land

MDPI

Article

The Spatiotemporal Change in Land Cover and Discrepancies within Different Countries on the Qinghai–Tibet Plateau over a Recent 30-Year Period

Yan Chen [1,2] and Erqi Xu [1,*]

[1] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; chenyan231@mails.ucas.ac.cn
[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: xueq@igsnrr.ac.cn

Abstract: The Qinghai–Tibet Plateau is a unique global natural geographical unit with a high altitude and fragile ecology, where land cover change has been affecting its regional ecological security and sustainable development. The plateau covers nine countries with different variations in climate change and human activities, which cause significant spatial variations in its land cover change. This paper uses land cover data to reveal the spatiotemporal characteristics and multi-country differences in land cover change on the Qinghai–Tibet Plateau from 1992 to 2020 by applying spatiotemporal characteristic analysis and mapping methods. The results show that grassland (65.70%), bare land (15.56%), and woodland (10.25%) are the main types of land cover on the plateau, accounting for 91.51% of the total area. The interconversion of bare land and grassland was dominant in 1992–2020, with an area share of 67.83%. The turning point year of grassland change occurred in 2015. The grassland area increased by 6312 km^2 in 1992–2015, while it decreased by 14,646 km^2 in the plateau in 2015–2020. The areas of woodland, cropland, and water increased by 2.77%, 5.85%, and 7.57%, respectively, and the area of built-up land increased from 299.17 km^2 to 1206.29 km^2. Overall, a warming and wetting trend of the climate in the Qinghai–Tibet Plateau has driven the expansion of natural vegetation and water in the central plateau within China, with its natural vegetation area increasing by 0.11%. However, the development of regional warming and drying caused local grassland degradation, where Kyrgyzstan and India within the Qinghai–Tibet Plateau experienced the most prominent vegetation degradation. Human activities are relatively frequent in the Qinghai–Tibet Plateau within China and India, causing higher growth rates of built-up land and cropland than in other countries. The establishment of reserves and effective forest management policies have led to significant increases in woodland areas in China and Nepal within the plateau, while weak forest management and limited investment in forest conservation have led to high rates of deforestation in India and Myanmar. Accelerated temperature rises and regional differences in precipitation are the main drivers of large-scale land cover change on the plateau and differences in human activities and land use policies are responsible for the dramatic and diverse localized land cover change.

Keywords: Qinghai–Tibet Plateau; climate change; land cover change characteristics; multi-country differences; vegetation degradation

check for updates

Citation: Chen, Y.; Xu, E. The Spatiotemporal Change in Land Cover and Discrepancies within Different Countries on the Qinghai–Tibet Plateau over a Recent 30-Year Period. *Land* **2023**, *12*, 1797. https://doi.org/10.3390/land12091797

Academic Editor: Alexandru-Ionuţ Petrişor

Received: 9 August 2023
Revised: 5 September 2023
Accepted: 13 September 2023
Published: 16 September 2023

1. Introduction

Land cover refers to the surface elements created by nature and covered by artificial constructions resulting from the joint action of natural and human activities [1]. Land cover has significantly changed worldwide at different temporal and spatial scales over the past decades [2], resulting in a range of impacts such as climate change [3], biodiversity loss, declining ecosystem services [4], and land degradation [5], causing widespread concern in the international community. The "International Geosphere-Biosphere Programme" (IGBP), the LUCC Program, and the Future Earth Program were implemented at the international level, making significant progress in the theory, methodology, and practice of land use/land cover research [6]. The study shows that climate change, human activities, and government policies are the main causes of land cover change, with natural factors playing an important role in land cover change and the frequency and extent of human-induced land cover change escalating worldwide [7]. In addition, the emergence of new technologies and tools, in particular the application of remote sensing and GIS, has provided technical and data security for land use and land cover monitoring and assessment [8].

The Qinghai–Tibet Plateau is an exceptional global natural unit characterized by a high altitude and fragile ecology and its land cover showed a solid sensitivity to global change and human activities [9]. There has been a clear climate warming trend in the Qinghai–Tibet Plateau since 1980 [10,11], with a warming rate approximately twice the global average [12]; the warming has shown significant regional differences, causing a series of impacts on the plateau surface, such as lake changes, glacier shrinkage, permafrost degradation, and desertification shrinkage and expansion [13]. Meanwhile, the plateau is subject to increasing external pressures, such as human activities in the localized area [14], which exacerbate land cover change and have complex implications for regional ecological security [3]. Therefore, exploring land cover change on the Qinghai–Tibet Plateau helps to meet the real needs for the coordinated development of socioeconomic and ecological conservation on the plateau and adjacent areas. It also helps to enrich scientific research on land change science in alpine regions. It further provides scientific information for constructing ecological safety barriers and regional sustainable development in the global plateau and related areas in the context of climate change and intensified anthropogenic disturbances and regional differentiation.

Currently, research on land cover change in the Qinghai–Tibet Plateau primarily has investigated change patterns [15], processes [9], driving mechanisms [16], and environmental effects [17]. Most of the studies on land cover change patterns and processes in the Qinghai–Tibet Plateau used land use and land cover data generated by remote sensing image interpretation and detected land cover change dynamics through GIS technology [18]. Studies primarily have focused on the main types of change, such as grassland degradation [19], land desertification [20], construction land, and lake expansion [21,22], as well as forest change [23]. They have pointed out that climate change [24], population growth, socioeconomic development, and related policies [25] are critical driving factors for land cover change in the Qinghai–Tibet Plateau. Spatial and temporal change characteristics are the basis of research on land cover change. Still, most studies are concentrated on the meso–micro scale, such as the Qaidam Basin [26], Qilian Mountains [27], Lhasa [28], and other representative areas, while studies on plateau-wide land cover change are relatively scarce.

Due to the relative lack of and limited accuracy of data on the Qinghai–Tibet Plateau, there is a wide variation in the understanding of the extent of the plateau [29,30]. The plateau range delineated in most studies is limited to China [31,32] and studies of land cover change across the plateau and in different countries within the plateau are relatively uncommon [33]. The land cover structure of the Qinghai–Tibet Plateau within China remained generally stable from 1992 to 2015, characterized by an overall improvement and a local degradation in grassland, significant recovery of woodland, essential stabilization of cropland, and considerable expansion of built-up land. Changes in built-up land, cropland, and planted forest land in the Hehuang Valley and the Yarlung Zangbo River and the area of its two tributaries are remarkable and highly correlated with the intensity of human activities [18]. Kashmir, within India, has experienced lake degradation, glacial snow decline, and an increase in barren land, swamps, and shrubs since the 1990s [34]. Furthermore, increased population and economic activities have accelerated the conversion of forest and agricultural land to pasture, construction land, and horticultural land in the area [35]. Grassland expansion and degradation coexist in the western Pamirs of Tajikistan, where grassland expansion is dominant [36]. Although some studies [15,18] have analyzed spatiotemporal changes in land cover on the Qinghai–Tibet Plateau through long-term series data, investigations that compare spatiotemporal characteristics of land cover change across the whole plateau as well as in different countries within the plateau are relatively lacking. Thus, it is urgent to research land cover change and its regional differences over the entire plateau scale.

Given these considerations, this paper explores the spatial and temporal characteristics of land cover change through descriptive statistics, transfer matrix, GIS spatial analysis, and mapping methods based on yearly land cover data from 1992–2020, revealing the multi-country differences in land cover change on the Qinghai–Tibet Plateau. Our research further provides scientific suggestions for promoting the coordinated development of socioeconomic and ecological conservation in the plateau area.

2. Data and Methods

2.1. Study Area

The Qinghai–Tibet Plateau, with its unique natural geography and complex topography, is known as the "roof of the world" and the "third pole of the earth" and a significant ecological security barrier for China and Asia. The study area in this paper is shown in Figure 1 and is the newly defined range of the Qinghai–Tibet Plateau by Zhang Yili and others [33]. Zhang Yili et al. used natural features such as geomorphology as the main factor in determining the extent of the Qinghai–Tibet Plateau. They proposed the principle of determining the extent of the Qinghai–Tibet Plateau based on geomorphological features such as the altitude of the plateau surface and its distribution and the integrity of the mountains. Zhang Yili et al. used recent information, high-resolution remote sensing imagery, and DEM data to compare and analyze the geomorphological features of the Qinghai–Tibet Plateau and its surroundings, then used the ArcMap software to achieve a 1:1,000,000 scale vector definition of the extent of the Qinghai–Tibet Plateau. The Qinghai–Tibet Plateau extends from 25°59′30″ N to 40°01′00″ N and 67°40′37″ E to 104°40′57″ E, with a total area of 3,083,400 km^2 and an average altitude of about 4320 m. It extends from the northern foothills of the western Kunlun–Qilian Mountains to the southern foothills of the Himalayas and other mountains, with a maximum width of 1560 km from north to south and, from the western edge of the Hindu Kush and Pamir Plateau to the Hengduan Mountains and other mountains, with the longest east–west distance of about 3360 km. The Qinghai–Tibet Plateau involves nine countries: China, India, Pakistan, Tajikistan, Afghanistan, Nepal, Bhutan, Myanmar, and Kyrgyzstan. The Qinghai–Tibet Plateau in China is approximately 2,581,300 km^2, accounting for 83.7% of the total plateau area. In contrast, the site in the other countries is 502,100 km^2, accounting for 16.3%.

2.2. Data Sources

The European Space Agency (ESA) Climate Change Initiative (CCI) has produced the land cover data used in this paper, providing global land cover data at a 300-m spatial resolution for every year since 1992. Liu et al. demonstrated that the overall accuracy of CCI-LC data in parts of the Qinghai–Tibet Plateau reaches 53.92%, which is a high accuracy compared with other land use and land cover data [37]. The classification of CCI-LC data was defined using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO). The UN-LCCS defines LC classes using a set of classifiers. The system was designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available to describe each LC class, whilst following a standardized classification approach. The CCI-LC data are classified at two levels, the first level of classification is at the global scale and includes 22 land cover categories, while the second level of classification provides land cover information at the regional scale, which contains more categories and more detailed information.

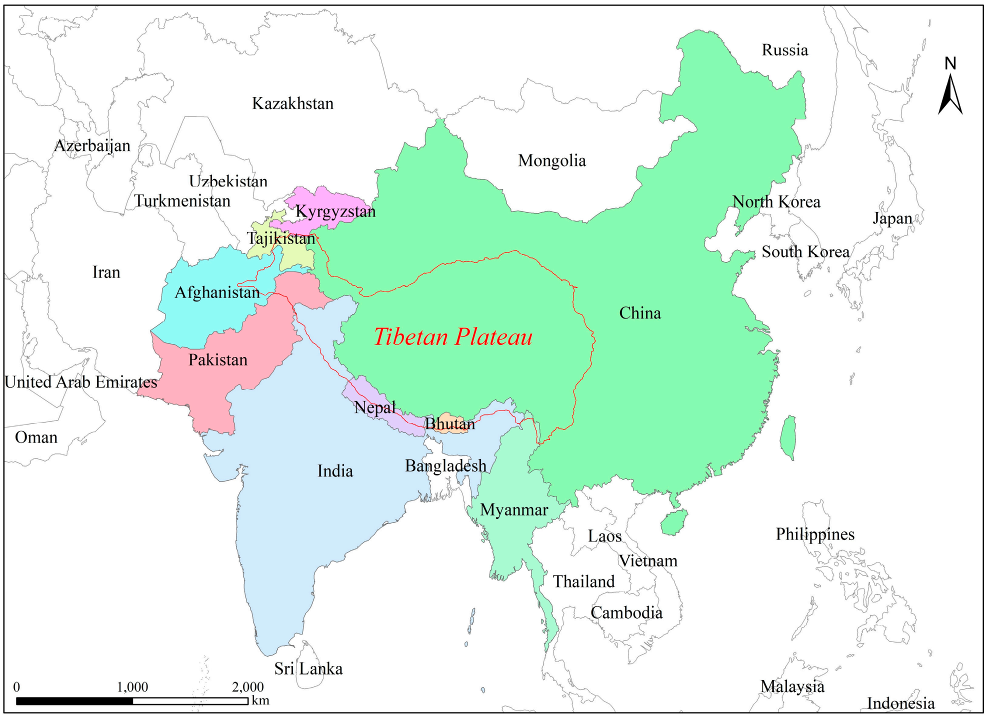

Figure 1. Location map of the study region.

2.3. Research Methods

(1) Pre-processing methods

Arcgis10.7 is a software for creating, editing and maintaining geographic data, mapping, visualization, and spatial analysis, which is commonly used for land use and cover change analysis. This paper uses ArcGIS10.7 software to define the projection of land cover data. The projections of the data in this paper all use the Asia North Albers Equal Area Conic to ensure that the area of all regions included in the data is proportional to the area of the same parts on Earth. It is unnecessary to classify land cover in too much detail to analyze the land cover change characteristics of the Qinghai–Tibet Plateau because most of the land cover types of the plateau account for a relatively low proportion. It is difficult to detect the main change patterns of land cover with too many categories. Therefore, we reclassified the CCI-LC data into nine types: cropland, woodland, shrubland, grassland, built-up land, wetlands, bare land, water, and permanent snow and ice (as shown in Table 1).

Table 1. Land cover classification systems and reclassification methods.

CCI-LC Code	CCI-LC Classification System	Classification Code in This Article	Classification System in This Article
20	Cropland, irrigated or post-flooding		
10	Cropland, rainfed		
11	Cropland, rainfed, Herbaceous cover	1	Cropland
12	Cropland, rainfed, tree or shrub cover		
30	Mosaic cropland (>50%)/natural vegetation (tree, shrub, herbaceous cover) (<50%)		

Table 1. *Cont.*

CCI-LC Code	CCI-LC Classification System	Classification Code in This Article	Classification System in This Article
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	2	Woodland
60	Tree cover, broadleaved, deciduous, closed to open (>15%)		
61	Tree cover, broadleaved, deciduous, closed (>40%)		
62	Tree cover, broadleaved, deciduous, open (15–40%)		
70	Tree cover, needleleaved, evergreen, closed to open (>15%)		
71	Tree cover, needleleaved, evergreen, closed (>40%)		
72	Tree cover, needleleaved, evergreen, open (15–40%)		
80	Tree cover, needleleaved, deciduous, closed to open (>15%)		
81	Tree cover, needleleaved, deciduous, closed (>40%)		
82	Tree cover, needleleaved, deciduous, open (15–40%)		
90	Tree cover, mixed leaf type (broadleaved and needleleaved)		
100	Mosaic tree and shrub (>50%)/herbaceous cover (<50%)		
151	Sparse tree (<15%)		
120	Shrubland	3	Shrubland
121	Evergreen shrubland		
122	Deciduous shrubland		
152	Sparse shrub (<15%)		
110	Mosaic herbaceous cover (>50%)/tree and shrub (<50%)	4	Grassland
130	Grassland		
140	Lichens and mosses		
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)		
153	Sparse herbaceous cover (<15%)		
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%)/cropland (<50%)		
190	Built-up land	5	Built-up land
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water	6	Wetlands
160	Tree cover, flooded, fresh or brackish water		
170	Tree cover, flooded, saline water.		
200	Bare areas	7	Bare land
201	Consolidated bare areas		
202	Unconsolidated bare areas		
210	Water bodies	8	Water
220	Permanent snow and ice	9	Permanent snow and ice

(2) Descriptive statistics

This paper analyzes the area and percentage of land cover types on the plateau through descriptive statistics and then calculates the rate of change in the area of the major cover types to reveal the pattern and trend of land cover across countries on the Qinghai–Tibet Plateau. The expression is as follows:

$$F_{ij} = \frac{S_j}{S_i} \times 100\% \tag{1}$$

F_{ij} is the area proportion of j land cover type in country i within the plateau in a certain period, S_j is the area of land cover type j in a certain period, and S_i is the total area of country i in the plateau.

(3) Transfer matrix

The land-use status transfer matrix comprehensively and specifically portrays the structural characteristics of regional land-use changes and reflects the direction of land-use changes. This method originates from the quantitative description of system state and state transfer in system analysis, which reflects the process of state transformation of a sub-stable system from T to T+1 moments under a certain time interval, so as to better reveal the spatio-temporal evolution process of land use pattern [15]. This paper uses a transfer matrix to reveal the characteristics of land cover change on the Qinghai–Tibet Plateau, which is expressed as follows.

$$S_{pq} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \tag{2}$$

where S_{pq} is the land cover status at the beginning and end of the study period and n is the number of land cover types.

(4) Spatial mapping and analysis methods

Since land cover change at the exact location may occur several times, this paper extracts the raster cells where land cover change occurs yearly to analyze its frequency of change during the study period. We assigned the extracted raster cells a value of 1 and overlaid the raster data from all years to produce a series of land cover change data. Finally, we counted the value of each raster cell in the series data as the number of times land cover change occurred from 1992 to 2020. In addition, we used ArcGIS10.7 software to overlay the land cover data of the Qinghai–Tibet Plateau in 1992 and 2020 to produce a spatial distribution map of land cover change and to analyze the characteristics of cover change on the plateau. The limited and fragmented spatial distribution of land cover change on the Qinghai–Tibet Plateau makes spatial analysis and visualization difficult. Thus, we analyzed the intensity of change in the main land cover types by creating 10 km^2 × 10 km^2 fish nets. Firstly, we extracted the pixels of cropland converted to other land cover types and other land cover types converted to cropland as pixels of cropland decreased and increased, respectively, based on the land cover change map from 1992 to 2020. Then, we counted the total number of pixels that cropland decreased and increased in each grid and their area proportions to reflect the intensity of the change by zonal statistics. The formula is as follows:

$$F_c = \frac{S_c}{S_b} \times 100\% \tag{3}$$

where S_c is the area of c land cover type increased or decreased in the unit grid, S_b is the area of the unit grid (100 km^2), and F_c is the variation intensity of c land cover type in the unit grid.

3. Results

3.1. Land Cover Status on the Qinghai–Tibet Plateau

Grassland is the main land cover type on the Qinghai–Tibet Plateau, with an area of 2,025,645 km^2, accounting for 65.70% of the study area. The bare land and woodland areas are 479,911 km^2 and 316,134 km^2, accounting for 15.56% and 10.25%, respectively. These three types account for 91.51% of the total area. The cropland, permanent snow and ice, and water area are 93,073 km^2, 104,472 km^2, and 46,816 km^2, respectively, comprising 1.5–3.5% of the total area. The areas of shrubland, built-up land, and wetlands are even smaller, all accounting for less than 0.5%. The central part of the Qinghai–Tibet Plateau is located in China. Therefore, the plateau's land cover structural characteristics within China are similar to those of the whole plateau. Grassland dominates the Qinghai–Tibet Plateau within China, accounting for 68.42% of the area, followed by bare land (15.72%) and woodland (8.53%); but the share of the rest of the land cover types is lower, with cropland, water, and built-up land only accounting for 2.78%, 1.77%, and 0.04%, respectively. In contrast, the land cover characteristics of the plateau for non-Chinese ranges present significant differences. The proportion of grassland area is relatively low, falling to 51.68%, while the proportion of the woodland area rises to second place at 19.12%. The bare land and permanent snow and ice area coverage are in third and fourth place at 14.75% and 9.66%, respectively, and the proportion of shrubs, built-up land, water, and wetlands area is relatively low, with none exceeding 0.3%.

The distribution within the plateau varies considerably from country to country, as do physical geographic features such as climate, directly contributing to the significant differences in land cover composition between countries. Most countries have a very limited area within the Qinghai–Tibet Plateau. At the same time, the high altitude characteristic of the Qinghai–Tibet Plateau determines the special features of the land cover in these areas compared to the country as a whole. Table 2 shows the structure of land cover in each country within the plateau. The proportion of grassland area exceeds 20% in each country but only the regions within Tajikistan, Afghanistan, Pakistan, and China account for more than 50%. However, the Qinghai–Tibetan Plateau regions within Bhutan and Myanmar are dominated by woodland, accounting for approximately 70% of the area, followed by grassland accounting for about 20% of the area and the rest of the types accounting for less than 4%. The grassland area in the Qinghai–Tibet Plateau regions within India and Nepal is around 40% and the woodland area is relatively high at 20%. However, the plateau region within India has a relatively high proportion of bare land area at 21.16%, while in Nepal, it is only 2.87%.

Table 2. Comparison of the share of land cover type area in different countries within the Qinghai–Tibet Plateau in 2020 (%).

	Pakistan	Afghanistan	Bhutan	Nepal	Tajikistan	India	Kyrgyzstan	Myanmar	China
Cropland	3.87	4.89	1.21	4.89	2.23	5.49	6.50	1.54	2.78
Woodland	8.52	4.27	72.14	38.86	0.30	20.97	0.80	75.97	8.53
Shrubland	0.13	0.11	0.49	0.29	0.09	0.13	0.02	0.85	0.34
Grassland	58.31	77.35	22.00	45.46	60.34	41.52	39.07	20.86	68.42
Build-up land	0.05	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.04
Wetlands	0.09	0.05	0.00	0.03	0.08	0.20	0.00	0.53	0.23
Bare land	15.67	8.63	0.24	2.87	23.31	21.16	26.84	0.04	15.72
Water	0.01	0.08	0.03	0.04	0.81	0.29	0.00	0.00	1.77
Permanent snow and ice	13.36	4.60	3.90	7.55	12.84	10.09	26.77	0.21	2.17

Note: The area of built-up land, wetlands, and water in Kyrgyzstan within the Qinghai–Tibet Plateau is zero and the size of the built-up land in Myanmar within the Qinghai–Tibet Plateau is zero. The rest of the site is rounded to the nearest zero.

Due to the exceptional alpine natural conditions, the land cover is mainly characterized by grassland on the broad Qinghai–Tibet Plateau surface, bare land distributed primarily on the northern part of the plateau, and forest distributed in the south. The rest of the land cover types are generally scattered (Figure 2). Grassland is mainly found in China's Qiangtang Plateau, Qinghai Plateau, Qilian Mountains, the northern highlands of Pakistan, and the northwestern part of the Hindu Kush Mountains in Afghanistan. Woodland is distributed in the Hengduan Mountains in China, central and southern parts of Bhutan and Nepal, and the southeastern part of Kashmir Valley in India. Shrubland is more scattered, mainly along the Indus River northwest of Namcha Parbat Peak, Ali of the Tibet Autonomous Region, and along the Yarlung Zangbo River. Most bare land is distributed in the northern part of the Qiangtang Plateau and the Qaidam Basin in China and partly in the north of the Pamir Plateau in Tajikistan. The vast majority of water and wetlands are scattered across the Qiangtang Plateau and the Qaidam Basin in China. Cropland is mainly distributed in the Huangshui Valley Basin, the Yellow River Valley Basin, the Yanyuan Basin in China, and the Kashmir Valley in India. Built-up land is mainly distributed in Xining, Lhasa, and Diqing Tibetan Autonomous Prefecture in China and Srinagar in India. Permanent snow and ice are primarily scattered in the western Kunlun Mountains, the Hindu Kush, the Karakoram Mountain, the Himalayas, and the Nyingchi Tanggula.

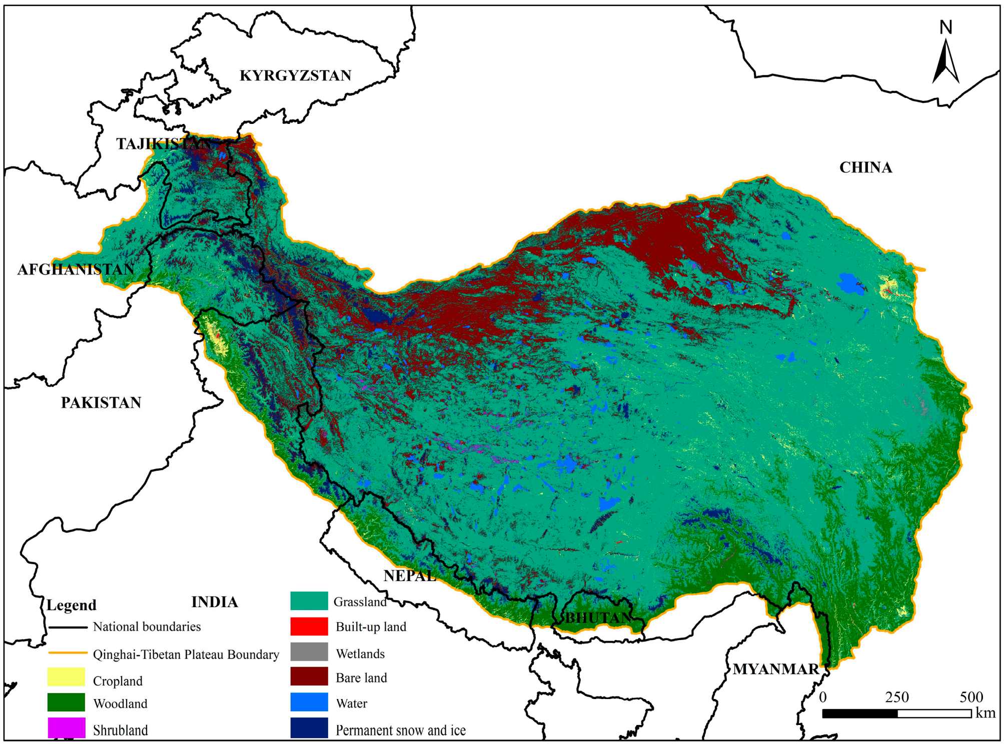

Figure 2. Spatial distribution of land cover on the Qinghai–Tibet Plateau.

3.2. General Characteristics of Land Cover Change on the Qinghai–Tibet Plateau

The characteristics of land cover change on the Qinghai–Tibet Plateau from 1992 to 2020 showed no significant difference in permanent snow and ice, a net decrease in the areas of bare land, grassland, and shrubland, and a net increase in the remaining cover types. However, different types showed different temporal variation characteristics (Figure 3). The net reduction in bare land and grassland was even more considerable, at 9222.47 km^2 and 8333.44 km^2, respectively, with corresponding reduction rates of 1.89% and 0.41%. The bare land and grassland area showed corresponding trends of significant decrease and increase, respectively, in 2001–2015, before transitioning to an oppositely directed trend of pronounced increase and decrease in 2016–2020. The net reduction in shrubland is even more slight, with a subtle decline of 350.93 km^2 from 1992 to 2020. Woodland had the most significant net increase in the area among the land cover types, with an increase in 8534.35 km^2 or 2.77%, and showed a general and consistent increasing trend. The second most significant increase in area was in cropland, with a net gain of 5143.36 km^2 or 5.85% and featured a trend of growth followed by a decrease. The cropland area rose significantly in 1992–2004 and declined slightly after 2014, losing 1173.90 km^2 from 2014 to 2020. The size of water in the plateau also showed a considerable increase, with a net gain of 3295.63 km^2 or 7.57% compared to the initial period and it maintained a general growth trend. Meanwhile, the area of wetlands displayed a fluctuating trend, with an overall increase in 26.39 km^2. The built-up land increased from 299.17 km^2 at the beginning of the study period to 1206.29 km^2 at the end of the period, and the growth rate improved almost every year, rising from 1.23% in 1993 to 5.88% in 2020.

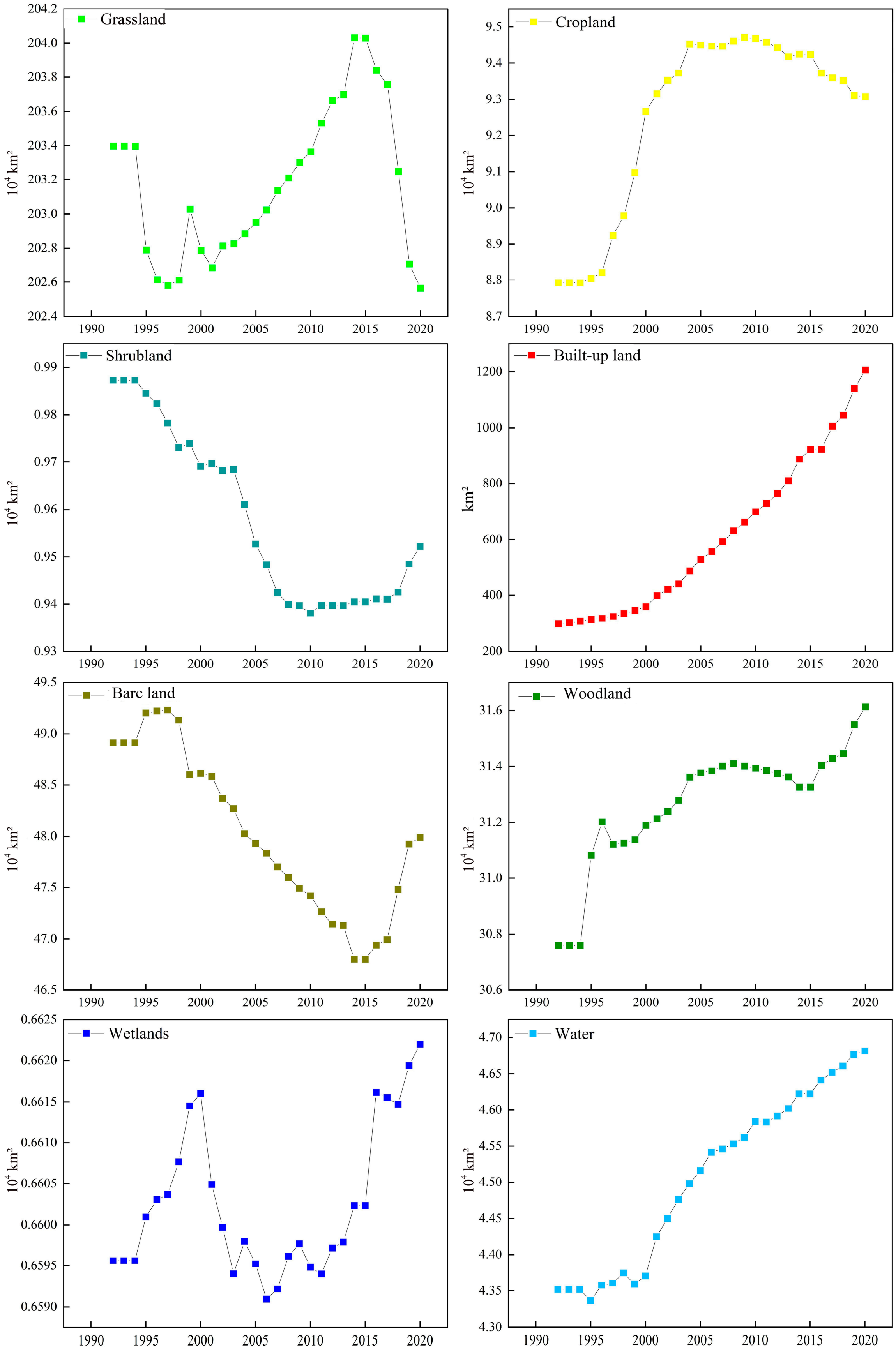

Figure 3. Area change in major land cover types on the Qinghai–Tibet Plateau.

The area of land cover change on the Qinghai–Tibet Plateau was 122,500 km^2 from 1992 to 2020, accounting for about 3.97% of the total area. Single changes dominate the land cover change on the plateau, while multiple changes account for only 0.15%. Grassland is the most dominant land cover type on the Qinghai–Tibet Plateau and its change dramatically impacts the plateau land cover structure. The interconversion between grassland and bare land is the primary land cover change type on the plateau (Table 3 and Figure 4). The conversion of bare land to grassland has occurred in an area of 44,244.28 km^2, mainly distributed in the Qaidam Basin, the western part of the Yarlung Zangbo River and its two tributaries area, and the eastern Pamir Plateau (Figure 5). An area of 36,040.06 km^2 on the Qinghai–Tibet Plateau has been converted from grassland to bare land, mainly located in the northern plateau. For example, the degradation of grassland around Jingyu Lake and Dajian Lake in the northern plateau is pronounced (Figure 6a,b).

Table 3. Land cover change types and their area statistics on the Qinghai–Tibet Plateau in 1992–2020 (km^2).

Sorting	Change Type	Area (km^2)	Sorting	Change Type	Area (km^2)
1	Bare land → Grassland	44,244.28	10	Water → Grassland	806.95
2	Grassland → Bare land	36,040.06	11	Shrubland → Woodland	697.49
3	Grassland → Woodland	13,637.82	12	Cropland → Woodland	662.95
4	Grassland → Cropland	6657.68	13	Grassland → Build-up land	419.27
5	Woodland → Grassland	3943.12	14	Cropland → Build-up land	408.06
6	Grassland → Water	3260.30	15	Water → Bare land	396.65
7	Cropland → Grassland	2764.90	16	Woodland → Shrubland	210.65
8	Woodland → Cropland	2246.98	17	Grassland → Shrubland	106.09
9	Bare land → Water	1216.95	18	Bare land → Cropland	78.27

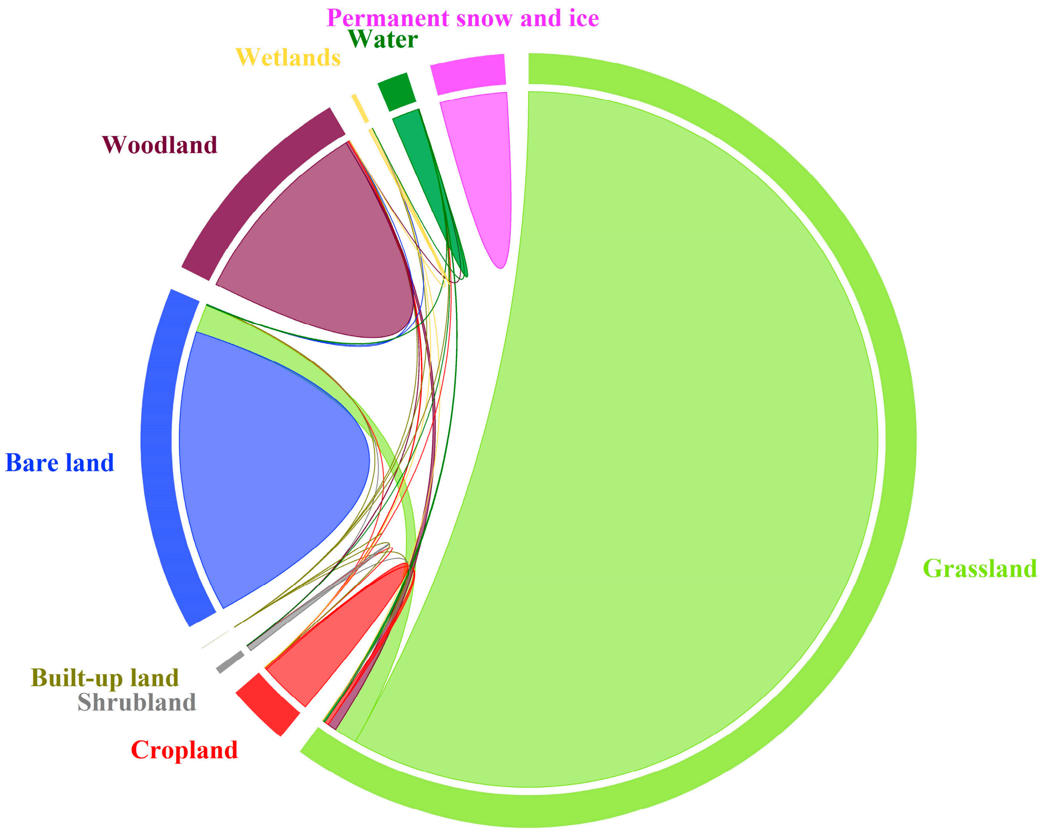

Figure 4. Interconversion chord diagram of different land cover types on the Qinghai–Tibet Plateau in 1992–2020.

The interconversion of grassland with other land cover types is also of considerable scale in the plateau. There were 13,637.82 km^2 and 6757.68 km^2 converted from grassland to woodland and cropland, respectively. Meanwhile, 3943.12 km^2 of woodland and 2764.90 km^2 of cropland were converted to grassland. The area where grassland was converted to woodland was mainly distributed in the southeastern plateau and the southern Himalayas. The transformation of grassland to cropland primarily occurred in the eastern part of the plateau. In contrast, cropland conversion to grassland mainly happened in the southern and northeastern parts of the plateau. Grassland is the primary source of increased water on the plateau, followed by bare land; there were 3260.30 km^2 and 1216.95 km^2 converted from grassland and bare land to water, respectively, scattered in the Qaidam Basin and the Qiangtang Plateau. For example, the Crow Lake area in the Qaidam Basin significantly expanded between 1992 and 2020 (Figure 6c,d). The size of the remaining land cover change types was relatively insignificant. The ninth largest type of land cover change was the conversion of bare land to water, with an area of 1216.95 km^2, and after that, all areas of conversion types were less than 1000 km^2. The scale of built-up land expansion is smaller than most conversion types but the expansion rate is rapid. The growth of built-up land is concentrated in Kashmir Valley, the southern Sichuan–Tibet alpine and gorge region, and the Yarlung Zangbo River and its two tributaries area, which are flat and densely populated. For example, there have been significant expansions of built-up land in both Srinagar, a city located in the Kashmir Valley, and in Diqing Tibetan Autonomous Prefecture, which has been located in the southeastern plateau since 2000 (Figure 6e–h).

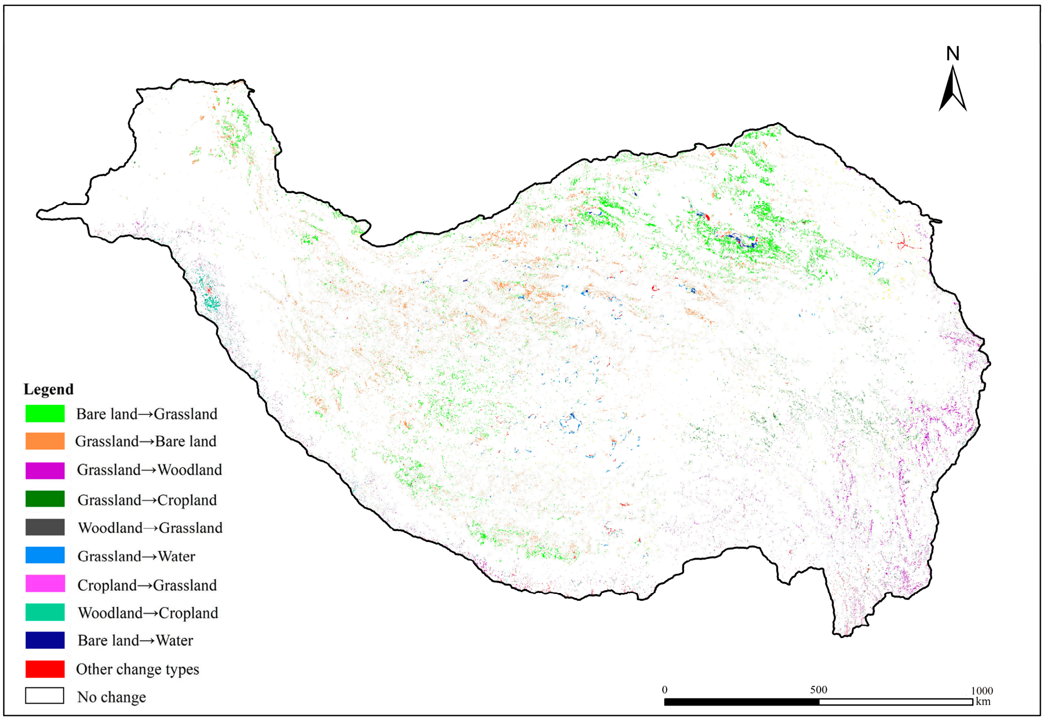

Figure 5. Spatial distribution of land cover change on the Qinghai–Tibet Plateau in 1992–2020.

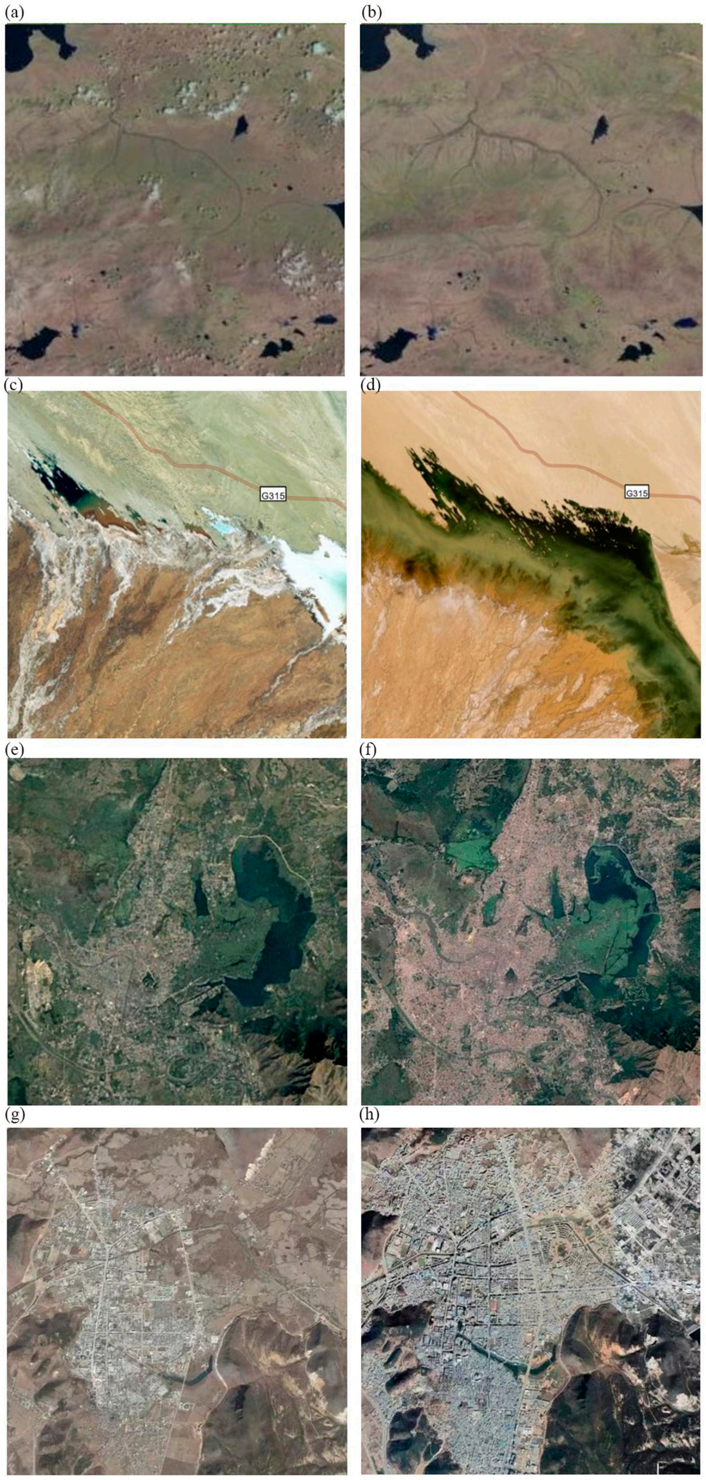

Figure 6. Examples of typical land cover change types on the Qinghai–Tibet Plateau. Note: Panels (**a**,**b**) are images of the northern plateau around Jingyu Lake and Dajian Lake in August 2015 and August 2017, respectively, noting the reduction in grassland area during this period; (**c**,**d**) are images of Ya Lake in the Qaidam Basin in 2014 and 2019, respectively, noting the significant expansion of lake area during this period; (**e**,**f**) are images of northern Srinagar within the Kashmir Valley in 2004 and 2020, respectively, noting a significant built-up land expansion during this period; and (**g**,**h**) are images of Diqing Tibetan Autonomous Prefecture in China in 2002 and 2019, respectively, noting a significant built-up land expansion during this period. The above images are derived from a Landsat 8 satellite and Google Earth Pro.

3.3. Analysis of the Main Type of Changes in Countries within the Plateau

The portion of the Qinghai–Tibet Plateau region located within China accounts for 83.7% of its area. Thus, most hotspots of land cover change are contained in China. However, land cover change varies among countries within the plateau due to differences in regional climate change, economic development, and land use policies. Vegetation recovery occurred mainly in the Qinghai–Tibet Plateau region within China between 1992 and 2020. The proportion of bare land in the plateau region within China decreased by 0.40% and the area of natural vegetation increased by 0.11%, with an increase in woodland and a decrease in grassland. The remaining countries in the Qinghai–Tibet Plateau have experienced differing degrees of vegetation degradation. Furthermore, vegetation degradation in the Qinghai–Tibet Plateau within Kyrgyzstan and India is most pronounced, the share of vegetation area decreased by 1.33% and 1.59%, respectively, and the share of the bare land area increased by 0.41% and 0.63%, respectively. In addition, there was a significant increase in water in the Qinghai–Tibet Plateau within China and a slight change in water within the remaining countries. The individual national wetlands within the plateau were insignificantly altered. The Qinghai–Tibet Plateau regions within China and India have more frequent human activities, resulting in more significant growth in built-up land and cropland than in other countries. In contrast, the Qinghai–Tibet Plateau regions within Afghanistan, Nepal, Bhutan, and Tajikistan have a more stable area of the above-mentioned land.

3.3.1. Comparison of Changes in Grassland

The area of grassland in the Qinghai–Tibet Plateau within Myanmar increased from 1992–2020, while the size of grassland within all other countries decreased. The most considerable net reduction in grassland in the Qinghai–Tibet Plateau region within China was 6258.63 km^2. Although the area of grassland in the Qinghai–Tibet Plateau within Kyrgyzstan, India, and Nepal is lower, the reduction in share is more dramatic, constituting 1.66%, 0.62%, and 0.87%, respectively, compared to the initial period. In addition, the temporal trends in grassland vary from country to country. The changes in the area of grassland in the Qinghai–Tibet Plateau within Pakistan, India, and Tajikistan are similar. They all showed an overall increase in area from 1992–2005 but a gradual decrease after 2006. In contrast, the area of grassland within China increased yearly between 2001 and 2014 but decreased significantly after 2015 (Figure 7). There has been a general trend of fluctuating declines in grassland in the Qinghai–Tibet Plateau areas within Nepal, Kyrgyzstan, and Afghanistan. The areas where grassland decreased during the study period are primarily located in the northern and eastern parts of the Qiangtang Plateau in China and the areas where grassland increased were mainly observed in the Qaidam Basin, the central Qiangtang Plateau, the northern Himalayas, and the eastern part of the Pamir Plateau (Figure 8a).

3.3.2. Comparison of Changes in Bare Land

The area of bare land in the Qinghai–Tibet Plateau did not change significantly within Myanmar between 1992 and 2020, decreased within China and Nepal, but increased within all other countries. Regions where the bare land has improved are mainly in the northern and southern parts of the Qiangtang Plateau in China and the northeastern part of the Kashmir Valley in India, while areas where it has decreased are mainly in the south-central part of the Qiangtang Plateau, the Qaidam Basin, and to the east of the Pamir Plateau in China (Figure 8e). The Qinghai–Tibet Plateau had the most significant net reduction in the bare land area within China, with an area reduction of 10,400.55 km^2 and an area share reduction of 0.40% from 1992 to 2020. The area of bare land in the Qinghai–Tibet Plateau decreased by 6.71 km^2 within Nepal, with a drop of area share of 0.01%. The increase in bare land in the Qinghai–Tibet Plateau is more pronounced within India, where the net gain is 964.68 km^2 and the proportion of bare land increased by 0.63%. The net increase in bare land area in the Qinghai–Tibet Plateau within Kyrgyzstan was 11.49 km^2 and the proportion of bare land area increased by 0.41%, second only to that of India. The increased proportion of bare land area in the rest of the countries is less than 0.14%.

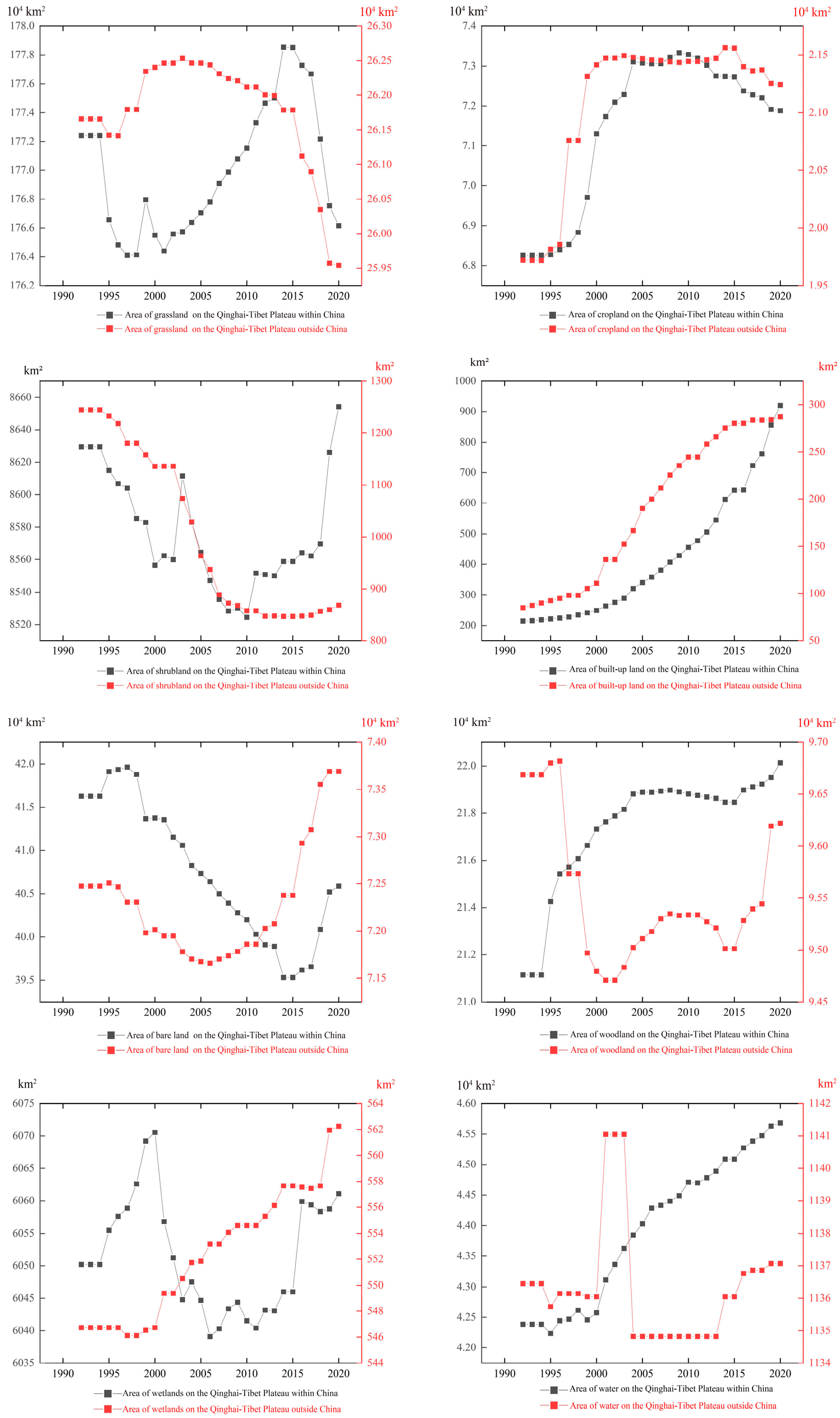

Figure 7. Changes in land cover types on the Qinghai–Tibet Plateau within and outside China.

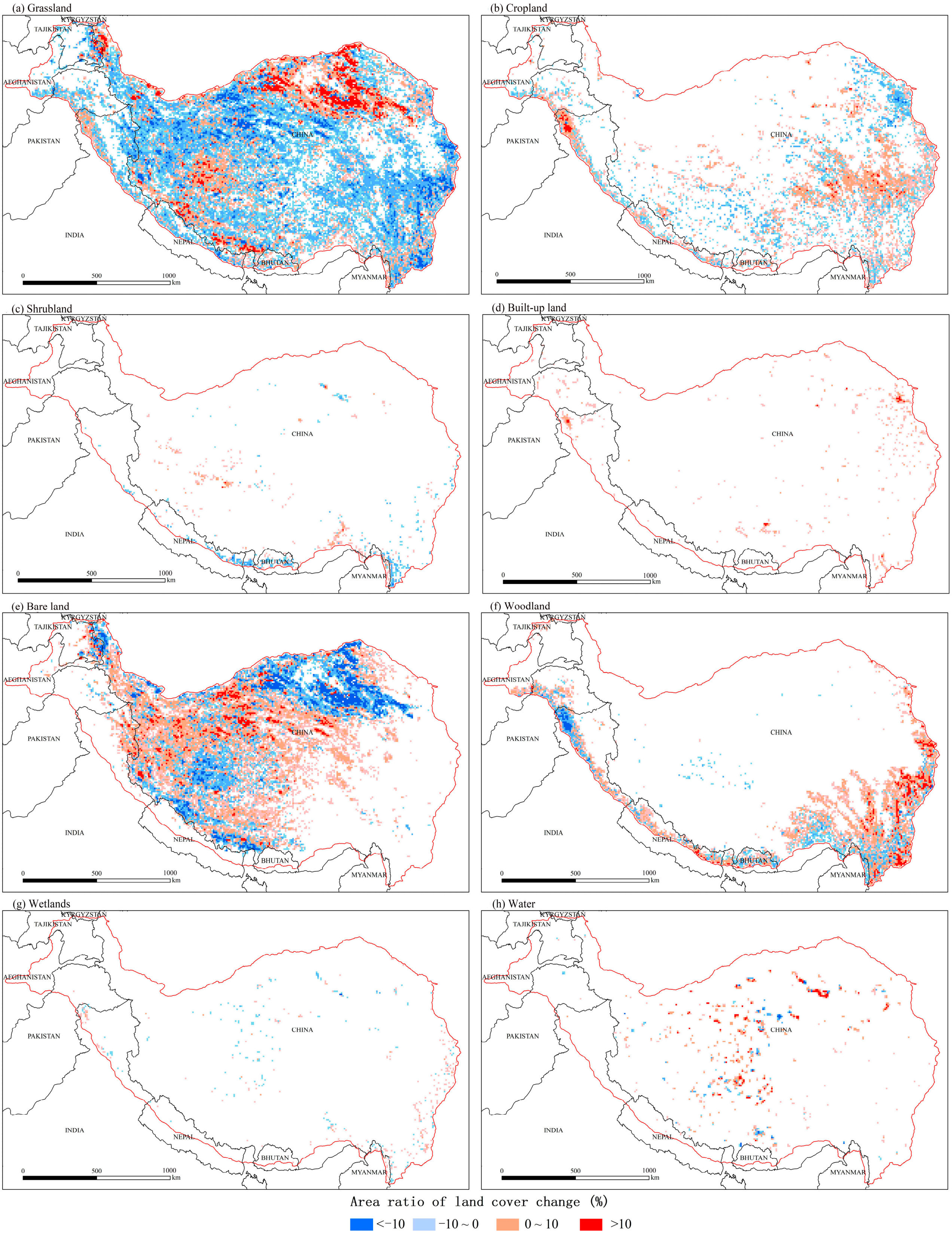

Figure 8. Area ratio of land cover change on the Qinghai–Tibet Plateau.

3.3.3. Comparison of Changes in Woodland

Most countries within the Qinghai–Tibet Plateau showed an increasing trend in woodland area during the study period, while only India, Myanmar, and Pakistan experienced a decrease in woodland area. The area proportion of woodland in the Qinghai–Tibet Plateau within India and Myanmar decreased by 0.89% and 0.58%, respectively, whereas the area proportion within Pakistan decreased by 0.004%. The net increase in the area of woodland in the Qinghai–Tibet Plateau is the largest within China, with a rise of 8998.41 km^2, and is mainly distributed in the central and southern parts of the Sichuan–Tibet alpine and gorge region. The most significant increase in the share of woodland area was in Nepal within the plateau, with a rise of 1.04% compared to the initial period. The area share of woodland in the Qinghai–Tibet Plateau within Bhutan, Afghanistan, Tajikistan, and Kyrgyzstan has also increased, all by 0.05–0.5%. The regions where the woodland area increased are mainly distributed in the southern Himalayan and the southern Hindu Kush (Figure 8f).

3.3.4. Comparison of Changes in Wetlands and Water

The change in the area and proportion of wetlands in each country within the Qinghai–Tibet Plateau is insignificant from 1992 to 2020. The net increase in wetland areas in the Qinghai–Tibet Plateau within China and India was 10.90 km^2 and 9.54 km^2, respectively, with variations in the share of wetlands area below 0.007%. Wetland expansion in the Qinghai–Tibet Plateau is mainly located in the eastern part of China's Sichuan–Tibet alpine and gorge region and the northwestern part of the Kashmir Valley in India (Figure 8g). However, there is no distribution of wetlands and water in Kyrgyzstan within the Qinghai–Tibet Plateau, and there is no significant change in wetlands in Afghanistan and Tajikistan within the plateau. There is a limited increase in wetlands areas within the other countries in the Qinghai–Tibet Plateau. In contrast, there was a significant increase in plateau water within China, by 3295.02 km^2, increasing the area share by 0.13%, while the rest of the water within other countries in the Qinghai–Tibet Plateau did not change dramatically (Figure 8h).

3.3.5. Comparison of Changes in Cropland

There was a net increase in cropland in all countries within the Qinghai–Tibet Plateau from 1992 to 2020. The increase in cropland is mainly in areas with relatively flat terrain and concentrated population, such as the northwestern Sichuan province in China, the Kashmir Valley in India, and the central regions of Bhutan and Nepal, while the decrease in cropland was mainly in the eastern part of the Qinghai Lake in China (Figure 8b). The Qinghai–Tibet Plateau has a much more significant net increase in cropland area within China and India, with 3624.79 km^2 and 1259.28 km^2, respectively, and an increase in the share of cropland area of 0.14% and 0.83%, respectively. At the same time, the plateau has experienced even more significant growth in the share of cropland within Kyrgyzstan, with the share of cropland increasing by 0.92%. Nevertheless, the increase in cropland area within the rest of the countries was relatively slight, with an increase in the proportion of cropland area ranging from 0.01% to 0.15%. In addition, changes in cropland presented different chronological characteristics at the national scale in the plateau. Except for Kyrgyzstan in the Qinghai–Tibet Plateau, where the cropland area has been increasing yearly, all the other countries showed a significant increase in cropland area from 2000 to 2015 but exhibited a slight decrease after 2015.

3.3.6. Comparison of Changes in Built-Up Land

The share of the built-up land on the Qinghai–Tibet Plateau is relatively lower. Still, it has risen markedly since 1992, particularly in the plateau region within China and India. The Qinghai–Tibet Plateau experienced an enormous net increase in the built-up land within China and India, at 705.60 km^2 and 175.04 km^2, respectively. However, the proportion of built-up land in the Qinghai–Tibet Plateau within India has risen even more sharply, with the proportion rising by 0.12% compared to the initial period. In comparison, in China, it rose only by 0.03%. The growth of the built-up land in the Qinghai–Tibet Plateau within China is concentrated in the southern part of the Yarlung Zangbo River and its two tributaries area, the Hehuang Basin and the Sichuan–Tibet alpine and gorge region, while the growth of the built-up land within India is mainly distributed in the Kashmir Valley (Figure 8d). In addition, the Qinghai–Tibet Plateau also experienced a more significant expansion of built-up land within Pakistan, with an increase in 0.02% in the proportion of the area. In comparison, the rest of the countries had an increase in the proportion of built-up land of less than 0.004%.

4. Discussion

Although we have basically clarified the spatial and temporal characteristics of land cover change in the whole Qinghai–Tibet Plateau and its key areas, there are still some problems associated with it. Firstly, the complicated natural conditions, diverse land cover types, and the difficulty of ground validation on the Qinghai–Tibet Plateau have resulted in fewer statistical data and land use and cover products for the plateau region, with lower classification accuracies [18]. Liu et al. analyzed the availability of commonly used land cover data such as Globeland30, CCI-LC, and MCD12Q1 on the Qiangtang Plateau, and found that the overall accuracy of the first-level types was mostly below 55% [38]. Peng et al. analyzed the classification accuracies of TPDC_LUCC, ESA_LUCC, and CASearth_LUCC in the Sanjiangyuan region of the Qinghai–Tibet Plateau and found that the overall accuracy is only close to 60%, which severely limits the accuracy of land cover analysis [15]. Secondly, there is a relative lack of land use and land cover classification systems suitable for highland areas, which constrains the scientific and comparability of data [18]. Currently, there are relatively few studies using multi-source data such as remote sensing data and basic statistical data to analyze land cover change on the Qinghai–Tibet Plateau and there is also a relative lack of attempts to process the data using advanced processing platforms and models. Studies of land cover change in plateau regions still need to improve the scientific validity of data in terms of data sources, classification systems, processing platforms, and field validation.

The alpine environmental conditions of the Qinghai–Tibet Plateau make the land cover of the plateau sensitive to climate change and human activities [39]. However, the extent of anthropogenic disturbances on the Qinghai–Tibet Plateau is relatively limited compared to other regions and land cover change is influenced by climate change at a larger scale [40]. The Qinghai–Tibet Plateau warmed at a rate of 0.42 °C/decade between 1979 and 2012 and the higher temperatures accelerated the melting of glaciers and snowpack, resulting in a significant enhancement in atmospheric moisture and precipitation [40]. According to statistics, the plateau precipitation increased at a rate of 11.5 mm/decade from 1967 to 2016 and the overall warming and wetting trend was noticeable on the plateau [3], resulting in an increase in the water area of 3295.02 km^2 on the plateau over the recent 30 years. At the same time, the warming and wetting trend of the plateau provided suitable hydrothermal conditions for vegetation growth and contributed to its recovery [41]. In addition, the construction of nature reserves, grassland pest prevention and control, and the Grain for Green program have been implemented in the Qaidam Basin, Yarlung Zangbo River, and its two tributaries area in recent years [41], resulting in a yearly increase in the area of the grassland on the plateau during 2001–2014 and an increase in 8534.35 km^2 in the area of woodland since 1992.

The Qinghai–Tibet Plateau has a vast territory and within it, regional differences in climate change, making regional land cover changes significantly different. The northeastern part of the plateau has experienced a higher annual temperature increase than other regions [42] and precipitation in the northern inland rivers, the Heihe River Basin, and the Qaidam Basin has been on a decreasing trend [43]. The impact of localized warming and drying has led to a decrease in grassland in the northern Qiangtang Plateau of China (Figure 8a). This paper shows that the land cover condition on the Qinghai–Tibet Plateau generally improved and locally degraded during the period from 1992 to 2015, which is consistent with the findings of Yili Zhang et al. [18]. However, this paper found that grassland degradation in the northern and southern parts of the Qinghai–Tibet Plateau aggravated during the period from 2015 to 2020. There has been a relative reduction in the intensity of human disturbances on the grassland in the Qinghai–Tibet Plateau due to the implementation of the Grazing Forbidden Policy in China since 2003. Despite this effort, the trend of grassland degradation has been aggravated. Thus, natural factors such as climate change may be among the leading causes of recent grassland degradation in the Qinghai–Tibet Plateau [44].

The driving factors of land use/land cover change are multiple, the socio-economic development and the positioning of the region directly influence land use change at the large national and regional scales. Areas with rapid socio-economic development have faster population growth and urbanization, resulting in a significant expansion of built-up land [45]. Areas orientated towards ecological conservation drive positive changes in vegetation [46]. The Qinghai–Tibet Plateau has experienced a significant increase in woodland within China, Nepal, and Bhutan from 1992 to 2020. In contrast, there has been a dramatic decline in woodland in the Qinghai–Tibet Plateau within India, Myanmar, and Pakistan, mainly attributed to deforestation, cultivation, and regional differences in forest conservation management practices. The plateau's woodland area increased by 8998.41 km^2 within China and this was due to the implementation of several ecological conservation projects in China which facilitated the recovery of forests in the southeastern and southern parts of the plateau [47]. Bhutan has protected its forests through centralized government management and Nepal has developed progressive community forestry and conservation area policies [23,48], resulting in an increase in the proportion of woodland area in both countries within the Qinghai–Tibet Plateau by 0.46% and 1.04%, respectively. The area of woodland in the Indian extent in the plateau has decreased by 1353.99 km^2 with a 0.89% reduction in area proportion, which can be attributed to factors such as agricultural expansion, timber extraction, poor forest management, etc. [49]. The Qinghai–Tibet Plateau region within Myanmar and Pakistan has relatively weak forest management policies and prioritizes timber extraction and subsequent export. Hence, the conversion to commerce and agriculture has become more widespread [50,51], resulting in a reduction in the area of woodland. This study found that the Qinghai–Tibet Plateau experienced a significant increase in cropland and built-up land in the Kashmir Valley of India and in the Yarlung Zangbo River and its two tributaries: the Huangshang Basin and the southern part of the Chuan–Tibetan alpine valleys of China (Figure 8b). This is due to the fact that anthropogenic activities on the plateau were more frequent in the Chinese and Indian ranges during the study period. Population growth, migration, and increased accessibility due to socio-economic development have led to a more pronounced expansion of cropland and built-up land in the plateau within India and China. The cropland in the Qinghai–Tibet Plateau within India has decreased marginally after 2015. This is due to factors such as urban sprawl, climate change, groundwater depletion, and pollution of agricultural land that have stymied the development of cultivation [52], resulting in a gradual loss of cropland in northern India [53]. As urbanization and industrialization deepened after 2010 in China, the population continued to flow into cities, while the rural population continued to decline. At the same time, the effects of a series of ecological protection and restoration projects, such as Grain for Green, have gradually emerged, promoting the development of regional forestry and animal husbandry, resulting in a slight reduction in cropland in China within the Qinghai–Tibet Plateau [54].

The existing research generally explained the spatial and temporal characteristics and drivers of land cover change in the whole Qinghai–Tibet Plateau and critical areas of the plateau in recent decades. However, land cover change on the Qinghai–Tibet Plateau generally showed the diversity of characteristics, complexity of processes, and uncertainty of trends. Existing studies still face problems such as insufficient data, lack of generalization of the change patterns at different spatial and temporal scales, unclear impact mechanisms, and difficulty predicting trends. It is suggested that future research on the Qinghai–Tibet

Plateau's land cover needs to use multiple data sources to improve upon the accuracy of land cover data. Meanwhile, monitoring the ecological environment on the Qinghai–Tibet Plateau needs to be further strengthened and the number of observation stations in the uninhabited western part of the plateau can be increased to enhance the reliability of climate change observation data. Finally, it is necessary to explore the mechanisms of climate change's impact on land cover in-depth, strengthen research on the characteristics of land cover change at different spatial and temporal scales, and enhance comparative studies on the spatial and temporal differences in driving factors to help countries in the Qinghai–Tibet Plateau to formulate and adjust their land use policies both scientifically and rationally.

5. Conclusions

This paper uses ESA-CCL land cover data to reveal the general characteristics of land cover change on the Qinghai–Tibet Plateau from 1992 to 2020 and to compare the multi-country differences in the features of the main cover types and their driving factors. Grassland, bare land, and woodland are the main types of land cover on the Qinghai–Tibet Plateau, accounting for 91.51% of the total area, while shrubland, built-up land, and wetlands account for less than 0.5%. The land cover structure of the Qinghai–Tibet Plateau is stable, with an altered area of 122,500 km^2, accounting for 3.97% of the total plateau area, with a single change as the primary change type. The conversions between grassland and bare land were the most dominant type of land cover change on the plateau in 1992–2020, accounting for 67.83% of the area in all change types. The overall warming and wetting trend on the Qinghai–Tibet Plateau has driven the expansion of vegetation and water in the central part of the plateau. In contrast, localized warming and drying have led to increased grassland degradation in the northern and southern parts of the plateau in the last five years. The vegetation area in the Qinghai–Tibet Plateau region within China increased by 0.11% and the bare land area decreased by 0.40%. The proportion of vegetation area decreased in all other countries in the Qinghai–Tibet Plateau region, particularly Kyrgyzstan and India, where there were decreases of 1.33% and 1.59%, respectively; while the proportion of bare land area increased by 0.41% and 0.63%, respectively, showing the end result of the most prominent vegetation degradation. The proportional change in wetland areas is less than 0.06% in all countries within the Qinghai–Tibet Plateau. The area of water increased significantly in the Qinghai–Tibet Plateau region within China while the remaining countries showed slight changes in the area of water. The more frequent human activities in the Qinghai–Tibet Plateau within China and India have led to a markedly higher increase in built-up land and cropland than in other countries. Effective forest management policies in the Qinghai–Tibet Plateau within China and Nepal have resulted in remarkable forest restoration. In the future, research on land cover change on the Qinghai–Tibet Plateau should enrich data sources, further strengthen the monitoring of the ecological environment on the Qinghai–Tibet Plateau, enhance research on the characteristics and driving mechanisms of land cover change at different spatial and temporal scales, and reinforce land use management in the context of climate change.

Author Contributions: Conceptualization, Y.C. and E.X.; methodology, Y.C. and E.X.; writing—original draft preparation, Y.C.; writing—review and editing, Y.C. and E.X.; visualization, Y.C.; supervision, E.X.; funding acquisition, E.X. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA23100403), the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (2019QZKK0603), the National Natural Science Foundation of China (42271277, 72221002), and the Youth Innovation Promotion Association of the Chinese Academy of Sciences (2021052).

Data Availability Statement: The ESA land cover data used in this study can be downloaded from the Climate Data Store website (https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=overview1).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pepin, N.; Bradley, R.S.; Diaz, H.F.; Baraer, M.; Caceres, E.B.; Forsythe, N.; Fowler, H.; Greenwood, G.; Hashmi, M.Z.; Liu, X.D.; et al. Elevation-dependent warming in mountain regions of the world. *Nat. Clim. Chang.* **2015**, *5*, 424–430.
2. Winkler, K.; Fuchs, R.; Rounsevell, M.; Herold, M. Global land use changes are four times greater than previously estimated. *Nat. Commun.* **2021**, *12*, 2501. [CrossRef]
3. Zhang, B.; Zhou, W. Spatial–Temporal Characteristics of Precipitation and Its Relationship with Land Use/Cover Change on the Qinghai-Tibet Plateau, China. *Land* **2021**, *10*, 269. [CrossRef]
4. Zhou, Y.; Zhang, X.; Yu, H.; Liu, Q.; Xu, L. Land Use-Driven Changes in Ecosystem Service Values and Simulation of Future Scenarios: A Case Study of the Qinghai–Tibet Plateau. *Sustainability* **2021**, *13*, 4079. [CrossRef]
5. Zhou, C.; Shao, D.; Gu, W.; Yao, M. Impacts of land use change on soil erosion in farming areas of the Qinghai-Tibetan Plateau. *China Rural Water Conserv. Hydropower* **2022**, *473*, 126–133.
6. He, C.; Zhang, J.; Liu, Z.; Huang, Q. Characteristics and progress of land use/cover change studies from 1990 to 2018. *J. Geogr.* **2021**, *76*, 2730–2748.
7. Ning, C.; Subedi, R.; Hao, L. Land Use/Cover Change, Fragmentation, and Driving Factors in Nepal in the Last 25 Years. *Sustainability* **2023**, *15*, 6957. [CrossRef]
8. Sun, Z.P.; Bai, J.T.; Shi, Y.L.; Liu, S.H.; Jiang, J.; Wang, C.Z. Research on object-oriented land use change detection method based on high resolution imagery. *J. Agric. Mach.* **2015**, *46*, 297–303.
9. Wang, C.; Gao, Q.; Yu, M. Quantifying Trends of Land Change in Qinghai-Tibet Plateau during 2001–2015. *Remote Sens.* **2019**, *11*, 2435. [CrossRef]
10. Rangwala, I.; Miller, J.R. Climate change in mountains: A review of elevation-dependent warming and its possible causes. *Clim. Change* **2012**, *114*, 527–547. [CrossRef]
11. You, Q.; Chen, D.; Wu, F.; Pepin, N.; Cai, Z.; Ahrens, B.; Jiang, Z.; Wu, Z.; Kang, S.; AghaKouchak, A. Elevation dependent warming over the Tibetan Plateau: Patterns, mechanisms and perspectives. *Earth-Sci. Rev.* **2020**, *210*, 103349. [CrossRef]
12. Yao, T. Tackling on environmental changes in Tibetan Plateau with focus on water, ecosystem and adaptation. *Sci. Bull.* **2019**, *64*, 417. [CrossRef] [PubMed]
13. Latif, A.; Ilyas, S.; Zhang, Y.; Xin, Y.; Zhou, L.; Zhou, Q. Review on global change status and its impacts on the Tibetan Plateau environment. *J. Plant Ecol.* **2019**, *12*, 917–930. [CrossRef]
14. Xia, M.; Jia, K.; Zhao, W.; Liu, S.; Wei, X.; Wang, B. Spatio-temporal changes of ecological vulnerability across the Qinghai-Tibetan Plateau. *Ecol. Indic.* **2021**, *123*, 107274. [CrossRef]
15. Peng, H.; Ren, Y.; Li, Q.; Wei, J. Spatial and temporal characteristics of land use/cover change on the Qinghai-Tibet Plateau. *J. Chang. Acad. Sci.* **2022**, *39*, 41–49.
16. Fayaz, A.; Shafiq, M.u.; Singh, H.; Ahmed, P. Assessment of spatiotemporal changes in land use/land cover of North Kashmir Himalayas from 1992 to 2018. *Model. Earth Syst. Environ.* **2020**, *6*, 1189–1200. [CrossRef]
17. Zhang, L.; Zhang, H.; Xu, E. Information entropy and elasticity analysis of the land use structure change influencing eco-environmental quality in Qinghai-Tibet Plateau from 1990 to 2015. *Environ. Sci. Pollut. Res.* **2022**, *29*, 18348–18364. [CrossRef]
18. Zhang, Y.; Liu, L.; Wang, Z.; Pendulum, W.; Ding, M.; Wang, X.; Yan, J.; Xu, E.; Wu, X.; Zhang, B.; et al. Spatial and temporal characteristics of land use and cover change on the Qinghai-Tibet Plateau. *Sci. Bull.* **2019**, *64*, 2865–2875.
19. Du, J.; Wang, G.; Li, Y. Characteristics and causes of alpine grassland degradation in the Yangtze River and Yellow River source area in the last 45 years. *J. Grass Sci.* **2015**, *24*, 5–15.
20. Han, J.; Wang, J.; Chen, L.; Xiang, J.; Ling, Z.; Li, Q.; Wang, E. Driving factors of desertification in Qaidam Basin, China: An 18-year analysis using the geographic detector model. *Ecol. Indic.* **2021**, *124*, 107404. [CrossRef]
21. Wang, M.; Kong, D.; Mao, J.; Ma, W.; Ayyamperumal, R. The Impacts of Land Use Spatial Form Changes on Carbon Emissions in Qinghai–Tibet Plateau from 2000 to 2020: A Case Study of the Lhasa Metropolitan Area. *Land* **2023**, *12*, 122.
22. Zhang, M.; Chen, F.; Zhao, H.; Wang, J.; Wang, N. Recent Changes of Glacial Lakes in the High Mountain Asia and Its Potential Controlling Factors Analysis. *Remote Sens.* **2021**, *13*, 3757. [CrossRef]
23. Brandt, J.S.; Allendorf, T.; Radeloff, V.; Brooks, J. Effects of national forest-management regimes on unprotected forests of the Himalaya. *Conserv. Biol.* **2017**, *31*, 1271–1282. [CrossRef]
24. Wu, D.; Chen, F.; Li, K.; Xie, Y.; Zhang, J.; Zhou, A. Effects of climate change and human activity on lake shrinkage in Gonghe Basin of northeastern Tibetan Plateau during the past 60 years. *J. Arid Land* **2016**, *8*, 479–491. [CrossRef]
25. Chen, X.; Sun, M.; Lv, Y.; Hu, J.; Yang, L.; Zhou, Q. Characteristics of spatial and temporal land use changes and their drivers on the Ruoerge Plateau, eastern margin of Qinghai-Tibet. *J. Ecol. Rural. Environ.* **2023**, *39*, 306–315.
26. Xu, G.Y.; Wang, Z.J.; Hu, Z.D.; Zhang, J.X. Evaluation of a comprehensive land use cover index in the Qaidam Basin. *J. Hydropower* **2019**, *38*, 44–55.
27. Qian, D.; Cao, G.; Du, Y.; Li, Q.; Guo, X. Impacts of climate change and human factors on land cover change in inland mountain protected areas: A case study of the Qilian Mountain National Nature Reserve in China. *Environ. Monit. Assess.* **2019**, *191*, 486. [CrossRef]

28. Luo, J.; Xin, L.; Liu, F.; Chen, Q.; Zhou, Q.; Zhang, Y. Study of the intensity and driving factors of land use/cover change in the Yarlung Zangbo River, Nyang Qu River, and Lhasa River region, Qinghai-Tibet Plateau of China. *J. Arid Land* **2022**, *14*, 411–425. [CrossRef]
29. Sun, H. Land types on the Qinghai-Tibetan Plateau and their principles of agricultural use evaluation. *Nat. Resour.* **1980**, *2*, 10–24.
30. Chen, Y.; Chen, Y.; Liu, H. Status and eastern boundary of the zoogeographic region of the Qinghai-Tibet Plateau. *J. Aquat. Biol.* **1996**, *20*, 97–103.
31. Zhang, Y.; Li, B.; Zheng, D. On the extent and area of the Qinghai-Tibet Plateau. *Geogr. Res.* **2002**, *1*, 1–8.
32. Li, B.Y. Extent of the Tibetan Plateau. *Geogr. Stud.* **1987**, *3*, 57–64.
33. Zhang, Y.; Li, B.; Liu, L.; Zheng, D. Revisiting the extent of the Qinghai-Tibet Plateau. *Geogr. Stud.* **2021**, *40*, 1543–1553.
34. Alam, A.; Bhat, M.S.; Maheen, M. Using Landsat satellite data for assessing the land use and land cover change in Kashmir valley. *GeoJournal* **2019**, *85*, 1529–1543. [CrossRef]
35. Ahmed, R.; Ahmad, S.T.; Wani, G.F.; Ahmed, P.; Mir, A.A.; Singh, A. Analysis of landuse and landcover changes in Kashmir valley, India—A review. *GeoJournal* **2022**, *87*, 4391–4403. [CrossRef]
36. Vanselow, K.A.; Zandler, H.; Samimi, C. Time Series Analysis of Land Cover Change in Dry Mountains: Insights from the Tajik Pamirs. *Remote Sens.* **2021**, *13*, 3951. [CrossRef]
37. Liu, Q.; Zhang, Y.; Liu, L.; Li, L.; Qi, W. Accuracy evaluation of seven land cover data sets in Qiangtang Plateau. *Geogr. Res.* **2017**, *36*, 2061–2074.
38. Liu, Q.H.; Zhang, Y.L.; Liu, L.S.; Li, L.H.; Qi, W. The spatial local accuracy of land cover datasets over the Qiangtang Plateau, High Asia. *J. Geogr. Sci.* **2019**, *29*, 1841–1858. [CrossRef]
39. Yang, K.; Wu, H.; Qin, J.; Lin, C.; Tang, W.; Chen, Y. Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: A review. *Glob. Planet. Chang.* **2014**, *112*, 79–91. [CrossRef]
40. Wang, B.; Bao, Q.; Hoskins, B.; Wu, G.; Liu, Y. Tibetan Plateau warming and precipitation changes in East Asia. *Geophys. Res. Lett.* **2008**, *35*, L14702. [CrossRef]
41. Deng, X.; Wu, L.; He, C.; Shao, H. Study on Spatiotemporal Variation Pattern of Vegetation Coverage on Qinghai–Tibet Plateau and the Analysis of Its Climate Driving Factors. *Int. J. Environ. Res. Public Health* **2022**, *19*, 8836.
42. Sun, J.; Qin, X.; Yang, J. The response of vegetation dynamics of the different alpine grassland types to temperature and precipitation on the Tibetan Plateau. *Environ. Monit. Assess.* **2015**, *188*, 20. [CrossRef] [PubMed]
43. Zhou, S.R.; Xin, Z.B. Spatial and temporal variations of precipitation on the Qinghai-Tibetan Plateau over the past 40 years based on multi-source data. *J. Chang. Acad. Sci.* **2022**, 1–11. Available online: https://kns.cnki.net/kcms/detail/42.1171.TV.20221024.2010.014.html (accessed on 5 September 2023).
44. Lehnert, L.W.; Wesche, K.; Trachte, K.; Reudenbach, C.; Bendix, J. Climate variability rather than overstocking causes recent large scale cover changes of Tibetan pastures. *Sci. Rep.* **2016**, *6*, 24367. [CrossRef] [PubMed]
45. Chuai, X.; Wen, J.; Zhuang, D.; Guo, X.; Yuan, Y.; Lu, Y.; Zhang, M.; Li, J. Intersection of Physical and Anthropogenic Effects on Land-Use/Land-Cover Changes in Coastal China of Jiangsu Province. *Sustainability* **2019**, *11*, 2370. [CrossRef]
46. Liu, J.; Kuang, W.; Zhang, Z.; Xu, X.; Qin, Y.; Ning, J.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; et al. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Geogr. Sci.* **2014**, *24*, 195–210. [CrossRef]
47. Li, Y.; Wang, X.; Chu, I.; Niu, Z.; Foo, X. Spatial and temporal evolution of ecological barrier ecosystems and driving mechanisms on the Qinghai-Tibetan Plateau. *J. Ecol.* **2022**, *42*, 8581–8593.
48. Brooks, J.S. Avoiding the Limits to Growth: Gross National Happiness in Bhutan as a Model for Sustainable Development. *Sustainability* **2013**, *5*, 3640–3664. [CrossRef]
49. Thakur, S.; Negi, V.S.; Pathak, R.; Dhyani, R.; Durgapal, K.; Rawal, R.S. Indicator based integrated vulnerability assessment of community forests in Indian west Himalaya. *For. Ecol. Manag.* **2020**, *457*, 117674. [CrossRef]
50. Ahmad, A.; Ahmad, S.; Nabi, G.; Liu, Q.-J.; Islam, N.; Luan, X. Trends in Deforestation as a Response to Management Regimes and Policy Intervention in the Hindu Kush Himalaya of Pakistan. *Front. Environ. Sci.* **2022**, *10*, 810806. [CrossRef]
51. Woods, K. Commercial Agriculture Expansion in Myanmar: Links to Deforestation, Conversion Timber, and Land Conflicts. 2015. Available online: https://www.forest-trends.org/publications/commercial-agriculture-expansion-in-myanmar-links-to-deforestation-conversion-timber-and-land-conflicts-2/ (accessed on 5 September 2023).
52. Nath, R.; Luan, Y.; Yang, W.; Yang, C.; Chen, W.; Li, Q.; Cui, X. Changes in Arable Land Demand for Food in India and China: A Potential Threat to Food Security. *Sustainability* **2015**, *7*, 5371–5397. [CrossRef]
53. Shafiq, M.U.; Tali, J.A.; Islam, Z.U.; Qadir, J.; Ahmed, P. Changing land surface temperature in response to land use changes in Kashmir valley of northwestern Himalayas. *Singh* **2022**, *37*, 18618–18637. [CrossRef]
54. Wang, M.; Pan, K.; Wu, S. Spatial and temporal variations of arable land area on the Qinghai-Tibetan Plateau and their driving factors. *J. Appl. Environ. Biol.* **2022**, *4*, 859–868.