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Research on Vegetation Cover and Land Use Change in Northwest China Based on MODIS-MDVI

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Abstract: Vegetation is a vital ecological barrier that supports regional ecological security and sustainable development. Using MOIDS-NDVI data and a pixel binary model, this study analyzed vegetation cover and its driving factors in Northwest China. Spatiotemporal changes in vegetation coverage were assessed with trend analysis, and land use changes were examined using a land use change map. The results show that: (1) From 2000 to 2021, the vegetation coverage in Northwest China increased in a fluctuating manner with a period of 0.00173% per year, but overall showed a characteristic of high in the north, low in the south, high in the west, and low in the east. (2) NDVI in Northwest China is positively correlated with precipitation, with a correlation coefficient of 0.161, and not significantly negatively correlated with temperature, with a correlation coefficient of -0.015. (3) The land use change in Northwest China is mainly characterized by the mutual conversion between unused land and grassland, and there is a responsive relationship between vegetation cover change and land use change. The conversion map of unused land closely matches areas of significant vegetation improvement, indicating that turning unused land into grassland and farmland is the main driver of increased vegetation cover. Thus, analyzing vegetation cover and its driving factors is crucial for understanding ecosystem changes, guiding vegetation restoration, and planning spatiotemporal adjustments.

1. Introduction

Vegetation is an important ecological barrier in a region, playing an irreplaceable role in ensuring ecological security and sustainable development [1]. Therefore, extracting vegetation cover information and analyzing the driving factors of vegetation cover changes are of great significance for revealing changes in ecosystem environment, vegetation restoration and reconstruction layout, and other aspects [2]. Normalized Difference Vegetation Index (NDVI) is an important indicator that can reflect the vegetation coverage status, and it has been widely used for dynamic monitoring of vegetation. Currently, many scholars have conducted research on the spatiotemporal changes of vegetation cover using NDVI data at different spatial scales. Ma Nan et al. analyzed the changes in vegetation coverage in Northwest China and found that the overall trend of vegetation coverage in

Northwest China is not significantly increasing [3]. Wang Jianguo et al. studied the spatiotemporal distribution pattern of vegetation coverage in Northwest China and found that there is significant spatial differentiation in vegetation coverage in Northwest China [4].

Pixel binary method is an empirical modeling approach that uses NDVI as remote sensing information to estimate vegetation coverage. It weakens the influence of atmosphere, soil, and vegetation types, and has good universality [5]. Therefore, it has been widely used by researchers. Wang Si et al. used MODIS-NDVI data and a pixel binary model to extract vegetation coverage in Guangdong Province from 2000 to 2020. Based on this, they used a univariate linear regression model to study the spatiotemporal evolution of vegetation coverage in the region [6]. Jin Chengming et al. used a pixel binary model to analyze the impact of meteorological factors on vegetation cover changes in northern Shaanxi from 2000 to 2021 [7]. Zhong Jing et al. used MODIS-NDVI data to perform a secondary inversion of vegetation coverage in the western mountainous areas of Hubei Province from 2000 to 2021, obtaining vegetation coverage information in the region and analyzing the rate of change in vegetation coverage from a spatiotemporal perspective [8].

Northwest China is located in the northwest border of China, with a unique geographical location, complex terrain, and a very fragile natural ecological environment. Over the past half century, vegetation activity in Northwest China has significantly increased, attracting widespread attention from scholars on the relationship between regional vegetation and climate change response [9]. With the accelerated development of urbanization and industrialization, land use types have undergone significant changes, which have also had a profound impact on the spatial pattern of vegetation cover in Northwest China region. The geographic information map analysis method uses map units to statistically analyze spatiotemporal composite information [10], which is a common land use research method. However, there are very few reports that combine land use change with vegetation cover change. Based on this, this article selects MODIS-NDVI data, meteorological data, and land use remote sensing monitoring data from 2000 to 2021 in Northwest China to explore the spatiotemporal evolution trend of vegetation cover over the past 22 years, the response relationship between NDVI and climate factors, and the mutual influence and driving relationship between land use and vegetation cover. This provides some scientific basis and countermeasures for ecological construction in Northwest China. (Data Sources:http://www.resdc.cn,https://ladsweb.modaps.eosdis.nasa.gov)

2. Research on the Relationship between Vegetation Coverage and NDVI

2.1 Vegetation coverage calculation

There is a highly significant linear correlation between vegetation coverage and NDVI, and by establishing a conversion relationship between the two, vegetation coverage information can be directly extracted. Assuming that the information of a pixel includes soil and vegetation, NDVI obtained by remote sensing sensors can be expressed as: NDVIV represented by data provided by vegetation and NDVIs represented by data provided by soil.

$$\mathrm{FVC} = \frac{\mathrm{N}DVI - \mathrm{NDVIs}}{\mathrm{NDVIv} - \mathrm{NDVIs}} \tag{1}$$

In the formula, FVC represents the vegetation coverage of the pixel, NDVIs represents the pixel information including soil type, color, humidity, etc., and NDVIV represents the pixel value including the type and structure of vegetation. Based on previous experience, different vegetation cover levels in Northwest China are classified into the following levels, as shown in Table 1.

Table 1: Distribution of vegetation cover types

FVC Classification standard	FVC Level
FVC≤0.1	Low
0.1<FVC≤0.3	Lower middle
0.3<FVC≤0.5	Medium
0.5<FVC≤0.8	Medium to high
0.8<FVC≤1	High

2.2 Trend analysis

Univariate linear regression trend line analysis is a method of conducting regression analysis on a set of variables that change over time. This method calculates the vegetation greenness change rate based on the trend of each pixel, and the calculation formula is:

$$\theta_{\text{slope}} = \frac{\text{n} \times \sum_{i=1}^{n}(i \times C_i) - (\sum_{i=1}^{n} i)(\sum_{i=1}^{n} C_i)}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \tag{2}$$

In the formula, slope is the slope of the regression equation, C is the vegetation coverage in the i-th year, N is the number of years in the detection period. The variables from 1 to n are the sequence numbers of the years in the study period. The vegetation coverage in this study area was graded as extremely significant degradation (slope -0.005), significant degradation (-0.005 slope -0.002), insignificant change (-0.002 slope 0.002), significant improvement (0.002 slope -0.005), and extremely significant improvement (slope>0.005).

2.3 Correlation analysis

Using the spatial analysis method of pixels, the relationship between vegetation NDVI and various meteorological elements in Northwest China was studied. The calculation formula for the correlation coefficient between NDVI and temperature and precipitation is:

$$R_{\text{xy}} = \frac{\sum_{i=1}^{n}(\text{x}_\text{i} - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(\text{x}_\text{i} - \bar{x})^2 - \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{3}$$

In the formula: R_{xy} is the correlation coefficient between variables x and y, x_i is the NDVI value for the i-th year, y_i is the meteorological factor for the i-th year, Average NDVI from 2000 to 2021. The average values of various meteorological factors from 2000 to 2021.

2.4 Land use change map

On the basis of spatial superposition of land use data from 2000 to 2021, referring to the previous map fusion method, the map units of 2000 and 2021 were encoded, and map algebraic superposition operation was used to achieve map fusion and record the evolution process of map units. The calculation formula is:

$$C = 10 \times A + B \tag{4}$$

In the formula, C is the grid unit of the graph that describes the evolution characteristics of land use patterns in the study area during that period.

2.5 Analysis of Characteristics of Land Use Change Map

In order to more clearly demonstrate the changing characteristics of land use type map units, the change ratio and spatial separation index of land use change are introduced. The calculation formula is as follows:

$$C_{ij} A_{ij} \times 100\% / \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij} (i \neq j) \tag{5}$$

$$F_{ij} = \frac{1/2 \times \sqrt{N_{ij} / \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}}}{A_{ij} / \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}} \tag{6}$$

In the formula, i refers to the area and nature of land use types in the initial stage of the study, j refers to the land use types in the final stage of the study, and n is the total number of land use type classifications in this study.

3. Results and Analysis

3.1 Spatial differentiation and interannual variation of vegetation coverage

3.1.1 Spatial distribution characteristics of vegetation coverage

Using ENVI software and pixel binary method to extract vegetation coverage, and using ArcGIS to reclassify FVC, as shown in Figure 1, the overall distribution of NDVI shows significant differences in spatial distribution of vegetation coverage in Northwest China, with higher coverage in the northwest and lower coverage in the southeast. Due to the unique topography of Northwest China's "three mountains sandwiching two basins" and the ocean currents in the Atlantic and Arctic oceans, the precipitation in the western region is higher than that in the eastern region. In addition, the barrier of the Tianshan Mountains has resulted in significant climate differences between the northern and southern regions. Overall, the NDVI in Northwest China region shows a high trend in the west and a low trend in the east, with significant spatial differentiation. Among them, the Northwest China region is mainly dominated by low vegetation coverage and medium low vegetation coverage, accounting for 63.58% and 17.61% of the entire study area, mainly in the hinterland of the Taklamakan Desert, the Kumtag Desert, and areas north of the Kunlun Mountains. The middle vegetation coverage and middle high vegetation coverage in Northwest China accounted for 6.93% and 11.68% of the whole study area, mainly in the northern slope of Tianshan Mountains, Tacheng area, southern part of Mount Taishan Mountains, Hami, and oases around Tarim Basin. The high vegetation coverage area in Northwest China accounts for 0.21% of the whole study area, mainly in the Altay Mountains, the Ili River Valley and the oasis around the Tarim Basin.

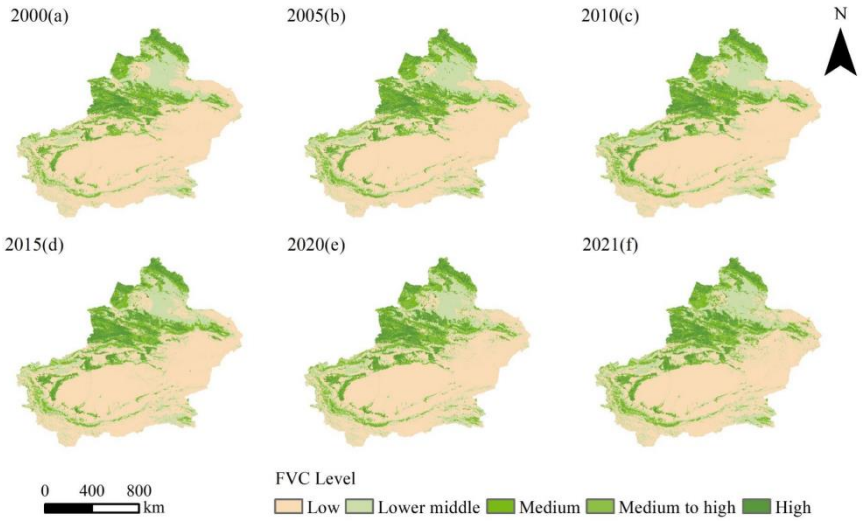

Figure 1: Spatial distribution of vegetation coverage in Northwest China from 2000 to 2021

3.1.2 Inter annual variation characteristics of vegetation coverage

A statistical analysis was conducted on the average vegetation coverage in Northwest China from April to October 2000 to 2021, as shown in Figure 2. The average vegetation coverage in Northwest China varied between 0.16 and 0.20 from 2000 to 2021, with an overall trend of fluctuating growth at a rate of 0.002%/a. Among them, the average annual NDVI of Northwest China in 2016, 2017, and 2021 was relatively high, while the average annual NDVI of 2000 and 2001 was relatively low, which was closely related to the precipitation and temperature of that year . During the period of 2000-2007, there was a stable upward trend in NDVI values. In 2008, due to high temperatures and low precipitation, the average NDVI value in Northwest China sharply decreased to the lowest level. From 2007 to 2013, the average NDVI value in the region showed a stable upward trend. In 2014, Northwest China experienced another high temperature and low precipitation climate, and the average NDVI value fell again. From 2014 to 2017, the average NDVI value showed a rapid upward trend. From 2019 to 2021, the fluctuation was small. Overall, the NDVI value of vegetation in Northwest China showed an insignificant upward trend.

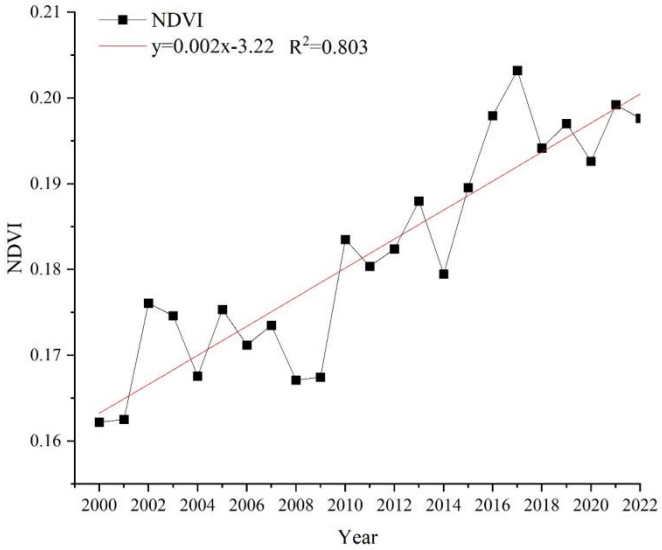

Figure 2: Multi year average vegetation cover change trend in Northwest China from 2000 to 2021

As shown in Figures 2 and 3, statistics and analysis were conducted on the vegetation coverage of different levels in Northwest China. The results indicate that the overall vegetation coverage in the medium, medium, and high vegetation areas in Northwest China has slightly increased over the past 22 years. Among them: (1) The proportion of low and medium low vegetation coverage ranges from 75.35% to 79.64%, with the lowest proportion in 2016 and the highest proportion in 2000. (2) The proportion of moderate vegetation coverage ranges from 6.04% to 7.71%, with the lowest proportion in 2009 and the highest proportion in 2021. (3) The proportion of high and medium high vegetation coverage fluctuates between 14.01% and 17.06%, with the highest proportion in 2016, accounting for 17.06%. The lowest proportion was in 2000, at 14.01%. Overall, the low vegetation coverage shows a downward trend, while the medium low vegetation coverage shows an upward trend. The areas of low vegetation coverage and medium low vegetation coverage are mutually converted, and the total area has decreased.

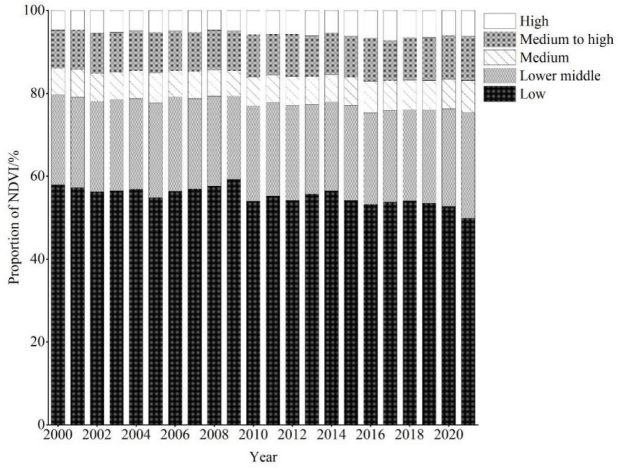

Figure 3: Inter annual variation of vegetation coverage at different levels in Northwest China

Using the univariate linear regression trend analysis method to calculate the 22 year change trend, the slope was reclassified using ArcGIS software (see Table 2), and the vegetation cover change trend in Northwest China over the past 22 years was finally obtained. According to the 22 year change trend, the slope value in Northwest China fluctuated between -0.048-0.060, with insignificant changes accounting for 72.61% of the total area. Significant and extremely significant improvement areas account for 20.62% of the total area, distributed in the northwest of South Northwest China Basin and the northern slope of Tianshan Mountains, and significant and extremely significant degradation areas account for 6.78% of the study area, distributed in the northwest edge of the Junggar Basin and the northeast edge of Tarim Basin.

Table 2: Significance statistics of vegetation coverage changes in Northwest China from 2000 to 2021

Serial number	Change scope	Grading standard	Proportion
1	Extremely significant degradation	$\theta_{slope}<0,P<-0.005$	1.92%
2	Significant degradation	$\theta_{slope}<0,-0.005<P<-0.002$	4.86%
3	Insignificant change	$\theta_{slope}<0,-0.002<P<0.002$	72.61%
4	Improve	$\theta_{slope}>0,0.002<P<0.005$	11.38%
5	Significantly improve	$\theta_{slope}>0,P<0.005$	9.24%

3.2 Driving factors of vegetation change

Use Figures 4 and 5 to analyze the spatiotemporal pattern of temperature changes in Northwest China from 2000 to 2021. Overall, during the research period, there was a slight increase in the average temperature in Northwest China, with an average annual temperature between 5.16-7.69 ℃ and an average warming rate of 0.15 ℃/(22 years). The highest average annual temperatures occurred in 2007 and 2016, reaching 6.79 ℃ and 6.59 ℃, while the lowest temperatures occurred in 2003 and 2012, reaching 5.16 ℃ and 5.31 ℃. The spatial distribution pattern of average annual temperature in Northwest China is that the average annual temperature in southern Northwest China is higher than that in northern Northwest China, and the temperature in western Northwest China is higher than that in eastern Northwest China. The high-temperature areas are located in the Taklamakan Desert and the southwestern part of Hami, while the low-temperature areas are located in the northern part of Altay and the central part of the Tianshan Mountains.

The spatiotemporal variation pattern of precipitation in Northwest China shows a significant upward trend in annual precipitation, with annual average precipitation ranging from 17-574mm and an increase rate of 0.62mm/(22 years). The highest annual precipitation occurred in 2010 and 2016, while the lowest occurred in 2006 and 2008. The main reason for this is the sharp decrease in precipitation in 2008 due to the impact of severe drought related natural disasters, but the sharp increase in precipitation in 2010. The annual spatial distribution pattern of precipitation in Northwest China is that the northern Northwest China has more annual precipitation than the southern Northwest China, and the western Northwest China has more annual precipitation than the eastern Northwest China.

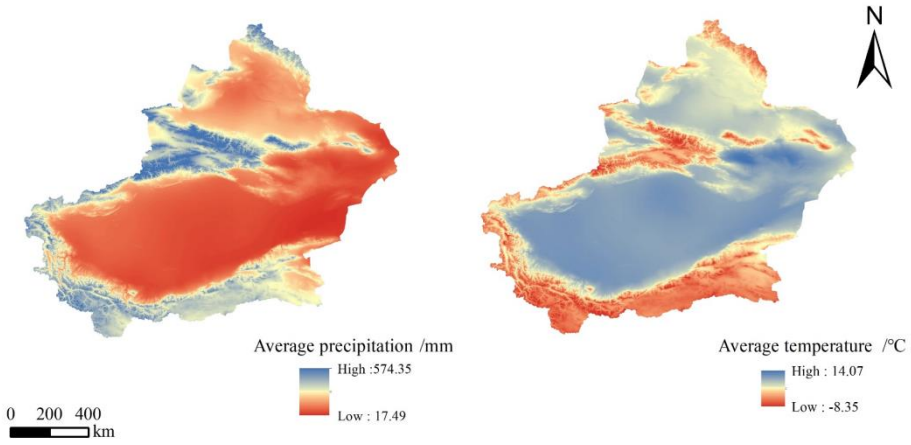

Figure 4: Spatial distribution of average annual precipitation and temperature in Northwest China from 2000 to 2021

By analyzing the correlation between NDVI, temperature, and precipitation in Northwest China from 2000 to 2021, the correlation between NDVI, temperature, and precipitation in Northwest China is shown in Figure 5. The correlation between temperature, precipitation, and NDVI in Northwest China region shows significant spatial differentiation at different periods. The relationship between NDVI and temperature in Northwest China is mainly characterized by insignificant negative correlation. The average correlation coefficient between NDVI and temperature in Northwest China is -0.015, with a highest value of 0.992 and a lowest value of -0.938. From 2000 to 2021, the NDVI response to precipitation in Northwest China mainly showed a positive correlation. The average correlation coefficient between NDVI and precipitation in Northwest China was 0.161, with a highest value of 0.944 and a lowest value of -0.852.

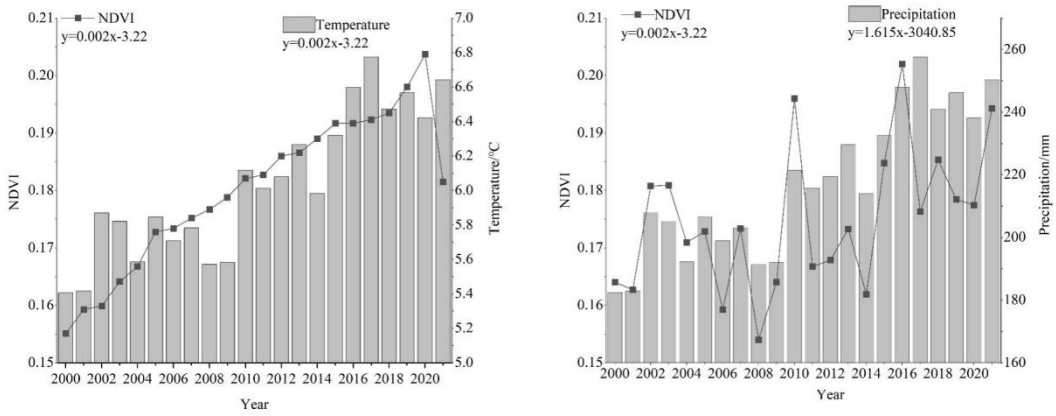

Figure 5: Changes in Annual Average Temperature, Precipitation, and NDVI in Northwest China from 2000 to 2021

3.3 Land use change

Based on the land use data from two periods in 2000 and 2021 (see Figure 6), the map fusion method was used to obtain the land use evolution map from 2000 to 2021, and the transformation information between various land use types was extracted. Overall, the land use structure in Northwest China is mainly composed of grasslands and unused land, with an average annual area of 91.61%. Farmland, water bodies, and forest land follow closely, with an average annual area of 8.19%. The area occupied by construction land is the smallest, with an average annual area of 0.19%. In the past 22 years, the main areas have increased, including construction land, arable land, forest land, and water area, which have increased by 3973 km2, 24669 km2, 3434 km2, and 2815 km2 respectively. But the grassland and unused land areas have decreased, by 17429 km2 and 17662 km^2 respectively. This indicates that land use resources in Northwest China have occupied some grasslands, which has had a certain negative impact on the grasslands. Overall, the amount of newly added land is the result of the decline in unused land and the mutual transformation between various land types. From this, it can be seen that the overall ecological and economic construction level in Northwest China is steadily improving, while other types of land use are increasing and the area of unused land is gradually decreasing.

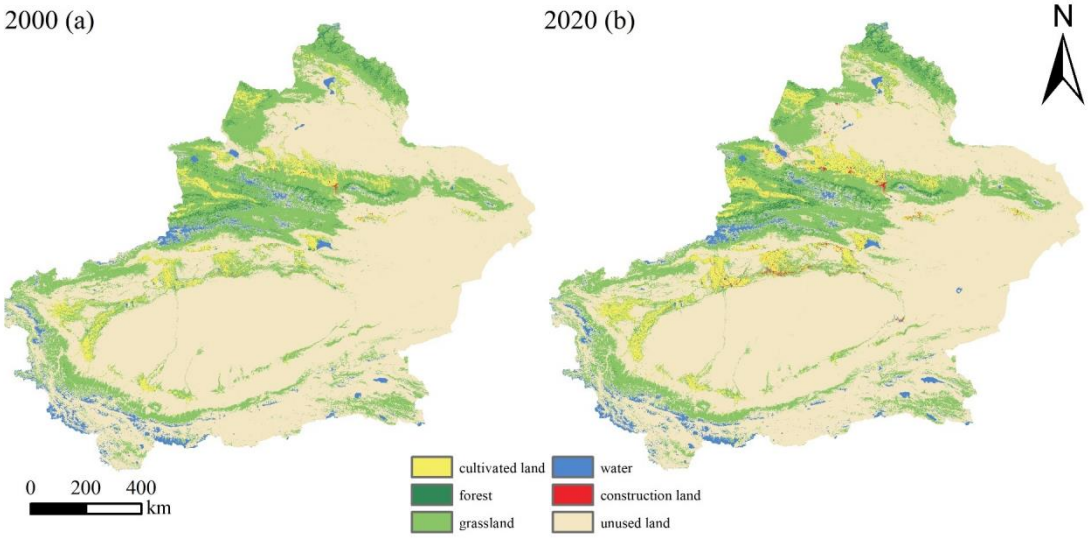

Figure 6: Distribution of Land Use Types in Northwest China in 2000 and 2021

Use a grid calculator to obtain a land use change map. There are a total of 25 types of land transfer in the land use transformation pattern from 2000 to 2021. Sorting them according to the size of the transfer area, three types of land transfer exceed 23000km^2, namely code (63) "Unused Land Grassland", code (36) "Grassland Unused Land", and code (31) "Grassland Farmland". There are three types of land transfer that account for over 80%, namely the coding of "forest land cultivated land" (21), "cultivated land grassland" (13), and "water area unused land" (46). Overall, the process of converting unused land into grassland plays an important role, reflecting the gradual development of Northwest China's unused land towards improving vegetation coverage.

4. Conclusions

Based on MODIS-NDVI data from 2000 to 2021, this article studied the vegetation cover changes in Northwest China over the past 22 years and combined them with the land use change map to explore the response driven relationship between land use and vegetation cover in Northwest China. The following conclusions were drawn:

(1) The average vegetation coverage in Northwest China over the years is within the range of 0.16-0.20, showing an overall fluctuating growth rate of 0.002% per year. The vegetation coverage in Northwest China region mainly shows insignificant changes, accounting for 72.61% of the total area. Significantly improved and extremely significantly improved areas account for 20.62% of the total area, most of which are located in the Ili River Valley, near the Tarim Basin, and the Altay Mountains. Significant and extremely significant degradation areas account for 6.87% of the total area, mainly located in the the Junggar Basin and the western region of northern Northwest China.

(2) The vegetation coverage in Northwest China is positively correlated with annual precipitation, with an average correlation coefficient of 0.161. The precipitation growth rate is 0.62 (22 years), and the spatial distribution is more in the west and less in the east, and more in the north and less in the south. The NDVI response to temperature in Northwest China mainly shows a non significant negative correlation. The average correlation coefficient between NDVI and temperature in Northwest China is -0.015, and the temperature growth rate is 0.15 ℃/(22 years). The spatial distribution is high in the south and low in the north, and high in the west and low in the east.

(3) Between 2000 and 2021, the types of land use in Northwest China increased to varying degrees, including construction land, cultivated land, water bodies, and forest land, while grassland and unused land decreased. In the land use transformation map, the mutual transformation between grassland and unused land dominates.

(4) The changes in land use map units in Northwest China region will have an impact on vegetation cover. The impact of different land use methods on vegetation varies, with unused land in Northwest China contributing the most, accounting for 68.32% of the total transferred area. The conversion map of unused land highly overlaps with the significant and extremely significant improvement areas of vegetation, and the conversion of unused land to grassland and farmland is the main reason for the improvement of vegetation cover.

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