCC [56] and is a scientific tool to reveal the response of land-use change to human activities [57]. The single land use dynamic degree showed that the share of the construction land area was the smallest, but the dynamic degree was the largest, at 3.70%, indicating that the construction land was disturbed by human activities with the greatest intensity from 2010 to 2015. The comprehensive land use dynamic degree showed that the intensity of overall land-use change in the study's time period was not significant, except for the time periods 1990–1995 (0.84%), 1995–2000 (0.80%), and 2015–2020 (0.56%), where the intensity of overall land-use change was relatively drastic, i.e., the degree of human activities influence on land use is weak. Land transfer is infrequent, and the intensity of land-use change is relatively stable.

From the land use transfer matrix, the conversion of various land-use types in the study area was infrequent during 2000–2005, 2005–2010, and 2010–2015. Overall, from 1980 to 2020, the largest increase in construction land, greater human activity was responsible for the 40.09% growth in construction land. The area of unused land decreased the most, at 4820 km^2, and was mostly converted to grassland, waters, and forest land; the area of grassland increased the most, 3621 km^2; and unused land, forest land, and arable land contributed most to the growth of grassland. The direct conversion of grassland and unused land to other land-use types was the main reason for the changes in spatial distribution for different land-use types.

The innovation of this study is that previous studies on LUCC in the northwest region have mostly focused on the Qinghai–Tibetan Plateau or small watersheds in the QMs, and the knowledge of LUCC in the QMs as a whole region is insufficient. And the time series of previous studies are short, which makes it difficult to analyze the long time series. However, this study focuses on the QMs, which are not widely noticed but ecologically fragile, and uses data from up to 40 years and 8 periods for analysis as well as discussing the driving forces of LUCC in the QMs from a qualitative perspective, which can better complement basic research. However, there are still some shortcomings. Firstly, in terms of research methods, this paper mainly adopts classical research methods, and some innovative research methods to study LUCC in the QMs could be considered in the future. Secondly, in terms of spatio-temporal analysis, this paper mainly focuses on the temporal analysis and spatial distribution of LUCC in the QMs. More detailed regionalization of the LUCC characteristics in the QMs could be analyzed according to different geographical units. Finally, the analysis of driving forces of LUCC in the QMs is discussed mainly from a qualitative perspective in this paper, but the quantitative results are more convincing and will be supplemented in the subsequent studies.

Based on the findings of the study and combined with the actual situation of the region, it is suggested that in the process of future land use and management, while ensuring regional economic development, the relationship between economic development and land use should also be managed in terms of the main drivers of changes in various land-use types so as to ensure the rational development and utilization of land resources.

4.2. Conclusions

(1) From 1980 to 2020, grassland, forest land, and unused land were the mainstay of land use in the QMs, construction land accounted for the smallest proportion. Grassland was mainly distributed in the central-eastern part of the study area, unused land in the central-western part of the study area, and forest land in the northeastern part of the study area. A small amount of arable land was distributed at the eastern boundary of the QMs, and the waters were dominated by Qinghai Lake and Hala Lake.

(2) The single land use dynamic degree showed that the dynamic degree of construction land was the highest and the fastest change rate from 2010 to 2015, at 3.70%, followed by the dynamic degree of waters from 2015 to 2020, at 3.34%. The comprehensive land use dynamic degree showed that the intensity of the overall land use change is relatively drastic in the three time periods 1990–1995 (0.84%), 1995–2000 (0.80%), and 2015–2020 (0.56%).

(3) The land use transfer matrix showed that the land-use types in the QMs shifted infrequently during 2000–2005, 2005–2010, and 2010–2015.

(4) The interconversion of grassland and unused land and direct conversion with other land-use types were the main reasons for the changes in the spatial distribution of different land-use types.
(5) The area of grassland (4.40%), arable land (5.64%), construction land (40.09%), and waters (9.39%) increased, and the area of forest land (−0.53%) and unused land (−6.08%) decreased from 1980 to 2020.

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