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Dynamic Evolution and Future Prediction of Land Use Patterns in the Arid Desert Region of Northwest China from 1990 to 2020

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Abstract: Based on temporal and spatial dynamic data on land use in the arid desert region of Northwest China from 1990 to 2020, this study quantitatively analyzed and predicted future scenarios of the dynamic distribution pattern of land use using remote sensing technology. Unused land was the dominant landscape in the arid desert region of Northwest China over the past 30 years. The largest patch index of cultivated and construction land is continuously increasing, exhibiting a spatial aggregation trend. Grassland is the main vegetation type in the arid desert region of Northwest China, with the proportion of patches fluctuating between 27 and 28% during the 30-year study period. The proportion of patches in forests decreased yearly, whereas the proportion of patches in water areas relatively changed little. Meanwhile, the area of construction land is continuously increasing, accounting for 80% of the total increased area. According to the prediction made by the model, unused land and grassland will account for the majority of land use in 2040. Environmental construction in the arid desert region of Northwest China is expected to improve the robustness of the rational development and utilization of unused land and boost the protection and construction of forests and grasslands.

Keywords: land use change; grasslands; forests; arid area; future scenario forecast

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1. Introduction

Land is an essential and foundational resource for human survival and development. Furthermore, changes in land utilization patterns are closely related to anthropogenic activities and rdetermine the quality and development of humans [1]. Changes in land use can affect landscape distributions and changing patterns [2]. The spatial distribution and structural characteristics of landscapes are referred to as landscape patterns [3]. As an important indicator of in the change monitoring of the ecological environment [4], vegetation (such as forests and grasslands) is a typical part of the various types of land use [5,6]. In addition to forest and grassland, cultivated and construction lands are closely related to human survival [7,8], as they address the food and living aspects of human survival, respectively. Other types of land use are water bodies and unused land.

After crossing the northwest desert oases, which are ecologically vulnerable areas, and the northern agricultural and animal husbandry interlaced areas, which are ecologically fragile areas, it can be seen that the arid desert region of Northwest is one of the most vulnerable areas in China. The arid desert region of Northwest China is also a key area for biodiversity protection and plays an important role in the national ecological security barrier [9]. In recent decades, the arid desert region of Northwest China has been tightly affected by anthropological activities, such as farming and building. Moreover, the ongoing improving of temperature (i.e., climate warming) has led to significant retreat of glaciers on the Qinghai-Tibetan plateau, resulting in big increasing of water resources in arid desert area of Northwest China [10,11]. The changing and distributions of water resources further alter the land use patterns there. Therefore, a series of evolutions have occurred between different land use types, forming different spatial and temporal distribution patterns. As the main area of desertification control in the northern sand control belt of China, the ecological environment of arid desert region of Northwest China has continuously been improved through a series of ecological engineering constructions in the past 30 years, resulting in big improvements in landscape patterns [12,13].

Following the rapid development of 3S (GIS, RS, and GPS) technology, the study of the spatial-temporal evolution of large-scale land use is greatly supported by big data sources and techniques [14,15]. Presently, numerous researchers have studied the arid desert region of Northwest China with respect to changes in the plants, animals, climate, and desert [16,17], but there is still a lack of long-term observation of the dynamic changes in land use patterns in the arid desert region of Northwest China. Using remote sensing technology to quantitatively analyze the types of land use in the arid desert region of Northwest China and simulate and predict the future under different scenarios, this study aimed to reveal the dynamic land features and make predictions of land use patterns in the arid desert region of Northwest China for >30 years. From the perspective of land use change, understanding the regularity of land use changes in the arid desert region of Northwest China can provide a theoretical basis for research and reference for future desertification control, ecological protection and restoration, sustainable management of ecosystems, and promotion of the rational allocation of land resources.

2. Materials and Methods

2.1. Study Area

The study area is a typical arid desert region in Northwest China (Figure 1). The average annual precipitation in this area is less than 200 mm, and the average annual potential evapotranspiration is more than 1200 mm, resulting in limited water resources. The study area spans from the Helan and Yinshan Mountains in the east, to the national border in the west, the Kunlun Mountain in the south, and the Altay Mountain and the national border in the north. The study area covers Ningxia, Gansu, Qinghai, Inner Mongolia, and Xinjiang (Figure 1). The area is mainly dominated by grasslands with occasional trees and shrubs. There are very few plant species with low coverage, vulnerable habitats, and significant limitation in vegetation restoration [13,18].

2.2. Data Source

This study used land use data from 7 periods in 5 northwestern provinces and autonomous regions: 1990, 1995, 2000, 2005, 2010, 2015, and 2020. Data were collected from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn; accessed on 15 August 2022) based on a Landsat series of images generated by artificial visual interpretation. Using ArcGIS software, the 1990–2020 land use dataset in the study area was obtained based on the batch extraction of the boundary of the northwest arid desert region. Based on the classification of the original data on the sharing platform, we divided land use into six first-level types: cultivated land, forests, grasslands, construction land, water area, and unused land.

2.3. Data Analysis

2.3.1. Single Landscape Dynamics Model

A single landscape dynamic model was used to quantitatively analyze the degree of change of a certain landscape type within a certain time range in the study area and directly reflect the quantitative change of a certain landscape type. The calculation formula is expressed as follows.

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

where U_a and U_b represent the area of a landscape type at the beginning and end of the study, respectively, and T is the study period.

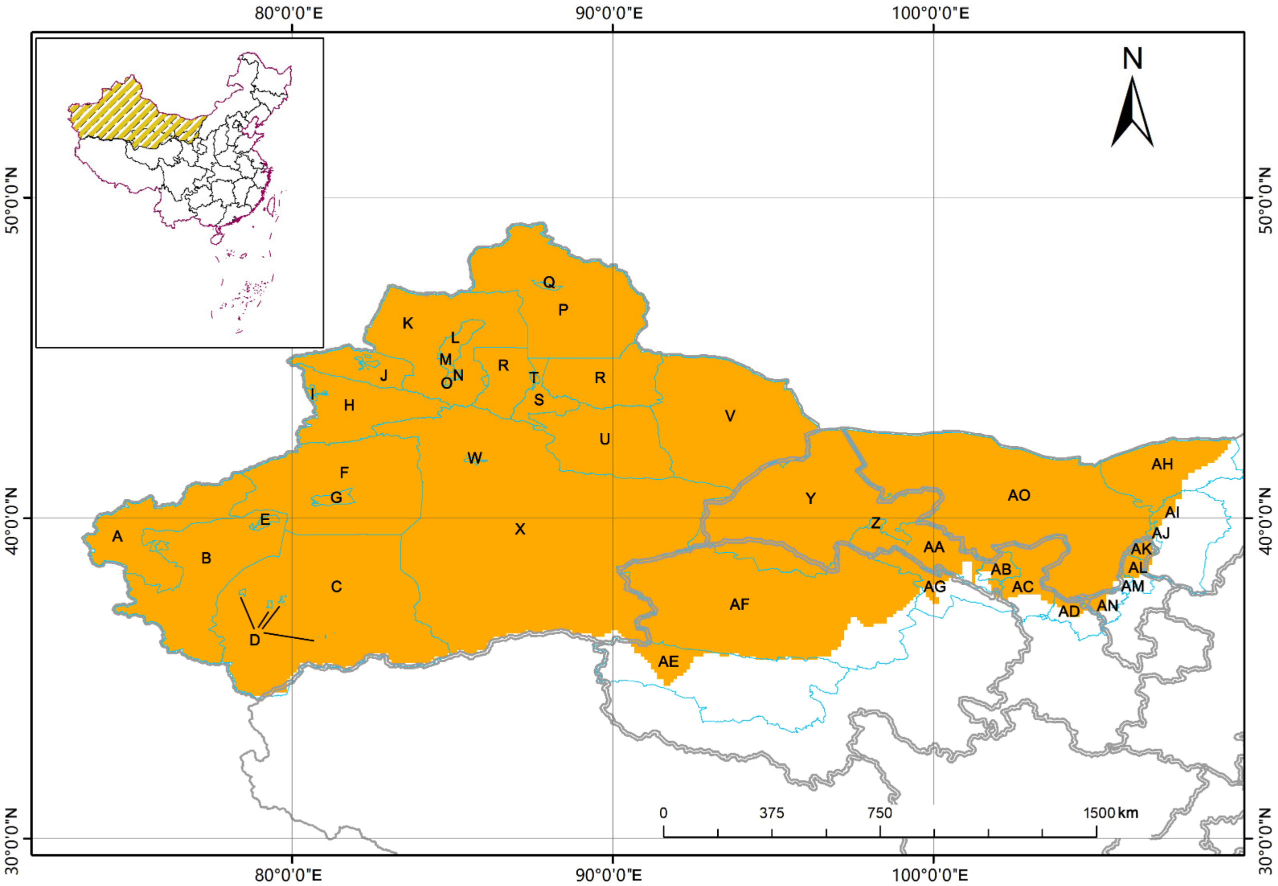

Figure 1. Map of arid desert areas in Northwest China. A: Kizilsu Kirgiz; B: Kashgar; C: Hotan; D: Kunyu; E: Tumushuke; F: Aksu; G: Alal; H: Ili kazak; I: Kudala; J: Shuanghe; K: Tacheng; L: Karamay; M: Huyanghe; N: Ili kazak; O: Karamay; P: Alertai; Q: Beitun; R: Changji; S: Urumqi; T: Wujiaqu; U: Turpan; V: Kumul; W: Tiemenguan; X: Korla; Y: Jiuquan; Z: Jiayuguan; AA: Zhangye; AB: Jinchang; AC: Wuwei; AD: Baiyin; AE: Yushu; AF: Haixi; AG: Haibei; AH: Bayanchore; AI: Ordos; AJ: Wuhai; AK: Shizhuishan; AL: Yinchuan; AM: Wuzhong; AN: Zhongwei; AO: Alxa.

2.3.2. Overall Dynamic Model

The overall dynamic model was used to reflect the speed of landscape type changes throughout the study area within a certain period of time and to reflect whether the degree of change in landscape types in the study area was obvious. The calculation formula is expressed as follows.

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

where LU indicates the total area of the study site, ΔLU_{i-j} represents the absolute value of the area of landscape type i transformed to a non-type i landscape in the study period, and T is the study period.

2.3.3. Relative Dynamic Model

The relative dynamic model was used to reflect the differences in landscape type changes in different regions, and is expressed as follows:

$$R = \frac{K_b - K_a}{K_a} / \frac{C_b - C_a}{C_a} \quad (3)$$

In Equation (3), K_a and K_b are the areas of a certain landscape type in a certain area at the beginning and end of the study, respectively, and C_a and C_b are the areas of a certain landscape type throughout the study area at the beginning and end of the study, respectively.

2.3.4. Landscape Pattern Index

Different landscape types play different roles in maintaining biodiversity, protecting species, improving overall structure and function, and promoting the natural succession of landscape structures. Meanwhile, different landscape types have different resistances to external disturbances. Therefore, research on the spatial pattern of landscapes in a certain region is an effective means of revealing the ecological status and spatial variation characteristics of the region [19,20]. In this study, two aspects, landscape and type levels, were selected. The landscape level comprised seven indices: number of patches (NP), landscape shape index (LSI), patch density (PD), contagion index (CONTAG), Shannon's evenness index (SHEI), Shannon's diversity index (SHDI), and aggregation degree (AI). At the type level, five indicators were selected: percentage of landscape (PLAND), number of patches (NP), landscape shape index (LSI), largest patch index (LPI), and patch density (PD). We used Fragstats software to analyze the landscape index of the study area, the calculation formulas of different indices, and their ecological significance [21,22].

2.3.5. Conversion of Land Use and Its Effect at Small Regional Extent Model

The Conversion of Land Use and its Effect at Small Regional Extent (CLUE-S) model is used to simulate land use changes caused by anthropogenic activities or natural influences, and can model future land use scenarios to address complex competition and interactions between different land use types [23]. CLUE-S is a comparison of mature and good land use models, because it can calculate the impact of natural and anthropogenic influencing factors on land use change and the different degrees of land conversion by setting the relative elasticity coefficient, using the iterative analysis method, simulating the time deduction of land use, and finally, reflecting the accurate results spatially [24].

3. Results

3.1. Landscape Pattern Index Evolution

3.1.1. Landscape Pattern at the Landscape Level

From 1990 to 2020, the NP, PD, and LSI in the arid desert region of Northwest China initially decreased and then increased (changing point in 2010). This indicated that the complexity of landscape shape and patch irregularity of land types first decreased and then increased, and it was easily affected by the surrounding environment. From 1995 to 2020, CONTAG showed a downward trend, and AI showed an increasing to decreasing trend, indicating that connectivity in the landscape was attenuated, and the degree of vulnerability of the landscape changed from weak to strong. Both the SHDI and SHEI showed an increasing trend, indicating that the landscape diversity in the study area increased and that the heterogeneity increased and tended to be evenly distributed (Table 1).

3.1.2. Landscape Pattern at the Patch Type Level

From 1990 to 2020, the PLAND of cultivated land increased year by year from 3.53% to 4.62% (Table 2), and that of forests decreased annually. Grasslands were the main vegetation types in the arid desert region of Northwest China and their PLAND fluctuated between 27 and 28% during the 30-year period. The PLAND of water land use type showed little change. Construction land was the least extensive land type in the arid desert region of Northwest China, and their patches accounted for less than 1% of the area. Unused lands were the most significant land type in the region, with their patches accounting for more than half of the total area, but the proportion increased year by year from 1990 to 2000, and gradually decreased after 2000.

Table 1. Change of landscape pattern index in the study area at landscape level.

Year	NP (Number of Patches)	PD (Patch Density)	LSI (Landscape Shape Index)	CONTAG (Contagion Index, %)	SHDI (Shannon's Diversity Index)	SHEI (Shannon's Evenness Index)	AI (Aggregation Degree, %)
1990	47,665	0.0198	112.6909	60.4190	0.9212	0.5141	85.7183
1995	46,687	0.0194	111.0818	60.5852	0.9201	0.5135	85.9257
2000	46,068	0.0191	110.1204	60.4942	0.9253	0.5164	86.0501
2005	45,365	0.0188	109.3393	60.3222	0.9331	0.5208	86.1514
2010	45,309	0.0188	109.7709	60.1287	0.9386	0.5238	86.0960
2015	46,331	0.0192	110.5267	59.5760	0.9526	0.5316	85.9994
2020	46,798	0.0194	111.1301	59.3142	0.9584	0.5349	85.9220

Table 2. Variation of patch type landscape pattern index in arid desert region of Northwest China.

Vegetation Type	Year	PLAND (Percentage of Landscape, %)	NP (Number of Patches)	PD (Patch Density)	LPI (Largest Patch Index, %)	LSI (Landscape Shape Index)
Cultivated lands	1990	3.5343	4464	0.0019	0.3802	103.9709
	1995	3.6629	4214	0.0017	0.4647	102.6655
	2000	3.8530	3860	0.0016	0.4933	100.0574
	2005	4.1512	3444	0.0014	0.5380	95.4676
	2010	4.2080	3382	0.0014	0.5735	94.7210
	2015	4.6045	3407	0.0014	0.6310	93.6642
	2020	4.6176	3418	0.0014	0.6290	93.8907
Forests	1990	1.6634	8375	0.0035	0.0533	117.0449
	1995	1.6174	8254	0.0034	0.0513	117.5227
	2000	1.6155	8112	0.0034	0.0513	117.1722
	2005	1.5990	8049	0.0033	0.0664	116.7964
	2010	1.5919	8040	0.0033	0.0663	116.9566
	2015	1.5835	8050	0.0033	0.0635	117.0230
	2020	1.5803	8035	0.0033	0.0635	116.8619
Grasslands	1990	28.4232	15,358	0.0064	8.0396	171.5779
	1995	28.1862	15,198	0.0063	7.9093	169.2001
	2000	27.8861	14,958	0.0062	7.9177	167.0993
	2005	27.6835	14,926	0.0062	7.7055	166.0575
	2010	28.1170	14,909	0.0062	7.6785	165.9338
	2015	27.7958	15,314	0.0063	7.6042	165.8883
	2020	27.7514	15,355	0.0064	7.5967	166.1668
Waters	1990	1.8329	8191	0.0034	0.0627	103.3587
	1995	1.8098	8374	0.0035	0.0434	103.8397
	2000	1.8395	8407	0.0035	0.0432	103.6848
	2005	1.8542	8402	0.0035	0.0432	103.3593
	2010	1.8535	8381	0.0035	0.0400	103.0804
	2015	1.8780	8444	0.0035	0.0408	103.2958
	2020	1.9720	8515	0.0035	0.0463	102.2746
Constructive lands	1990	0.3449	3923	0.0016	0.0137	65.6284
	1995	0.3382	3832	0.0016	0.0141	64.4088
	2000	0.3624	4022	0.0017	0.0180	65.7540
	2005	0.3881	4074	0.0017	0.0198	65.2990
	2010	0.4008	4256	0.0018	0.0202	67.1421
	2015	0.5115	4710	0.0020	0.0256	70.5785
	2020	0.5676	5037	0.0021	0.0280	73.4145

Table 2. *Cont.*

Vegetation Type	Year	PLAND (Percentage of Landscape, %)	NP (Number of Patches)	PD (Patch Density)	LPI (Largest Patch Index, %)	LSI (Landscape Shape Index)
Unused lands	1990	64.2013	7354	0.0030	57.0431	98.8248
	1995	64.3854	6815	0.0028	57.3945	96.9077
	2000	64.4435	6709	0.0028	57.4806	96.1263
	2005	64.3239	6470	0.0027	57.3688	95.6023
	2010	63.8288	6341	0.0026	56.8834	96.1906
	2015	63.6267	6406	0.0027	56.7146	96.9104
	2020	63.5111	6438	0.0027	56.5858	97.4515

From 1990 to 2020, the LPI of unused land was the largest and significantly higher than those of the other land types. This indicates that unused land was the dominant landscape in the arid desert region of Northwest China at this stage. During the study period, the LPI of cultivated and construction land continued to increase, indicating that the cultivated and construction lands were spatially aggregated. Simultaneously, the NP of construction lands increased steadily, and the LPI of grasslands gradually decreased. The LPI of water decreased from 1990 to 2015, and then increased from 2015 to 2020; the LPI of woodland increased in 2005 and remained basically stable, indicating that the landscape dominance of woodlands increased.

The LSI of a landscape patch type can describe the degree of patch aggregation or dispersion. The higher the LSI, the more complex the landscape shape and the more susceptible it is to disturbance. In the arid desert region of Northwest China, the LSI of the construction land was the smallest, but showed an increasing trend for 30 years, which indicated that this patch-type structure was the most stable; however, disturbance has gradually increased in recent years. Grasslands had the largest LSI and were constantly increasing, indicating the complexity of the grasslands. The LSI of forests in the arid desert region of northwest China remained almost stable during the targeted 30 years.

3.2. Temporal and Spatial Evolution Process of Each Landscape Type

3.2.1. Dynamic Transfer of Landscape Type

From 1990 to 2020, the area of cultivated land increased continuously, and the dynamic degree was 1.02% (Table 3), indicating that cultivated land increased by 26,128 km^2 at an average rate of 1.02% per year. The main source of cultivated land is grassland. During this period, 23,265 km^2 of grassland was converted to cultivated land, accounting for 68.80% of the change in cultivated land. In addition, 23.77% and 4.27% of cultivated land originated from unused land and forests, respectively. During 2010 to 2015, the dynamic degree of cultivated land reached a maximum of 1.88%, and the minimum change range was only 0.07%.

Table 3. Dynamic landscape changes in arid desert region of Northwest China.

Year	Index	Cultivated Lands	Forests	Grasslands	Waters	Constructive Lands	Unused Land	Overall Dynamic Degree
1990–1995	Area change (km^2)	3103	−1108	−5716	−557	−162	4440	
	Dynamic degree (%)	0.73	−0.55	−0.17	−0.25	−0.39	0.06	0.1614
1995–2000	Area change (km^2)	4583	−46	−7238	716	583	1402	
	Dynamic degree (%)	1.04	−0.02	−0.21	0.33	1.43	0.02	0.0546
2000–2005	Area change (km^2)	7194	−398	−4886	355	620	−2885	
	Dynamic degree (%)	1.55	−0.20	−0.15	0.16	1.42	−0.04	0.0512
2005–2010	Area change (km^2)	1368	−171	10,454	−17	306	−11,940	
	Dynamic degree (%)	0.27	−0.09	0.31	−0.01	0.65	−0.15	0.1161
2010–2015	Area change (km^2)	9564	−204	−7745	590	2670	−4875	
	Dynamic degree (%)	1.88	−0.11	−0.23	0.26	5.53	−0.06	0.0709
2015–2020	Area change (km^2)	316	−76	−1073	2266	1353	−2786	
	Dynamic degree (%)	0.06	−0.04	−0.03	1.00	2.19	−0.04	0.0244
1990–2020	Area change (km^2)	26,128	−2003	−16,204	3353	5370	−16,644	
	Dynamic degree (%)	1.02	−0.17	−0.08	0.25	2.15	−0.04	0.0703

In contrast with cultivated land, the forest area continuously decreased during this period, with a dynamic degree of −0.17%, and the area decreased by 2003 km^2. The decreasing forest areas were mainly converted to grasslands and cultivated lands, accounting for 58.77% and 30.20% of the change in forests, respectively. The peak of change dynamics in forests was −0.55% during 1990 to 1995, and the dynamics for the subsequent five years (i.e., 1995 to 2000) were the smallest throughout the study period.

Overall, compared with 1990, the grasslands in 2020 significantly decreased, and the change process can be divided into three stages. From 1990 to 2005, a total of 17,840 km^2 was reduced; it was mainly transformed into cultivated land and unused land (i.e., 15,656 km^2 of cultivated land and 34,138 km^2 of unused land over 15 years). However, from 2005 to 2010, grasslands increased by 10,454 km^2, with a dynamic degree of 0.31%. The main source was unused land, accounting for 91.34% of the grassland change. From 2010–2020, the number of grasslands continued to decrease. During 2010 to 2015, grasslands decreased by 7745 km^2 with an average dynamic degree of 0.13%.

During this 30-year period, the water area steadily increased, with the dynamic degree fluctuating between −0.25 and 1.00; the area decreased during 1990 to 1995 and 2005 to 2010 and was mainly converted into grasslands and unused lands. Water steadily increased the rest of the time, with the largest increase from 2015 to 2020, with a dynamic degree of 1.00%. Furthermore, the area increased by 2266 km^2, accounting for 4.76% of the total water area.

Following economic development and the expansion of anthropogenic activities, the area of construction land has also been increasing continuously since 1995, with the largest increase occurring from 2010 to 2015, during which the dynamic degree of constructive lands was 5.53% and the area increased by 2670 km^2, accounting for 79.70% of the total amount of increased land (3353 km^2) from 1990 to 2020. Unused land was the main land use type in the study area. After 1995, the area of unused land decreased annually, with a reduction of 16,644 km^2 during the 30 years, but the dynamic degree was relatively small.

The overall dynamic model can reflect the speed of landscape type changes throughout the arid desert region of northwest China during 1990 to 2020. From 1990 to 1995, the overall dynamic degree was 0.16%; from 1995 to 2000, the overall dynamic degree was 0.054%. The overall dynamic degree continuously decreased to 0.051%, 0.11%, 0.07%, and 0.02%, respectively. This indicates that from 1990 to 2020, the change rate of landscape types in the study area has been decreasing, which is conducive to the maintenance of ecological environment stability.

3.2.2. Regional Dynamic Differences

According to Figure 2, from1990 to 2020, the relative dynamic degree of cultivated lands in most regions was small, ranging from −8.72 to 2.51%. From 1990 to 1995, cultivated lands in Hotan, Beitun, Jinchang, and Yinchuan cities increased, with relative dynamic degrees of 2.73%, 4.27%, 4.47%, and 5.41%, respectively. From 1995 to 2000, the relative dynamics of cultivated land in the Haixi and Alal City were relatively large at 3.45% and 6.48%, respectively. From 2000 to 2005, cultivated lands in Karamay and Kunyu showed a significant increase. From 2005 to 2010, the cultivated lands in Bayanchore and the Alxa rapidly decreased, but rapidly increased in Huyanghe, Kunyu, and Alal Cities. From 2015 to 2020, changes throughout the study area were significant, and the relative dynamic degree of the Haixi, which featured the largest change in cultivated land area during the study period, reached 36.78%.

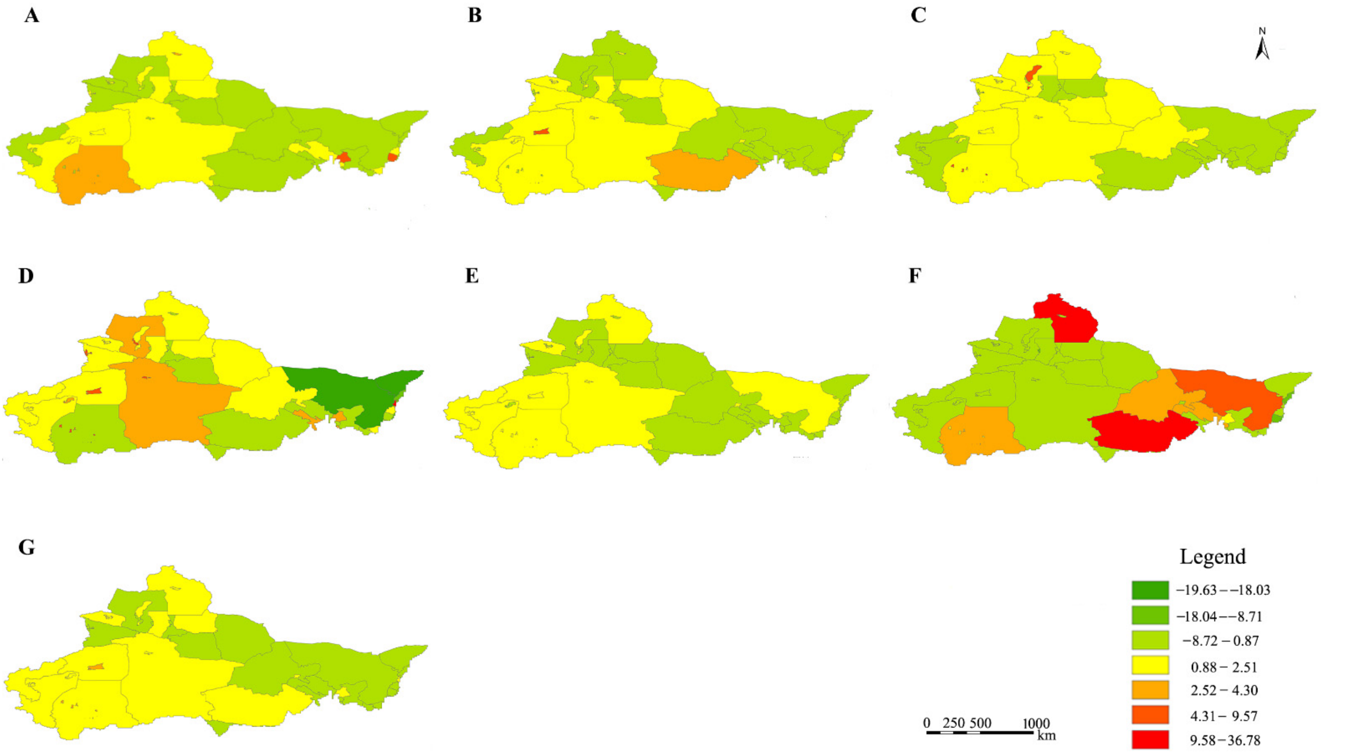

Figure 2. Relative dynamic degree of cultivated lands in the arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

From 1990 to 2020, the area covered by forests throughout the arid desert region of northwest China was dominantly in the southwest, and the area where forests decreased was dominantly in the northeast (Figure 3). From 1990 to 1995, the forests in 16 cities showed an increasing trend. The forests in Kunyu significantly increased with a relative dynamic degree of 4.38%. The forests in Wujiaqu showed the greatest decrease, with a relative dynamic degree of 36.20%. From 1995 to 2000, the change trend of forests in most regions was consistent with the change trend of the entire study area, which indicated a decrease in forests. From 2000 to 2005, the forests in Karamay and Alal rapidly decreased, with relative dynamic degrees of 5.59% and 2.42%, respectively. From 2005 to 2010, the forests in Karamay and Alal continued to decrease, but changed very little in other areas. From 2010 to 2015, the forests in the western region of the study area significantly decreased, while the forests in the nine eastern cities, including Bayanchore and Ordos, increased. From 2015 to 2020, only forests in Jinchang increased, with a relative dynamic degree of −3.77%, while the forests in other cities decreased.

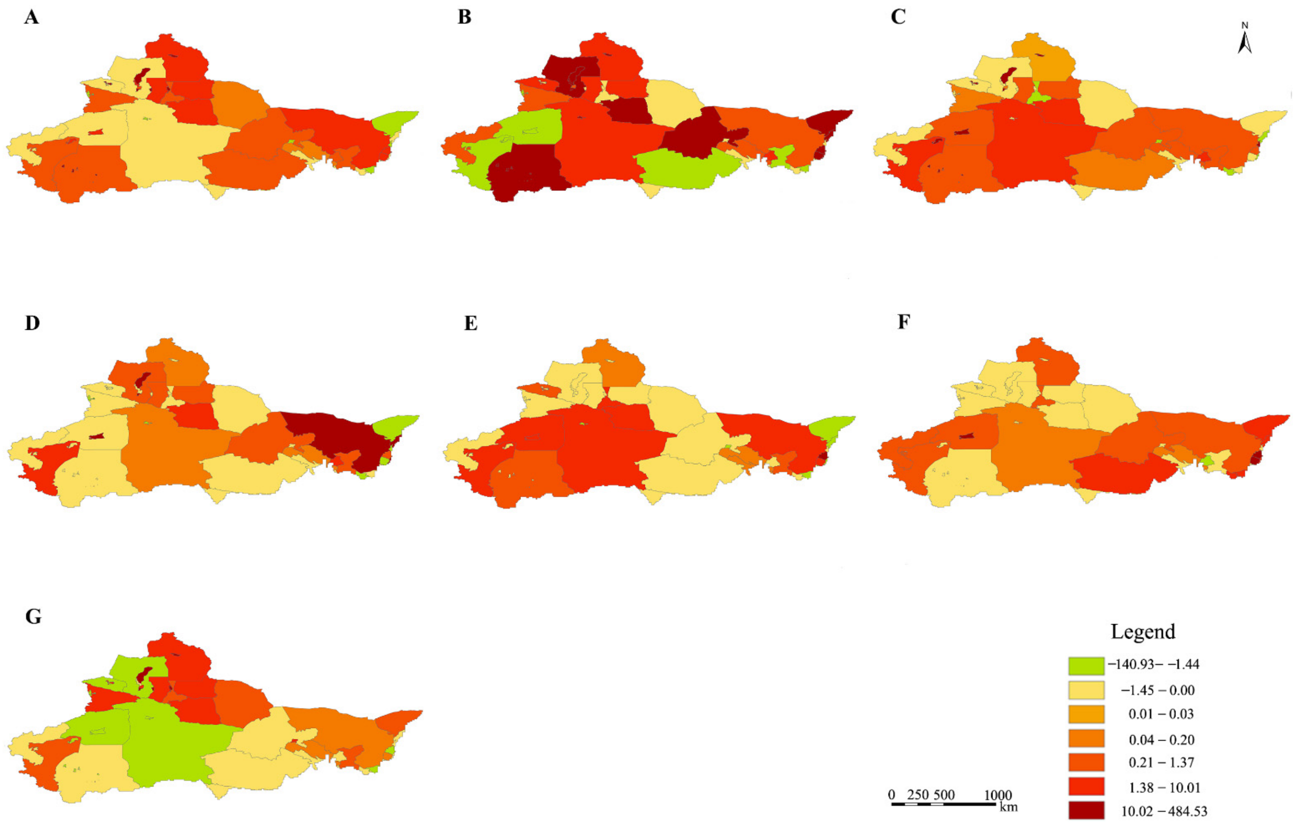

Figure 3. Relative dynamic degree of forests in the arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

Figure 4 shows that from 1990 to 2020, except for the increase in grasslands in the Alxa League, Bayanchore, Wujiaqu, and Wuwei, the other regions showed the same trend as the entire northwest arid desert region. From 1990 to 1995, the grasslands in Wujiaqu showed the largest increase, with a relative dynamic degree of −9.99%, whereas the grasslands in the Alxa League showed a large decrease, with a relative dynamic degree of 8.65%. From 1995 to 2000, grasslands in the Yushu, Jinchang, and Kunyu increased, with relative dynamic degrees of −0.017%, −0.15%, and −0.86%, respectively. Grasslands decreased in other areas. From 2000 to 2005, the grasslands in Aral and Baiyin increased, with relative dynamic degrees of −1.42% and −0.69%, respectively. From 2005 to 2010, the overall grassland area in the study area increased, and the area of the Alxa increased the most, with a relative dynamic degree of 32.98%. From 2010 to 2015, the grasslands throughout the northwest arid desert area decreased, but the changing areas were consistent with those of the previous five years. The grasslands of Tumushuke, Alxa, and Bayanchore continued to increase. From 2015 to 2020, grasslands in Jinchang, Yinchuan, Wuwei, and Zhangye increased.

The water content generally increased from 1990 to 2020 (Figure 5). From 1990 to 1995, cities with reduced water areas accounted for most of the study area, and Tiemenguan ranked first with a relative dynamic degree of 39.67%. From 1995 to 2000, the waters in Kunyu, Jinchang, Wujiaqu, Zhangye, and Karamay decreased, whereas those in other areas increased. Tumushuke (182.86%) exhibited the largest relative change. During 2000 to 2005, the water areas in a total of 15 cities increased, decreased in 16 cities, and did not change in 10 cities. The increase and decrease volumes were essentially the same, resulting in very little change in the water area of the study area during this period, with the overall area decreasing by 17 km^2. The period ranging from 2005 to 2010 exhibited the largest water change in the 30-year period. Water areas significantly changed in most places in the study area. The water areas of the Haibei, Kashgar, Tumushuke, and other cities mostly decreased, with a dynamic degree exceeding 30.47%. From 2010 to 2015, the water area of the entire northwestern arid desert increased. From a regional perspective, most areas were consistent with the overall change. Most cities with a decrease in water area were located in the western region. From 2015 to 2020, the waters of the eight cities decreased, and the Wujiaqu market exhibited the largest decrease, with a relative dynamic degree of −6.99%.

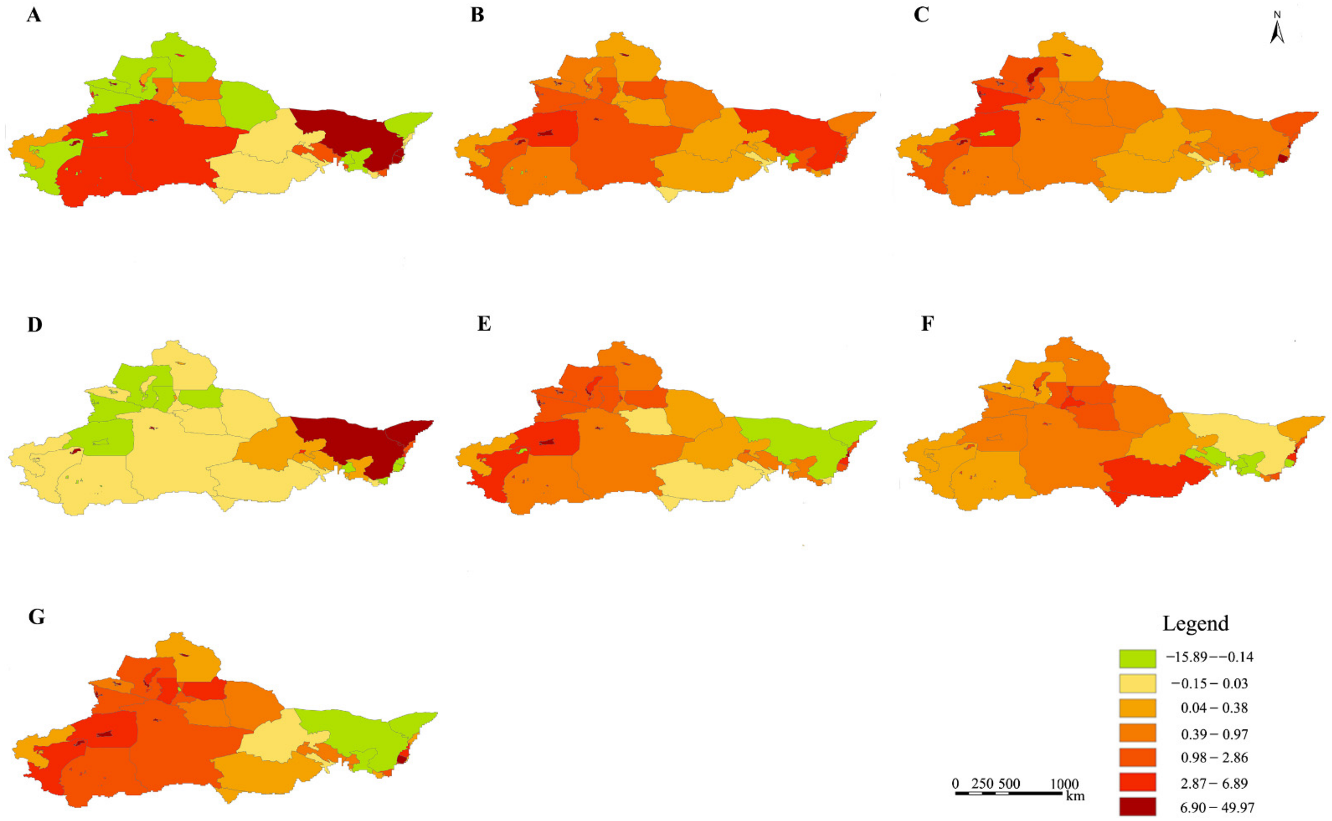

Figure 4. Relative dynamic degree of grasslands in the arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

Construction land in the Hotan and Alxa decreased, whereas the grasslands changed in other areas and showed an increasing trend throughout the study area from 1990 to 2020 (Figure 6). The largest relative change was −25.67% in Shuanghe from 1990 to 1995. Kunyu had the largest reduction in area, with a relative change of 31.59%. From 2005 to 2010, the construction land in Alxa, Ordos, Wuhai, and Zhongwei decreased. From 1995 to 2000, 2000 to 2005, 2010 to 2015, and 2015 to 2020, except for urban construction land areas that did not change, the rest of the urban areas increased, and the largest relative change in the first two periods was 2.79% and 11.74% in Kunyu. Alxa had the highest relative dynamic degree from 2010 to 2015 (7.14%). From 2015 to 2020, Kunyu had the highest relative dynamic degree of 3.79%.

As shown in Figure 7, from 1990 to 2020, except for Wujiaqu, Baiyin, Hotan, Ili Kazak, and Haibei, the unused lands in the study area consistently decreased. From 1990 to 1995, the amount of unused land in more than half of the cities decreased, and the relative dynamic degree of Alal City was the largest at −108.38%. From 1995 to 2000, Tumushuke exhibited the largest relative change (−269.26%) among the reduced areas. From 2000 to 2005, the differences between the unused lands and the positive and negative relative dynamic spans were large. From 2005 to 2010 and 2010 to 2015, the unused land area of most cities decreased. However, unused land in Haibei and Kizilsu increased during 2005 to 2010. The relative dynamic degrees were −0.22% and −0.028%, respectively. Unused land increased in Huyanghe from 2010 to 2015, with a relative dynamic degree of −45.11%; and in Wujiaqu, Alal, and Baiyin from 2015 to 2020.

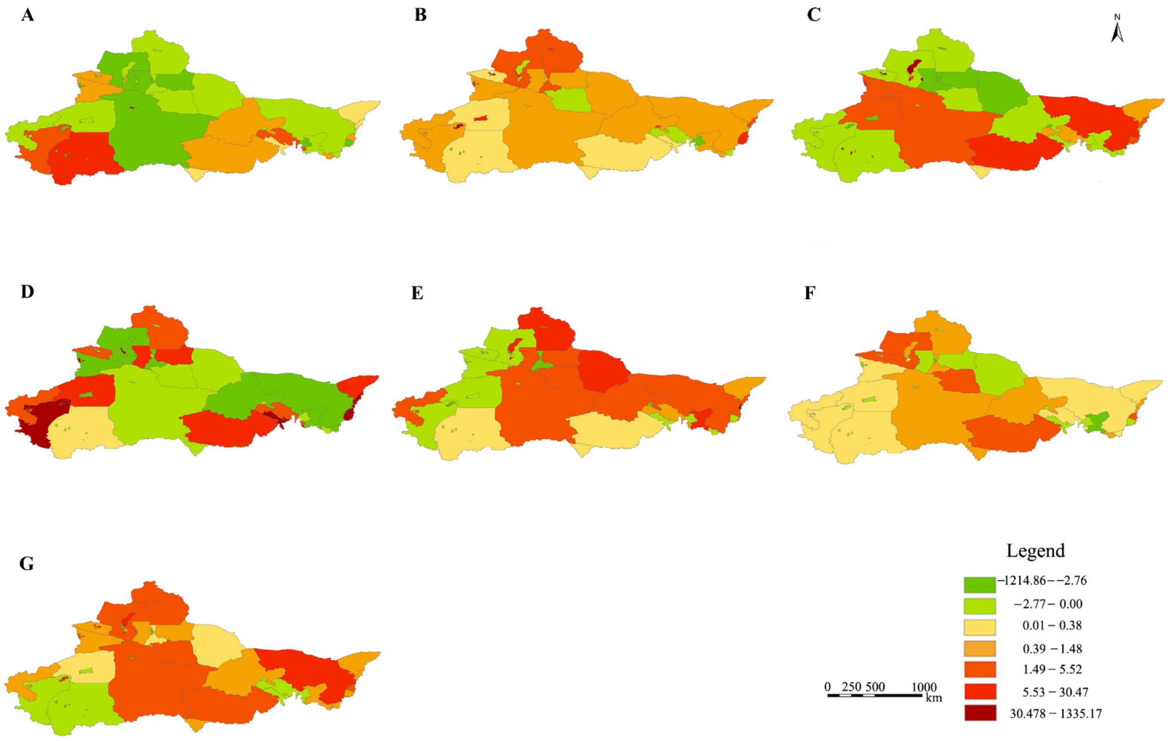

Figure 5. Relative dynamic degree of waters in the arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

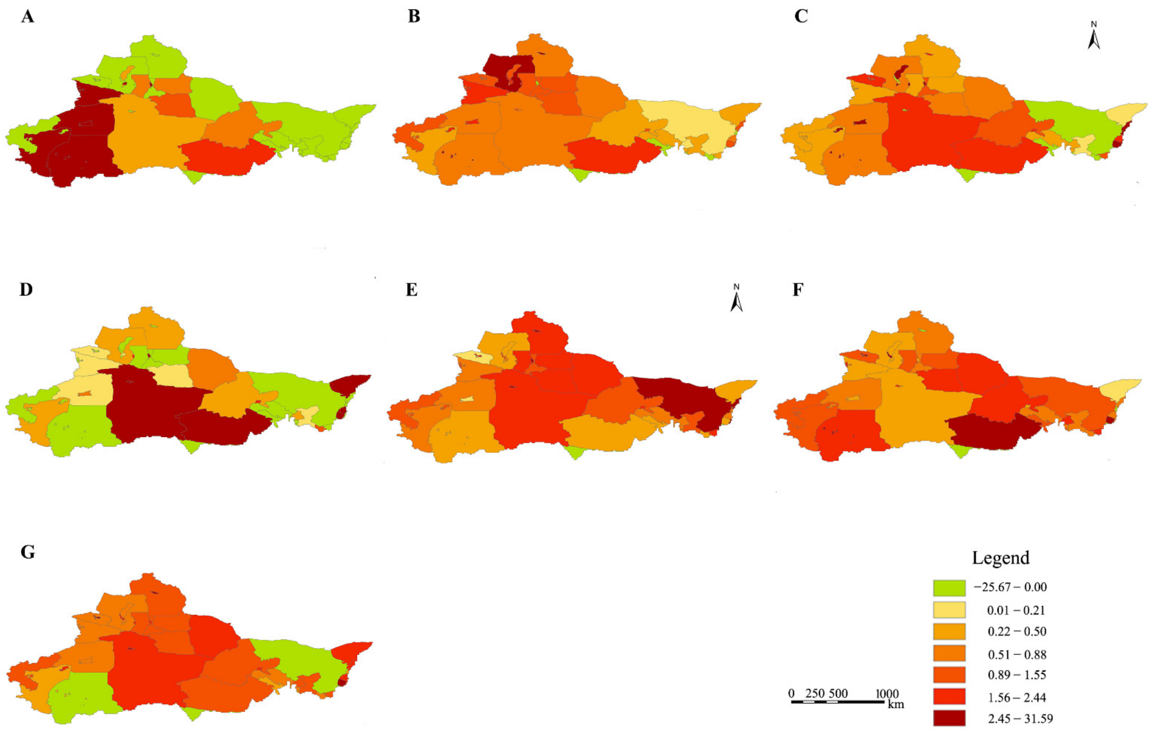

Figure 6. Relative dynamic degree of constructive lands in the arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

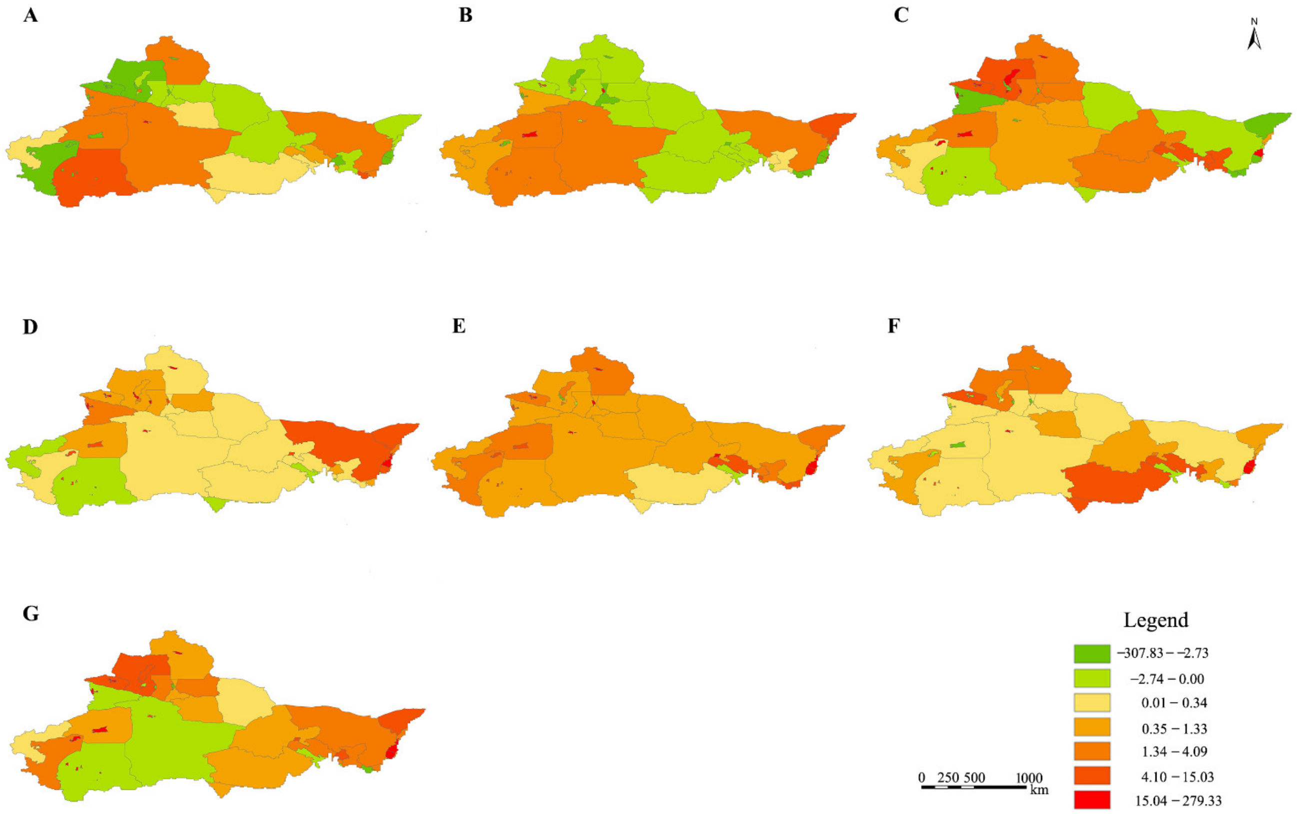

Figure 7. Relative dynamic degree of unused lands in arid desert region of Northwest China, (**A**) 1990–1995, (**B**) 1995–2000, (**C**) 2000–2005, (**D**) 2005–2010, (**E**) 2010–2015, (**F**) 2015–2020, (**G**) 1990–2020.

3.3. Dynamic Changes of Landscape Types under Different Simulation Scenarios

According to the CLUE-S model, the predicted land use patterns for 2040 under the natural development scenario are shown in Figure 8. The cultivated land area was 228,084 km^2, accounting for 9.46% of the total area. The forest area was 34,331 km^2, accounting for 1.42% of the total area. The grassland area was 709,892 km^2, accounting for 29.43% of the total area. The water area was 77,259 km^2, accounting for 3.20% of the total area. The construction land area was 47,489 km^2, accounting for 1.96% of the total area. The unused land covered an area of 1314,722 km^2, accounting for 54.51% of the total area. From 2020 to 2040, the construction land showed the highest rate of increase, with a dynamic degree of 13.35%; the cultivated land area increased by 116,720 km^2, exhibiting the largest increase. The forest land area decreased, with a dynamic degree of −0.49%, whereas the grasslands and water areas increased, with dynamic degrees of 0.30% and 3.12%, respectively. Most of the increased land types were converted to unused land. By 2040, the unused land area is expected to decrease by 216,932 km^2, and the dynamic degree is expected to be −0.71%.

The land use pattern in 2040 under the cultivated land protection scenario showed that the cultivated land area is 248,704 km^2, accounting for 10.31% of the total area; the forest area is 33,652 km^2, accounting for 1.39% of the total area; the grassland area is 701,652 km^2, accounting for 29.09% of the total area; the water area is 76,119 km^2, accounting for 3.16% of the total area; the construction land area is 39,648 km^2, accounting for 1.64% of the total area; and the unused land area is 1,312,052 km^2, accounting for 54.40% of the total area (Figure 8).

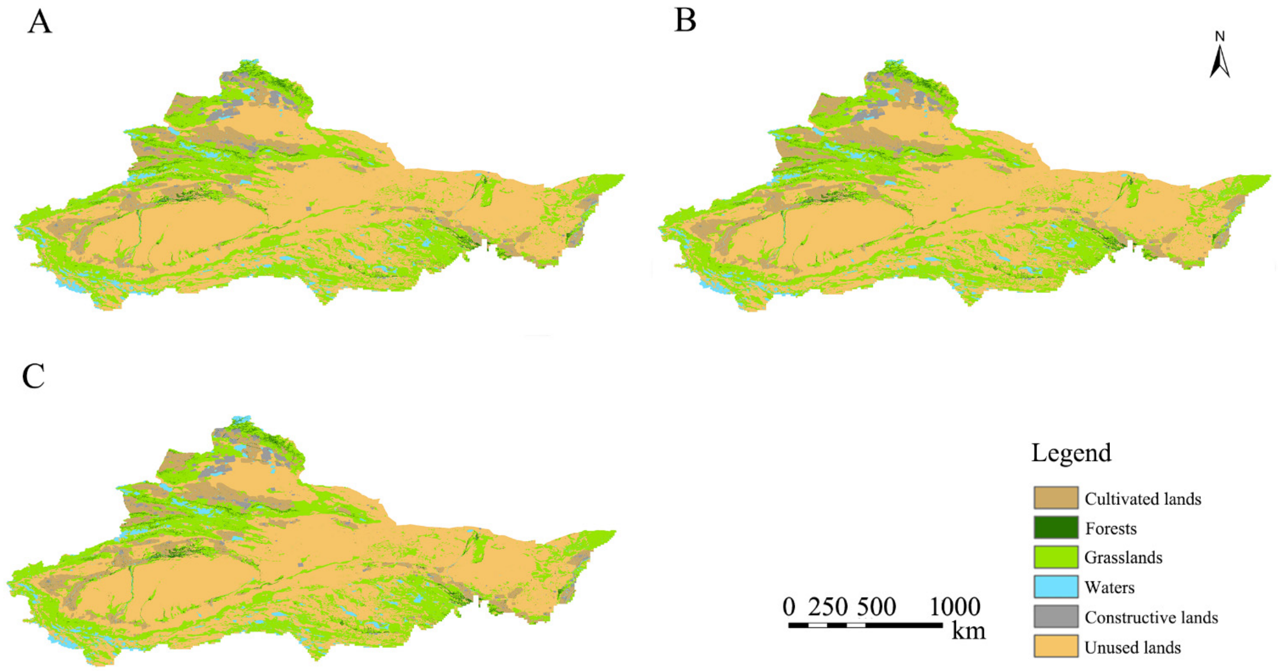

Figure 8. Prediction map of land use in the arid desert region of Northwest China in 2040 under three scenarios: (**A**) the natural development scenario, (**B**) the cultivated land protection scenario, and (**C**) the ecological protection scenario.

The results of the land use pattern in 2040 under the ecological protection scenario showed that the cultivated land area will be 232,624 km^2, accounting for 9.65% of the total area; the forest area will be 38,261 km^2, accounting for 1.59% of the total area; the grassland area will be 698,071 km^2, accounting for 28.94% of the total area, the water area will be 85,018 km^2, accounting for 3.53% of the total area; the construction land area will be 46,869 km^2, accounting for 1.94% of the total area; and the unused land area will be 1,310,984 km^2, accounting for 54.36% of the total area (Figure 8).

Compared with the natural development scenario, cultivated land increased more under the cultivated land protection scenario, while the growth rate of other land types decreased. Under the ecological protection scenario, the landscape types with higher ecological functions, such as forests and water areas, increased, and the dynamic degree of land construction was lower than that of the natural development scenario (Table 4).

Table 4. Dynamic changes of land types in the arid desert region of Northwest China under different scenarios from 2020 to 2040.

Land Type	Natural Development Scenario		Cultivated Land Protection Scenario		Ecological Protection Scenario	
	Area Change (km^2)	Dynamic Degree (%)	Area Change (km^2)	Dynamic Degree (%)	Area Change (km^2)	Dynamic Degree (%)
Cultivated lands	116,720	5.24	137,340	6.17	121,260	5.44
Forests	−3782	−0.50	−4461	−0.59	148	0.02
Grasslands	40,610	0.30	32,370	0.24	28,789	0.22
Waters	29,701	3.12	28,561	3.00	37,460	3.94
Constructive lands	33,801	12.35	25,960	9.48	33,181	12.12
Unused lands	−216,932	−0.71	−219,652	−0.72	−220,720	−0.72

4. Discussion

By combining the land use data of the five northwestern provinces from 1990 to 2020 through the single, overall, and relative dynamic models; the calculation and analysis of the landscape pattern index; and the prediction of the CLUE-S model, this study revealed that the arid desert region of the Northwest China from 1990 to 2020 and the temporal and spatial evolution characteristics of the landscape pattern under the simulated scenario from 2020 to 2040. The following conclusions were drawn:

(1) At the landscape level, the fragmentation and discretization of landscape patches increased, connectivity decreased, diversity increased, and heterogeneity increased and tended to be evenly distributed. At the patch-type level, unused land has always been the main landscape component in the arid desert region of Northwest China. From 1990 to 2020, the cultivated and construction land areas showed an increasing trend, and the LPI increased, showing a spatial aggregation trend. The shape index of constructive lands increased, and the structure was stable; the shape index of grasslands continuously fluctuated and changed complexly; the LPI of water first decreased and then increased; and the LPI of forests remained stable after increasing.

(2) From 1990 to 2020, the cultivated land area increased, with a dynamic degree of 1.02%. The main land types were grasslands, unused land, and forests. The forests continuously decreased, with a dynamic degree of −0.17%, and they were mainly converted into grasslands and cultivated lands. Grasslands were significantly decreased, and they were mainly converted into cultivated land and unused land. During the 30 years, the area of the waters steadily increased, as did the construction area. From 1990 to 2020, the change rate of landscape types in the study area continued to slow down, which was conducive to maintaining the stability of the ecological environment. There are many unused lands in the arid region of Northwest China, which indicates that the land utilization rate and maturity of this area are low, and the reserve resources are sufficient.

(3) During the study period, the relative dynamic degree of cultivated land in most areas was small, and the changes between years were different. In 2015–2020, the relative dynamics of the Mongolian and Tibetan ethnic groups in Haixi reached 36.78%, becoming the largest change area in cultivated land during the entire exploration period. From 1990 to 2020, the area of increased forests in the northwestern arid region was mainly distributed in the southwest, and the area of reduced forests was concentrated in the northeast. During the study period, except for the increase in grasslands in the Alxa, Bayanchore, Wujiaqu, and Wuwei, the change trend of grasslands in other areas was consistent with that in the entire study area. Except for constructive lands in the Hotan and Alxa that decreased, the other areas and the entire study area showed the same trend of grassland change. Except for Shihezi, Wujiaqu, Baiyin, and Hotan, unused land in the rest of the area and the entire study area showed a decreasing trend.

(4) The spatial patterns of the landscape in 2040 under the three forecast scenarios based on the CLUE-S models are mostly similar. Under the cultivated land protection scenario, the area of cultivated land increased; under the ecological protection scenario, the proportion of forests and water increased, and the dynamic degree of construction land was low. Unused land was dominant in all three simulated scenarios, accounting for approximately 54% of the total area. The largest area was followed by grasslands, accounting for approximately 29% of the total area. The larger area is cultivated land, accounting for approximately 10%, and the water area only accounts for approximately 3%. Forests and construction land accounted for the smallest area (less than 2%).

In addition to analyzing the dynamic evolution of landscape patterns at the landscape and patch-type levels, this study also analyzes the dynamic evolution process of landscape patterns based on the dynamic transfer of landscape types and regional dynamic differences in the arid desert region of Northwest China. The results of this study can provide a research basis and planning direction for more optimized exploration of regional differences in landscape patterns in the arid desert region of Northwest China. Regardless of the period of 1990–2020, or in the three simulation scenarios, the main landscape type is unused land, which indicates that the development and utilization in the arid desert region of Northwest China is still very limited, and there are sufficient reserve resources. The low development and utilization of arid desert areas in Northwest China may be largely because the arid areas in the northwest are dominated by deserts and lack of water resources [10], which brings great difficulties to the ecological construction of arid areas in the northwest.

Although the increasing of temperature can promote the melting of glaciers from the nearing Qinghai-Tibetan plateau [10,11], global warming is believed to lead a relatively negative impact on ecological environment construction in the arid desert region of Northwest China, which already features water shortage, increased evapotranspiration [25], and aggravated drought in arid regions [26]. Studies have shown that over time, the boundary of the arid desert region in Northwest China has significantly shifted to the north, increasing the area of the semi-arid region [27]. In the past 30 years, the area of grasslands and forests in the arid region of Northwest China has been decreasing, and the complexity of the landscape ecosystem has increased [28]. Under the ecological protection scenario, the forest area will increase. These trends were also observed in other regions, such as Taihu Lake [29]. Therefore, in future construction, environmental changes in the arid region of Northwest China and the impact of global warming should be comprehensively considered. From the perspective of sustainable ecosystem management, focusing on ecological landscape construction and increasing vegetation coverage is important [30]. According to the model predictions, forests and construction land will continue to increase under the three scenarios in the arid region of Northwest China, which will improve the ecological environment and meet the local communities' needs. Ultimately, construction is expected to further optimize the relevant management planning.

5. Conclusions

From 1990 to 2020, in the arid desert region of Northwest China, the main land types were grasslands, unused lands, and forests. During these 30 years, the areas of cultivated and construction lands increased, and the forests, grasslands, and unused lands significantly decreased. The increased area of forests was mainly located in the southwest and the decreased area of forests was mainly located in the northeast. The spatial patterns of landscape in 2040 under the three forecast scenarios showed that unused land was still the dominant land use type similar as the past 30 years, indicating the sufficient reserve resources in the arid desert region of Northwest China.

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