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Spatial-temporal variation of NDVI and its climatic response in Li River basin based on GEE

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Abstract. Vegetation serves as a crucial indicator of ecological environment in different regions. Land cover vegetation is significantly impacted by climatic factors and human activities, and good coverage can enhance the quality of the local ecological environment. The Lijiang River Basin is a typical karst landscape with a delicate ecological environment. Describing changes in the characteristics of vegetation cover under different influencing factors carries significant significance for the restoration of vegetation in karst areas, taking the Li River Basin as an example. This study is based on the vegetation NDVI dataset MOD13Q1 of the Li River Basin from 2000 to 2020. Results showed that: over the past 21 years, the Normalized Difference Vegetation Index (NDVI) mean value in the Li River Basin was around 0.85. The Li River Basin's inter-annual growth rate was 0.011/10yr; nevertheless, there are substantial discrepancies among regions. Vegetation was notably more impacted by temperature than precipitation in terms of land cover. NDVI exhibited a decline trend from the central area to the peripheral areas. Additionally, there was a lack of vegetation cover on the upper, western side of the middle **reaches, and eastern side of downstream.**

Keywords: NDVI; Li River Basin; characteristics of spatiotemporal evolution; Climate response.

1. Introduction

Vegetation plays the role of connecting ecological elements such as hydrology and soil, which is of great importance in maintaining ecosystem functions and services [1]. It also maintains local water, soil and biodiversity, while monitoring the quality of the ecological environment as an essential component of the ecosystem [2]. Vegetation represents one of the primary components of the global carbon cycle system. Vegetation cover is a powerful indicator of surface coverage, which is of great importance in assessing the quality of the ecological environment in the region [3]. It is a crucial parameter for reflecting the quality of the ecosystem and ecological environment. Research has shown that the vegetation cover is influenced by both natural factors and human activities [4].

Among these factors temperature and precipitation are the main natural factors affecting vegetation cover [5, 6]. Human activities influence vegetation in two distinct aspects: promoting or inhibiting [7]. These impacts vary across different regions, and haphazard social activities such as urban expansion, deforestation, and mining are leading to an alarming decline in vegetation [8, 9]. Implementing measures

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such as improving cultivation and irrigation technologies, and reclaiming farmland to forest, can help promote the growth of local vegetation. The Normalized Vegetation Index (NDVI) is an accurate representation of vegetation growth and density in the study area. It can also provide exact data about specific indices, including vegetation cover, productivity, and leaf area [10]. As it is not easily disturbed by clouds, terrain and other factors, NDVI is widely used in the study of vegetation dynamics and its driving factors [11], which is of great significance in revealing the changes in the quality of regional ecological environment quality under the influence of global warming [12]. Dynamic alterations in vegetation and the driving forces affecting vegetation growth have become a hot research topic as the impact of global warming and unreasonable human social activities increase. This research is guided by the concept of green sustainable development [13, 14].

2. Study area and methodology

The Lijiang River is part of the Pearl River system and is situated in Guilin City, it originates from the east of Mao'er Hill in Xing'an county, ending at the mouth of the Pingle Sanjiang River, flows from north to south through Xing'an, Lingchuan, Yongfu, Gongcheng Yao autonomous region, Yangshuo, Lipu city, Pingle county, Lingui district, Diecai district, Xiufeng district, Xiangshan district, Qixing district, and Yanshan district, with a total length of 259.67km and a catchment area of about 17,392 km2 (Figure 1). The topography in the northwest is elevated while it is low in the centre. The central part of the area is a standard karst landscape, surrounded by mountains, with a vast vegetation cover and plentiful natural resources. This part of Southwest China is considered a crucial ecological barrier for the karst region, with a sensitive ecological environment. The Li River's upper reaches have non-karst forest ecological zones, and the middle and downstream reaches of the river are karst ecological zones, with mountains and hills covering more than 50% of the area.

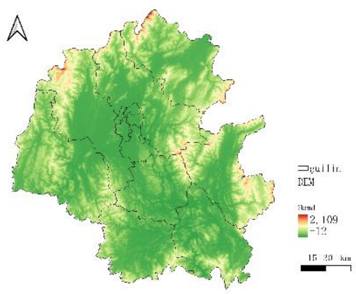

Figure 1. Schematic diagram of the study area

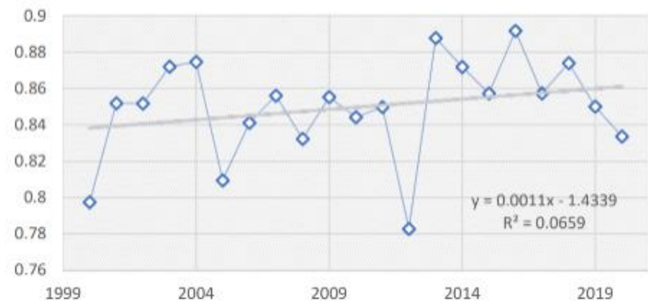

Figure 2. Trend of NDVI change of vegetation in Li River Basin from 2000 to 2020

2.1. Data sources and processing

1)We used the NDVI data product MOD13Q1 dataset based on the GEE platform. The dataset has a time resolution of 16-day intervals and a spatial resolution of 250m. Due to the Li River basin's predominant perennial evergreen vegetation, which is less affected by seasonal changes, the maximum value synthesis (MVC) was used to synthesize the annual vegetation NDVI data from 2000 to 2020 [15]. Upon projection transformation and data cropping, we obtained the NDVI for the last 21 years.

2)Precipitation data was acquired from the National Earth System Science Data Center (http://www.geodata.cn), and raster images representing the annual cumulative precipitation from 2000 to 2020 were obtained through station screening and spatial interpolation.

3)The temperature data are spatially interpolated from the surface meteorological data of China from 1942 to the present provided by the National Climatic Data Center (NCDC) of the United States of America. The data from 2000-2020 was selected for mask extraction to obtain the year-by-year monthly average temperature.

4)The karst landform data were obtained from the Guangxi Karst Science Experiment Data Center (http://gyig.cas.cn).

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5)The vector boundaries of Guilin City's administrative districts were obtained from the National Center for Basic Geographic Information (http://www.ngcc.cn).

3. Results and analysis

3.1. Characteristics of spatial and temporal variations

As the Figure 2 illustrated, there was a notable variation in the spatial and temporal distribution of the maximum annual vegetation NDVI in the Li River basin varied significantly between 2000 and 2020. During the study period, the annual mean values of vegetation NDVI in the Li River Basin were in the ranged from 0.78 to 0.89, maintaining a high level overall. The minimum NDVI value was 0.7828 in 2012, and the maximum value of vegetation NDVI was 0.8916 in 2016.The vegetation NDVI in the Li River Basin exhibited an overall fluctuating and slowly increasing trend. It had an average annual growth rate of 0.01201, while the average annual NDVI was 0.85.

Between 2000 and 2005, the NDVI exhibited a generally upward trend, with a growth rate of 0.012018. From 2005 to 2010, the NDVI manifested a significant upward trend with a growth rate of 0.034767. The growth rate from 2010 to 2015 was 0.013042. Furthermore, the inter-annual variations of NDVI in the final 5 years of the study period decreased at the rate of -0.023592. In the period from 2000 to 2020, the growth rate of NDVI was 0.03623. This exhibited an overall trend of initial increase, followed by decrease, then again, an increase. Furthermore, the average annual growth rate of vegetation NDVI was 0.011/10a ($P<0.05$).

As shown in Figure 3, there is significant variation in the spatial distribution of vegetation in the Li River Basin from 2000 to 2020. The vegetation cover among the districts and counties shows significant differences, with a gradual increase from both sides of the Li River towards the surrounding areas. Influenced by human activities and climatic factors, the vegetation cover in the upper Li River basin, the west side of the middle reaches and the east side of the downstream reaches is poor. The upper Li River basin has the worst vegetation cover among them. There exists an inverse relation between the local NDVI and urbanization, implying that the faster the urbanization process in the area, the lower the vegetation NDVI value. Over the past 21 years, the average vegetation NDVI in Qixing district, Xiufeng district, Diecai district, and Xiangshan district was considerably lower than that of other districts and counties. The vegetation NDVI increased by 0.030, 0.029, 0.005, and 0.029, respectively, in each district when comparing 2020 with 2000.

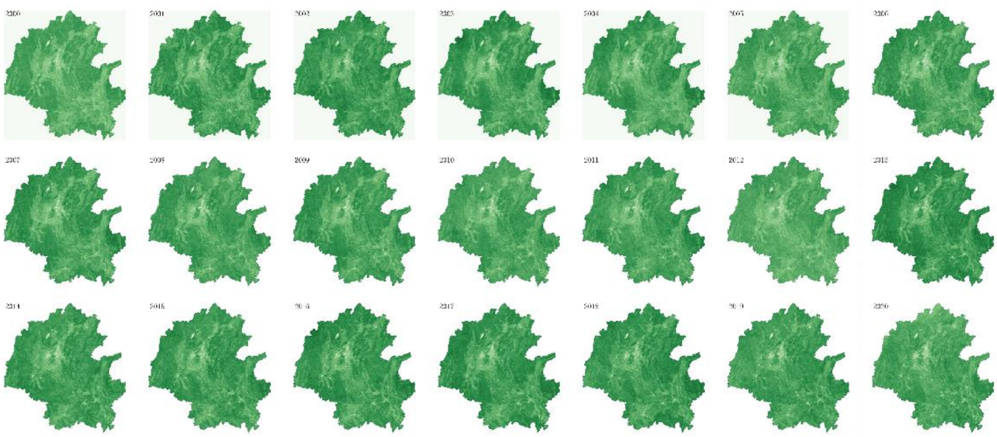

Figure 3. Spatial and temporal distribution of NDVI maximum of study area between 2000 and 2020

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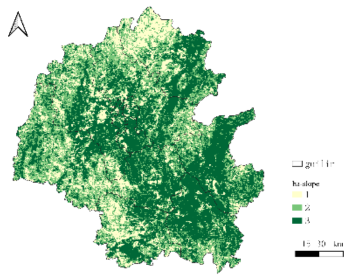

Figure 4. Trend of vegetation NDVI change and significance test from 2000 to 2020

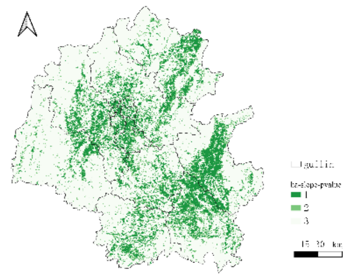

Figure 5. Trend of vegetation NDVI change and significance test from 2000 to 2020（P<0.05）

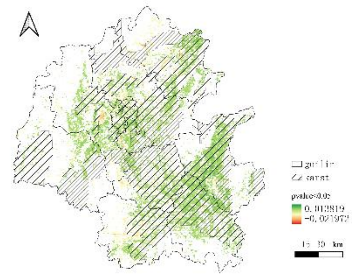

Figure 6. Spatial distribution of karst landforms and significance

As of 2020, low NDVI values are still present in several areas of Lingchuan, Xing’an, Yongfu, and Pingle counties. In Haiyang Moutian, Jialing Bridge, Dengyun Moutian, and Jiucai Hill, the vegetation shows high NDVI values. However, the NDVI values in Pingle county and Gongcheng county have improved significantly compared to those recorded in 2000. The vegetation NDVI trend in the Li River basin between 2000 and 2020 was analyzed by slope-by-cell analysis (Figure 4). Moreover, the trend of vegetation NDVI change exhibited clear spatial heterogeneity in the Li River basin. In terms of the number of image elements, 74.11% of the total have an increasing trend (slope > 0) of vegetation NDVI in the Li River basin. These elements are primarily distributed in Pingle county, Gongcheng Yao autonomous region, and Yanshan district. About 25.89% of the total number of image elements showed a decreasing trend (slope<0), mainly in Xing’an, Lingchuan, and Lipu city. Approximately 34.35% of the total area refers to regions with a strong significant correlation(P<0.05) (Figure 5), whereas 7.02% of the region have a significant correlation. Overall, the vegetation NDVI has shown a positive increasing trend, where NDVI values in 2020 were significantly higher compared to the ones recorded in 2000.

3.2. Characteristics of spatial variation of NDVI in different ground cover types

The Li River Basin covers an area of 17,392 km2, of which the karst landforms are about 9,064 km2, which is 52.12% of the total area. Soluble carbonate rocks constitute the primary component of rocks in the karst landforms of the Li River Basin. The flowing water erodes soluble rocks leading to address collapse, resulting in the formation of karst landforms, which are unique in nature. Due to the formation of karst landform, the Li River Basin are usually characterized by slow soil formation, infertile land, and well-developed groundwater systems, which are very likely to cause ground collapse and surface exposure, resulting in a large-scale reduction of vegetation. The NDVI of vegetation in karst landforms is more susceptible to change than that in non-karst landforms. The area showing significant vegetation NDVI coincides with that of karst landforms (Figure 6). Karst landforms with significant vegetation NDVI (P<0.05) cover approximately 45.82% of the total area.

3.3. NDVI response to climate change

Linear regression was utilized to model the cumulative annual precipitation and mean temperature in the Li River Basin for the period 2000 to 2020 (Figures 7-8). Trend graphs depicting the cumulative precipitation and annual mean temperature were generated. The results revealed that the annual mean temperature of the Li River basin showed an upward fluctuating trend (P>0.1) from 2000 to 2020, increasing at the rate of 0.2℃/10a. The temperature records indicate that the highest temperature recorded during that period was 18.67℃, while the lowest was 17.65℃. During that period, the average temperature was recorded as 18.22℃. The mean annual temperature showed greater fluctuations between 2000 and 2014, followed by a gradual decrease from 2015 to 2018. However in recent times, the temperature has once again shown an upward trend.

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From 2000 to 2020, the cumulative annual precipitation exhibited a consistent increasing trend (P > 0.1) with an annual average increase of 15.4mm/10a. Over that period, the mean amount of cumulative annual precipitation was 1607.07mm. During the period of 2000-2020, the highest amount of cumulative annual precipitation was observed in 2002 (2070.5mm); whereas, the lowest one was recorded in 2011 (1275.42mm). During the 2000-2012 period, the annual average precipitation exhibited significant fluctuations; however, from 2013 to 2020, the precipitation tendency was towards stability. In general, the Li River Basin's climate has been increasingly becoming wetter and warmer.

Vegetation NDVI values and their correlation with climate factors such as temperature and precipitation changes in the Li River basin, from 2000 to 2020, were analyzed using linear regression. The results are presented in Figure 10 and 11. The vegetation NDVI value decreased with an increase in precipitation. The correlation coefficient representing the precipitation effect was -0.044/10a.

Pingle county, Yangshuo county, Lipu city, Xiufeng district, Qixing district, Xiangshan district, and Yanshan district showed significant correlation trends. In the Li River basin, 73.91% of the area showed significant negative correlation between vegetation NDVI and precipitation, while 7.90% of the total area showed strong significant negative correlation (P<0.05) between these two factors as indicated in Figure 10 and 11. Vegetation NDVI showed an increasing trend with the annual mean temperature. The correlation coefficient was 0.401/10a, and the range of the coefficient varied between -0.69 to 0.85. In the Li River basin, 92% of the regions showed a positive correlation between vegetation NDVI and temperature. The areas with significant correlation (P<0.05) accounted for 43.92% of the total area. Temperature had a more significant influence on vegetation NDVI in the Li River basin as compared to precipitation.

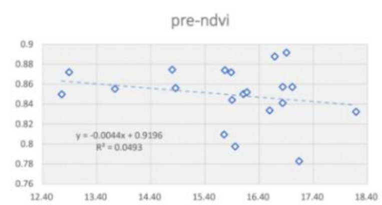

Figure 7. Trends in temperature and precipitation, 2000-2020

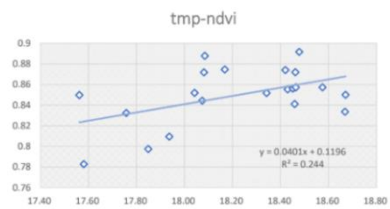

Figure 8. Trends in temperature and precipitation, 2000-2020

Figure 9. Correlation of NDVI with temperature and precipitation

Figure 10. Significance test and correlation of temperature with NDVI from 2000 to 2020

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Figure 11. Significance test and correlation analysis of precipitation with NDVI from 2000 to 2020

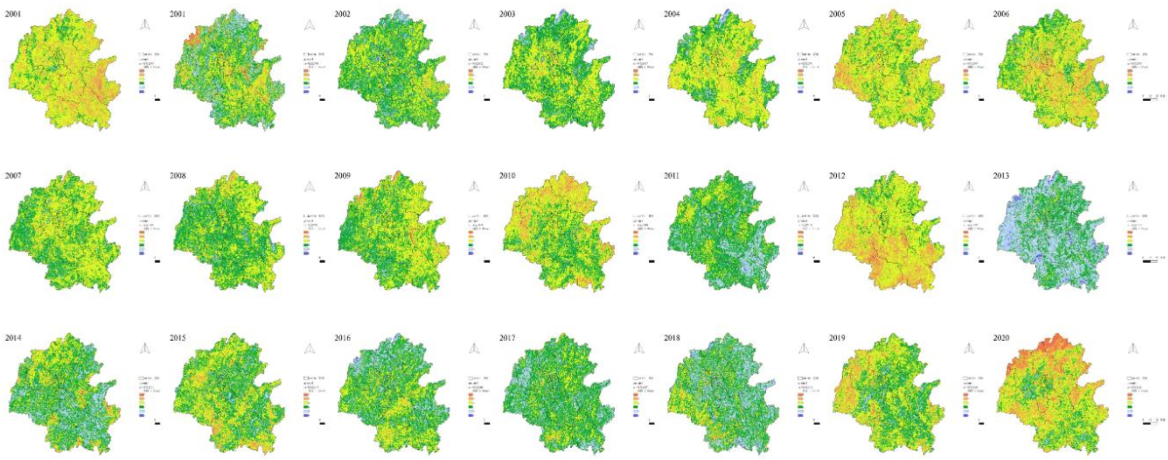

Figure 12. Spatial distribution of anthropogenic impacts, 2000-2020

3.4. Anthropogenic impacts on NDVI

There were considerable differences in the impact and strength of human activities on NDVI among different surface cover types. The residual analysis method was utilized to measure the impact of human activities on NDVI (Figure 12). Human activities had a more pronounced impact on vegetation NDVI in the Li River basin and exhibited distinct spatial and temporal differences. Out of all the cover types, 26.64% of the entire basin area had a significant correlation between human activities and vegetation NDVI. Strongly significant correlation was found in 7.29% of the total area. Over time, the influence of human activities on vegetation NDVI varied significantly. Human activities mostly impacted the vegetation's NDVI negatively across most of the Li River Basin. In particular, an unfavorable tendency was detected in 76.98% of the region. In contrast, only 23.02% of the area showed a positive trend while experiencing the influence of human activities. These areas were principally concentrated in Lingui and Pingle County's central region. Between 2000 and 2020, the impact of human activities on the vegetation's NDVI in the Li River basin generally had a positive trend. In particular, Xing'an, Lingchuan, and Yongfu counties, Lingui and Diecai districts accounted for 64.58% of the area where NDVIha showed a positive trend. The remaining 35.42% of the area, which was largely concentrated in Pingle county, Gongcheng Yao autonomous county, Yangshuo county, as well as Yanshan, Xiangshan, Qixing, and Xiufeng districts, displayed a negative trend. In recent years, the trend of industrial activities in the Li River Basin has had a predominantly negative impact on the vegetation's NDVI.

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4. Conclusion

Between 2000 and 2020, the vegetation cover in the researched area demonstrated a prolonged health status, accompanied by a consistent trend of annual increase in NDVI values, which was on average between 0.78-0.89 and had a growth rate of NDVI of 0.011/10a. In 2020, the Li River basin saw vegetation NDVI increase, covering 74.11% of the total basin area. Meanwhile, there was a decrease in vegetation NDVI accounted for 25.89% of the total area, indicating a substantial boost relative to 2000 when vegetation NDVI increased by 0.011/10a. There was a significant increase in vegetation NDVI compared with 2000.

From 2000 to 2020, the climate of the Li River Basin experienced a warm and humid transition, with an average yearly temperature of 18.67 °C. The temperature showed an average increase of 0.2 °C per decade. The area also received an average of 1607.07 mm of precipitation each year, which increased by 15.4 mm every decade. The correlation coefficient between vegetation NDVI and temperature was normally distributed within the range of -0.69~0.85. As temperature increases, the vegetation's NDVI showed an upward trend with a growth rate of 0.401/10 yr. The correlation coefficient between vegetation NDVI and precipitation showed a normal distribution with the range of -0.66~0.68. The vegetation's NDVI demonstrated a decreasing pattern with rising precipitation, with a growth rate of -0.044/10a. The impact on temperature due to vegetation's NDVI was significantly more substantial compared to that of precipitation in the Li River Basin. From 2000 to 2020, there is a positive correlation trend between human activities and the vegetation NDVI in the Li River basin as time goes by. The area with a positive correlation trend in the influence of human activities on vegetation NDVI residuals accounted for 64.58% of the total area, while the negative correlation trend area accounted for 35.42%.

Based on the above quantitative analysis, the study of NDVI in the Lijiang River Basin over the past 21 years indicates a fluctuating upward trend. Vegetation NDVI in the Li River Basin is locally deteriorating, but exhibits a positive trend overall, which may be attributed to the geological particularities and unique climate change of the Li River Basin.

The vegetation coverage is influenced by various factors besides temperature, precipitation, and human activities such as humidity, sunshine, climatic anomalies, topographic gradients, soil composition, geological features, and national policies [16]. In this paper, we analyzed the variation characteristics of NDVI in the Li River Basin from 2000 to 2020, and determines that vegetation NDVI is influenced by temperature, precipitation, and human activities, particularly in karst landscapes. Recently, the climate in the Li River Basin has become warmer and more humid, which has led to vegetation NDVI being more impacted by temperature than precipitation. Human activities also significantly influence NDVI. Furthermore, the high frequency of extreme events is a primary cause for the impact of vegetation in the Li River basin.

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