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DYNAMIC CHANGE OF VEGETATION COVER AND ITS CORRELATION WITH CLIMATIC FACTORS IN CENTRAL YUNNAN PROVINCE, CHINA

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Fractional vegetation cover (FVC) is an evaluation index reflecting the quality of the ecological environment, and mastering the changes in vegetation cover that can help to realize the construction of ecological civilization and ecological environmental protection. To study the complex relationship between climate factors and vegetation cover, the dynamic characteristics and spatial patterns of vegetation cover in central Yunnan Province (CYP) and the correlation between vegetation cover and climate factors were investigated by applying the univariate linear regression and correlation analysis methods based on pixels using MODIS - NDVI and Chinese 1 km resolution monthly precipitation and temperature datasets from 2000 to 2020. The results showed that (1) the average vegetation cover in the past 20 years was 0.57, and the overall vegetation cover was increasing, with 48.18%, 28.23%, and 23.59% of the area showing increasing, stable, and decreasing trends, respectively; (2) spatially, the vegetation cover pattern was decreasing from southwest to northeast, and the vegetation cover in Chuxiong and Yuxi was higher than that in Kunming and Qujing; (3) the vegetation cover change in CYP was correlated with the climate factor; (4) there is a significant correlation between vegetation cover changes and climate factors in CYP, and the response of vegetation cover to precipitation in CYP is stronger than that of temperature.

Key words: *MODIS; Fractional Vegetation Cover(FVC); Climate factors; Trend analysis; Correlation analysis; Central Yunnan Province*

Introduction

As a core component of terrestrial ecosystems, vegetation plays an important role in energy exchange and material cycling in terrestrial ecosystems and is a major indicator of ecological condition and performance (Wang et al., 2012). The seasonal variation of vegetation is obvious, and its growth is greatly influenced by climate factors such as temperature and precipitation, and the vegetation growth condition is a comprehensive reflection of climate characteristics (Zhao and Running, 2010; Jiang et al., 2017). As external environmental factors are necessary for the growth and development of plants, climatic elements (temperature and moisture, etc.) play an important role in changes in vegetation activities (Zhao, Running, 2010; Jiang et al., 2017). Changes in climatic conditions, while promoting vegetation growth and development as well as physiological and biochemical effects, may also have adverse effects on vegetation activity (Ding et al., 2013). Vegetation cover is an important indicator of vegetation growth status (Ma et al., 2014), and the magnitude of its value can characterize the strength of vegetation activity (Gao et al., 2017), and changes in vegetation cover status are important for evaluating regional ecosystems (Gao et al., 2017). Therefore, remote sensing estimation and change characterization of vegetation cover have become one of the hot spots of current research (Yan et al., 2018).

The Central Yunnan Province (CYP) is an important gateway for China to Southeast Asia and South Asia, and the development of this region affects the overall development of the whole Yunnan Province and even the country. Therefore, studying the interaction between vegetation cover and climate factors is of great significance in the current study of regional, and even global, sustainable development. A series of studies have been conducted by domestic and foreign scholars in Yunnan Province to quantitatively assess the spatial and temporal characteristics of vegetation cover and their response to climate change.

Wang and Gao (2010) studied the characteristics of vegetation index changes in Yunnan Province using a 20-year AVHRR 8 km NDVI dataset, and concluded that the seasonal variation of vegetation in Yunnan Province varied significantly, with the total growing season being from early May to mid-October and the vegetation index varying significantly. Xiong et al. (2018) estimated the vegetation cover in Yunnan Province from 2001 to 2016 by calculating the MODIS-NDVI vegetation index from 2001 to 2016, supplemented with trend analysis and coefficient of variation, and then exploring the spatial and temporal variation of vegetation cover and the distribution relationship between vegetation cover and topographic factors. Chen et al. (2022) used MODIS-NDVI data and meteorological data from 2000 to 2020 in southwest Yunnan Province and analyzed them by the dimidiate pixel model, transfer matrix, linear trend analysis, correlation analysis, and residual analysis. The results showed that the low vegetation cover in southwest Yunnan gradually transformed to high vegetation cover in the last 21 years, and the overall vegetation cover in southwest Yunnan showed an improvement trend from 2000 to 2020. The existing results cannot yet explain the dynamic changes in vegetation cover and the correlation with climate factors in CYP systematically and comprehensively in time and space. Therefore, this paper attempts to use MODIS-NDVI data from 2000 to 2020, adopt the one-dimensional linear regression trend analysis model and correlation analysis to analyze the spatial and temporal change patterns and characteristics of vegetation cover in CYP, and further analyze the relationship between vegetation cover distribution and climatic factors.

2. Study area

The CYP encompasses the central part of Yunnan Province (24.05° –25.46°N, 102.48° –103.04°E) with four prefectures and cities, namely the Kunming, Qujing, Yuxi, and Chuxiong prefectures (Figure1), and includes 42 counties (cities/districts). The CYP has an area of ~ 94,558 km^2 and falls within the East Yunnan Plateau Basin, with an elevation of 277–4,281 m. The terrain of the CYP is dominated by mountains and inter-mountain basins (dams). The CYP falls in a subtropical plateau monsoon climate zone, characterized by an uneven spatial and temporal distribution of precipitation, sunny conditions, and obvious three-dimensional climate characteristics. The region has a low intensity of land development, and there are a lot of available land resources. The CYP includes the Dianchi Lake, Fuxian Lake, and five other plateau lakes. Therefore, the CYP has a high degree of water security. However, the pollution of Dianchi Lake has aggravated water shortages. The overall quality of the atmospheric environment of the CYP is good. The CYP contains diverse vegetation types, consisting mostly of secondary vegetation and artificial vegetation. The CYP is the core political, social, and economic area of Yunnan and is responsible for generating 53.0% of the province's gross domestic product (GDP) (based on data for 2019). In the context of globalization, the region occupies an important strategic position as a land transportation hub, connecting China to Southeast Asian and South Asian countries.

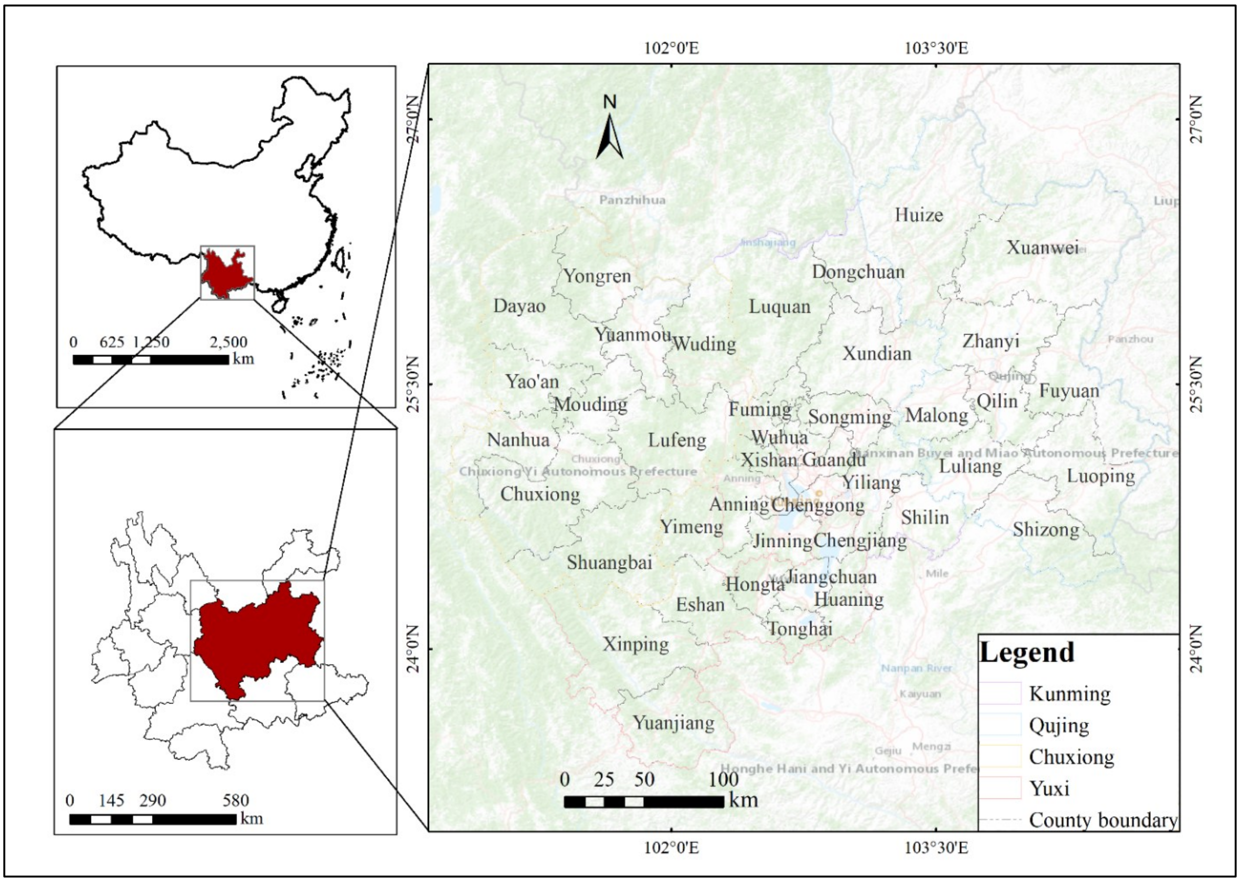


Figure 1. Maps of central Yunnan Province (CYP)

3. Materials and Methods

3.1. Datasets and Data Processing

MODIS-NDVI data were used for the study. Batch stitching, cropping, and reprojection of the raw MODIS data were performed by the MRT tool (Dwyer, Schmidt, 2006). Among them, for MODIS 16-day NDVI images with a spatial resolution of 250 m, we used maximum value composite (MVC) (Carreiras et al., 2003) to obtain monthly NDVI data. A dimidiate pixel model was used to calculate interannual vegetation cover (Gutman. Ignatov, 1998; Li et al., 2021); temperature and precipitation data were obtained mainly from the National Earth System Science Data Center, National Science & Technology Infrastructure of China (http://www.geodata.cn), 1 km monthly temperature and precipitation dataset for China from 1901 to 2020.

3.2. Methods

3.2.1. Dimidiate pixel model

Inversion of vegetation cover by a dimidiate pixel model based on the Normalized Difference Vegetation Index (NDVI) with the following equation (Li et al., 2004):

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \tag{1}$$

Where: $NDVI_{soil}$ is the NDVI value of bare soil area or area without any vegetation; $NDVI_{veg}$ is the NDVI value of complete vegetation cover. In this study, the maximum and minimum values of the given confidence interval are taken to replace $NDVI_{soil}$ and $NDVI_{veg}$, and the NDVI value corresponding to the cumulative frequency of 5% is taken as $NDVI_{soil}$, and the NDVI value corresponding to the cumulative frequency of 95% is taken as $NDVI_{veg}$.

3.2.2. Trend Analysis

In this paper, we used a one-dimensional linear regression method to analyze the vegetation cover raster trends, reflecting the spatial and temporal evolution of vegetation cover in the study area. If the slope is positive, the image element value has an increasing trend and the vegetation is benign, while the opposite represents vegetation degradation (Jin et al., 2020). This was achieved by using the raster calculator in ArcGIS 10.6. The trend analysis was calculated as follows:

$$slope = \frac{n\times\sum_{i=1}^{n} i\times y_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} y_i}{n\times\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \quad (2)$$

Where: $slope$ is the slope of linear regression, which indicates the trend and rate of change of the study subject; n indicates the total number of study years, here 21; y_i indicates the value of the climate or vegetation indicator in the first year.

3.2.3 Correlation Analysis

The correlation analysis method was used to calculate the trend of correlation coefficients between vegetation cover and climate factors (annual mean temperature and annual precipitation) in CYP on a spatial and temporal scale, image by image (Wang et al., 2009). The correlation coefficient $R_{xy}$was calculated as:

$$R_{xy} = \frac{\sum_{i=1}^{n}[(x_i - \bar{x})(y_i - \bar{y})]}{\sqrt{\sum_{i}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\sum_{i}^{n}(y_i - \bar{y})^2}} \quad (3)$$

In equation (3), R_{xy} denotes the correlation coefficient of variable x and variable y; n is the year number; x_i is the vegetation cover value of image element in the year i; $\bar{x}$ is the mean value of vegetation cover from 2000 to 2020; y is the value of climate factor (mean annual temperature and precipitation) in the year i; $\bar{y}$ is the mean value of climate factor (mean annual temperature and precipitation) from 2000 to 2020.

4. Results and Discussion

4.1. Vegetation coverage spatial variation characteristics

Based on numerous studies (Chen, Wang, 2009; Gu et al., 2021) and the actual situation in CYP, vegetation cover was classified into five classes: low vegetation cover (FVC < 0.2), medium-low vegetation cover (0.2 ≤ FVC < 0.4), medium vegetation cover (0.4 ≤ FVC < 0.6), medium-high vegetation cover (0.6 ≤ FVC < 0.8), and high vegetation cover (FVC ≥ 0.8) (Figure 2 and Table 1). The average vegetation cover in CYP from 2000 to 2020 was 0.57, and the spatial distribution showed a decreasing trend from southwest to northeast, with vegetation cover in Chuxiong and Yuxi cities generally higher than that in Kunming and Qujing cities. The area of the low vegetation cover zone in CYP was 9,287.31 km^2, accounting for 9.95% of the total area, mainly distributed around Yuanmou County, Dongchuan District, Anning City, Jinning District, Chengjiang County, and other cities and counties, where several important cities in CYP are located.

The area of vegetation cover in the medium-low coverage zone is 15,049.3 km^2, accounting for 16.12%, mainly distributed in An Ning City, Yiliang County, Huize County, and so on. The area is mainly distributed in the marginal areas of lakes, urban radiation areas, and other scattered areas. The topography is gentle and low, and the land use type is mainly dry land and sloping land, which is suitable for crop cultivation. The median vegetation cover area of the study area is 23,415.19 km^2, accounting for 25.07%, which is widely distributed in the central part of Yunnan, near towns and lakes, and dominated by medium-high cover grassland and shrubland. The area of medium-high vegetation cover in the study area is 24,076.31 km^2, accounting for 25.78%; the area of high vegetation cover in the study area is 21,558.13 km^2, accounting for 23.08%; it is mainly concentrated in Chuxiong City, Shuangbai County, Xinping County and Yuanjiang County in the area of the Ailao Mountains Range, where broad-leaved forests, coniferous forests, and high-coverage grasslands dominate.

Table 1 . **Area statistics of different grades of vegetation coverage in CYP (km^2)**

	0-0.2		0.2-0.4		0.4-0.6		0.6-0.8		0.8-1	
year	**area**	**proportion**	**area**	**proportion**	**area**	**proportion**	**area**	**proportion**	**area**	**proportion**
2000	11670.13	12.50%	16202.06	17.35%	22790.19	24.40%	22136.56	23.70%	20587.38	22.05%
2005	8168.56	8.75%	13607.56	14.57%	22652.69	24.26%	24499.69	26.23%	24457.81	26.19%
2010	12413.19	13.29%	16699.63	17.88%	22821	24.44%	21751.44	23.29%	19701.06	21.10%
2015	10687.69	11.44%	13636.75	14.60%	21520.25	23.04%	23914	25.61%	23627.63	25.30%
2020	10884.75	11.66%	12914.63	13.83%	19817.44	21.22%	23536.75	25.20%	26232.75	28.09%

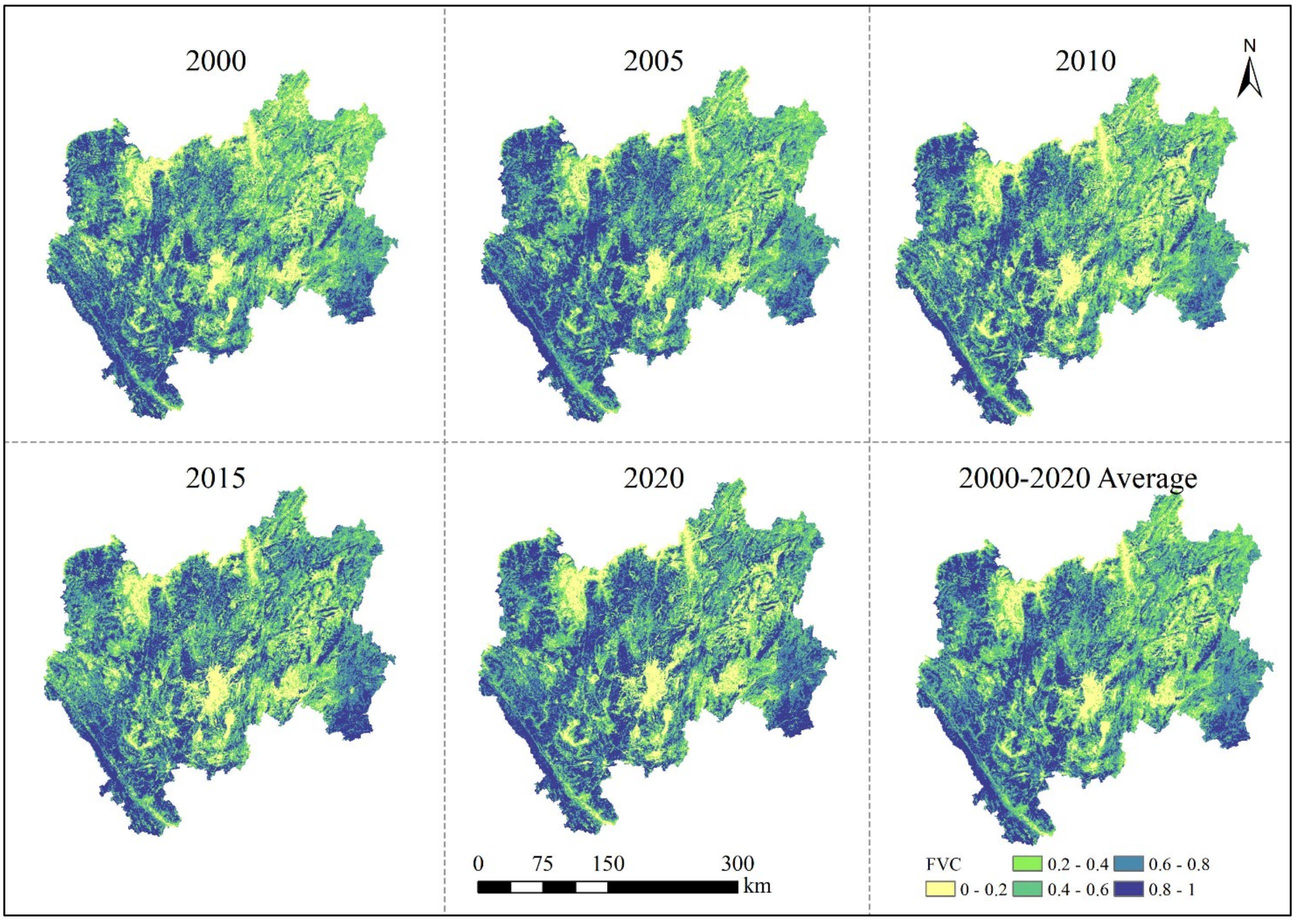
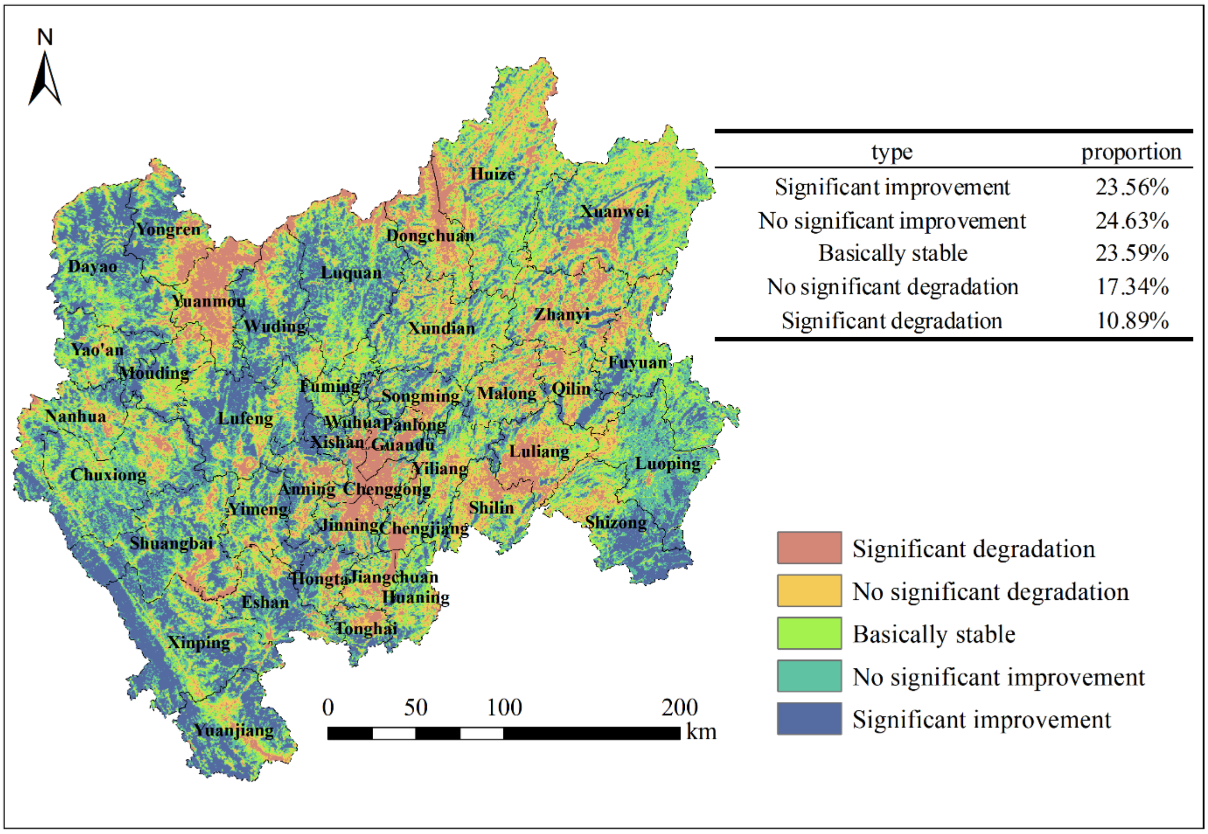


Figure2. Spatial distribution of vegetation coverage from 2000 to 2020

4.2. Temporal variation characteristics of vegetation cover

The trend of FVC from 2000 to 2020 was obtained by linearly fitting the trend of vegetation cover in CYP for the 21a interval by the method of linear regression trend analysis based on least squares, image by image (Figure 3), and it was classified into five classes according to the trend of change (Chen et al., 2022): significant decrease (Slope ≤ -0.015), insignificant decrease (-0.015 < Slope ≤ -0.005), basically stable (-0.005 < Slope ≤ 0.005), insignificant increase (0.005 < Slope ≤ 0.015), and significant increase (Slope > 0.015). From 2000-2020, the vegetation cover in CYP mainly showed an improving trend. The improved area accounts for 48.18%, and the area of significantly improved area accounts for 23.56%, which is concentrated in the northwest of Chuxiong City, the west of Yuxi City, and the southeast of Qujing City. The area of insignificantly improved areas accounted for 24.63%, concentrated in most areas of Chuxiong Prefecture, western Yuxi City, and southeastern Qujing City. Degraded areas accounted for 28.23%, significantly degraded areas accounted for 10.89%, and insignificantly degraded areas accounted for 17.34%, mainly in most areas of Kunming, northern Chuxiong and Qujing, and northeastern Yuxi. The basic stable area accounted for 23.59% and was mainly scattered in various counties in CYP. In general, the trend of vegetation cover change in CYP over the past 21 years is that the west is stronger than the east, and the south is stronger than the north. This indicates that the construction of ecological civilization in CYP has been effective, and the implementation of the policy of returning farmland to forest and grassland and the vigorous protection of forest and grassland have created a good growing environment for vegetation.



type	proportion
Significant improvement	23.56%
No significant improvement	24.63%
Basically stable	23.59%
No significant degradation	17.34%
Significant degradation	10.89%

Figure 3. Spatial variation characteristics of 21a vegetation coverage in CYP

4.3. Effect of meteorological factors on changes in vegetation cover

The correlation coefficients between vegetation cover and climate factors in CYP from 2000 to 2020 were calculated image by image (Figure 4). The maximum positive and negative correlation coefficients between vegetation cover and annual mean temperature were 0.999 and -0. 999, and the maximum positive and negative correlation coefficients between vegetation cover and annual precipitation were 0.999 and -0.999, respectively. There is a significant correlation between vegetation cover and annual average temperature and annual precipitation, in which the area with a negative correlation between vegetation cover and annual average temperature is 47.35%, mainly in

Kunming City and most of Yuxi City, Chuxiong City, Shuangbai County, Xinping County, Yuanjiang County and other counties. The area of the region with a positive correlation between vegetation cover and annual average temperature is 52.65%, mainly in Dongchuan District and northern and central Qujing City; the area of the region with a positive correlation between vegetation cover and annual precipitation is 46.45%, mainly in southern Chuxiong Prefecture, northern and central Qujing City. The area with a negative correlation between vegetation cover and annual precipitation is 53.55%, mainly in the northern part of Chuxiong Prefecture, Kunming City, and Yuxi City. Overall, there is a positive correlation between vegetation cover and temperature and precipitation in CYP, and the absolute correlation coefficient between vegetation cover and annual precipitation is greater than that between vegetation cover and annual average temperature, which indicates that the response of vegetation cover to precipitation is stronger than that of temperature in CYP from 2000 to 2020.

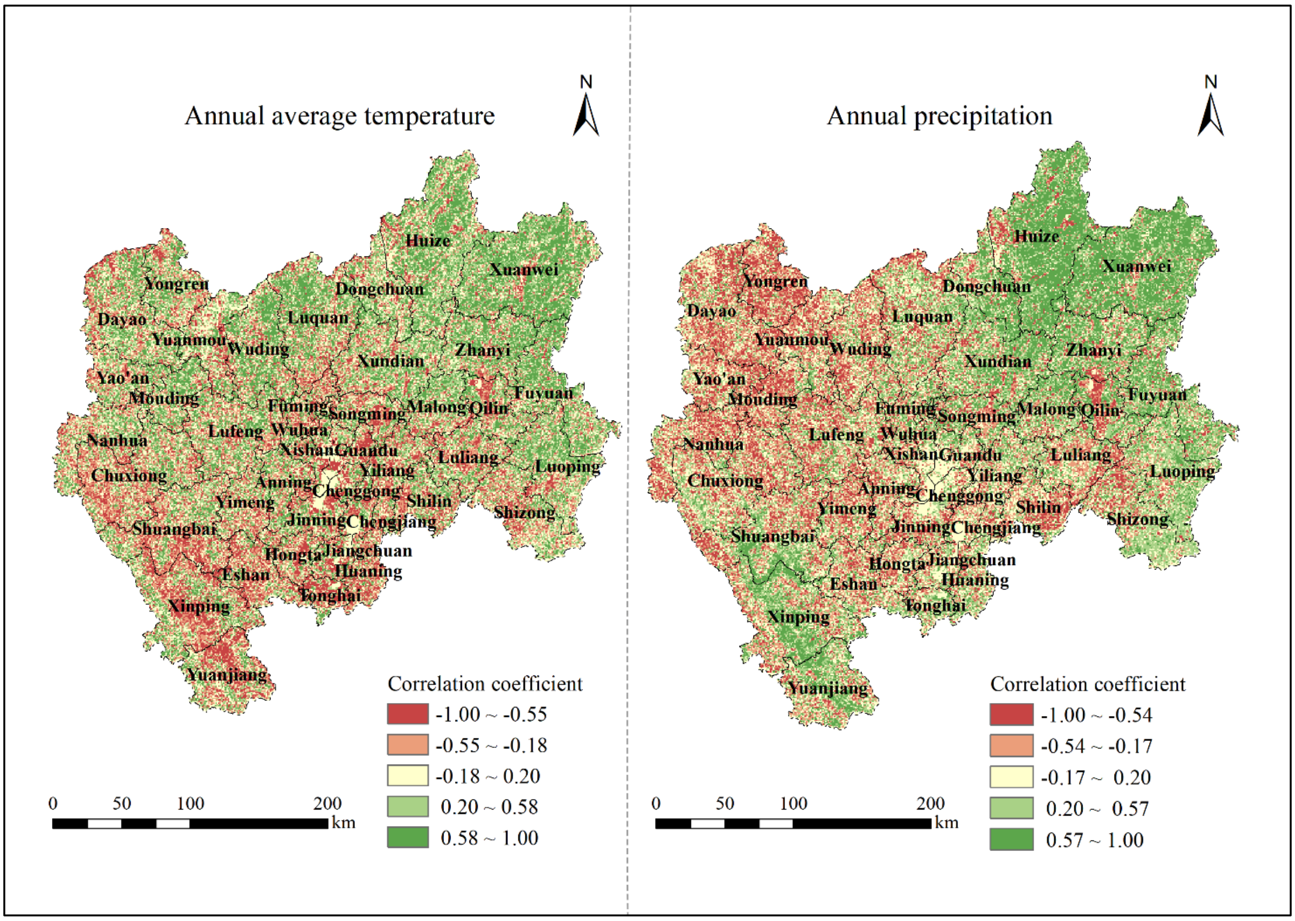


Figure 4. Spatial distribution of the correlation coefficients of the annual anomalies between NDVI and temperature, and between NDVI and precipitation from 2000 to 2020

4.4. Discussion

Based on the Normalization difference vegetation index (NDVI) from 2000 to 2020, the study used the dimidiate pixel model to calculate the vegetation cover and applied the spatial trend analysis to analyze the spatial and temporal characteristics of the vegetation cover in CYP. At the same time, the influence of climatic factors on vegetation cover was analyzed by combining temperature and precipitation data with correlation analysis and GIS spatial analysis. Correlation analysis is an intuitive quantification of the response of vegetation cover changes to climatic factors, which can better explain the dynamic relationship between annual mean temperature, annual precipitation, and vegetation cover changes. And because the differences in the effects of annual mean temperature and annual precipitation on the regions are very obvious, it can be seen that the analysis of vegetation cover change and climate factors as the research objects can better reflect the relationship between vegetation cover change and climate change.

However, vegetation growth is not only influenced by climatic factors but also has a close relationship with non-climatic factors. In this paper, only climatic factors are considered in the influence of vegetation cover dynamics, but in fact, many other environmental factors also have an important influence, including topography and human activities. For example, Xiong *et al.* (2018) found a clear pattern between vegetation cover change and topography in Yunnan Province. The average vegetation cover showed a trend of increasing, then decreasing, then increasing, then decreasing with increasing elevation. In addition, large-scale ecological engineering is also an important factor affecting the ecological environment (Zhang et al., 2017; Lu et al., 2015). However, this paper only analyzed the influence of vegetation cover in CYP through climatic factors, and did not take into account the influence of human activities, land use, and natural disasters, and subsequent studies should include more influencing factors for comprehensive research. In addition, the study used trend analysis and correlation analysis to analyze the spatial and temporal changes of vegetation cover and lacked research on the driving mechanism of vegetation change. The next step will be to analyze the driving factors of vegetation cover change, find the main influencing factors, and take effective measures to ensure the development of vegetation cover in the region.

5. Conclusions

Vegetation cover was estimated using MODIS-NDVI data, supplemented by trend analysis and correlation analysis, and the spatial and temporal variation characteristics of vegetation cover in CYP and its relationship with climate factors were analyzed. The following conclusions were mainly drawn: temporally, the vegetation cover in CYP showed an overall increasing trend from 2000 to 2020, with a large fluctuating decrease in 2010; the vegetation cover in CYP showed an increasing trend, with 48.18%, 28.23%, and 23.59% of the area showing an increasing, stable, and decreasing trend, respectively.

Spatially, the average vegetation cover in CYP from 2000 to 2020 was 57.33%. The vegetation cover pattern shows a decreasing pattern from southwest to northeast, with high vegetation cover and good vegetation growth in Chuxiong Prefecture and Yuxi City, and relatively lower vegetation cover and poor vegetation growth in Kunming and Qujing City.

There is a significant correlation between vegetation cover changes and climate factors in CYP. The absolute correlation coefficient between vegetation cover and annual precipitation was greater than that between vegetation cover and annual mean temperature, and the response of vegetation cover to precipitation in CYP was stronger than that of temperature.

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