Assessment of Ecological Quality Changes of Vegetation in Fuzhou City from 2000 to 2020 Based on MODIS Observations

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Abstract. As an advocate of "urban ecology construction" and the capital of Fujian, an "ecological province", the ecological quality of vegetation in Fuzhou City is crucial to the development of ecological civilization in the region. The ecological quality of vegetation in Fuzhou City was assessed by quantifying the distribution and changes in the Normalized Difference Vegetation Index (NDVI) and the Net Primary Productivity (NPP) of vegetation from 2000 to 2020 and exploring the influence of urban development on their distribution. The result shows that the multi-year average Vegetation Fraction Cover (VFC) of the region is 68%, showing a significant growth trend (0.32% yr^{-1}), reaching 72.43% by 2020. The multi-year average NPP is 14.6 × 10^3 kg C·m^{-2}·yr^{-1}, and the vegetation carbon sequestration showed a smooth fluctuation in the last two decades. VFC and NPP are relatively low on the eastern coastal and riverine areas, while they had higher levels in the inland mountainous areas. However, the ecological quality of vegetation in urban areas is poor and showing a decreasing trend, for the effect from urbanization. The construction of ecological civilization has led to an upward trend in the overall ecological quality of vegetation in Fuzhou City, but regional economic development has caused a decline in the ecological quality of vegetation in urban areas and surrounding areas. This study provides a basis for further regional vegetation ecology research and also has important implications for balancing urban development and vegetation.

Keywords: Fuzhou City · MODIS observations · Ecological quality

1 Introduction

Vegetation is significant for the stability of ecosystems [1]. As an essential component of ecosystems, it has an important role in many aspects such as carbon sequestration, temperature regulation, soil and water conservation, and maintenance of ecological balance [2]. Ecosystem quality, however, encompasses environmental integrity including biological, physical and chemical aspects. The study of the ecological quality of vegetation in a region can provide a better understanding of the local environmental conditions and make timely and appropriate measures. Among them, NDVI and NPP are key data for calculating vegetation fraction cover and carbon sequestration, which in turn can be used to effectively measure changes in vegetation ecological quality in conjunction with land cover types [3].

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Many scholars have conducted studies using NDVI and NPP for the ecological quality of vegetation in several regions [3, 4]. In addition, studies have shown that influencing factors such as precipitation, temperature, and human activities can affect vegetation coverage to different degrees [1, 5]. Within Fujian Province, there have been relevant studies for the province and the Wuyishan National Nature Reserve [6, 7]. However, among the existing studies, there is a lack of more detailed remote sensing studies on Fuzhou City in terms of the ecological quality of vegetation.

Based on the NDVI, NPP and Landcover data from 2000 to 2020, the spatio-temporal variation of vegetation ecological quality in Fuzhou city and their statistics in each district and county were obtained. The second section of this paper lists the study area, data sources and methods. The third section presents the results of the spatio-temporal variation, and their distribution in the districts and counties. In the last section, we present the discussion and conclusion.

2 Data and Method

2.1 Study Area

Fuzhou City, located between 118°08′–120°31′ E and 25°15′–26°29′ N, has a total area of 11,968 km^2. It is the capital of Fujian Province, People's Republic of China, located in the eastern part of Fujian Province in downstream and coastal areas of the Min River (Fig. 1a). Fuzhou city is located in a typical estuarine basin, surrounded by mountains and hills. Its elevation is mostly between 0.6 and 1 km, with the terrain sloping from west to east. Fuzhou has a typical subtropical monsoon climate, with an average annual sunshine of 1700–1980 h, an average annual precipitation of 900–2100 mm, an average annual temperature of 16–20 °C, and an annual relative humidity of about 77%.

In 2020, the city's forestry land area of 7505 km^2 (including 3135 km^2 of ecological public welfare forests, 4370 km^2 of commercial forests), with forest land area of 6481 km^2. The city's forest coverage rate of 58.36%, the total forest tree accumulation 51.34 million m^3, 49.24 million m^3 of forest storage.

Fuzhou City was the first city in China to introduce the concept of "urban ecological construction" and incorporate ecological planning into its urban development strategy

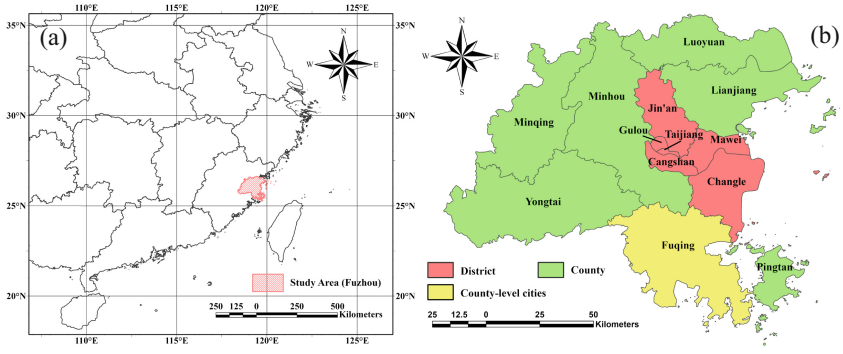

Fig. 1. Geographical location of the study area (a) and its administrative divisions (b).

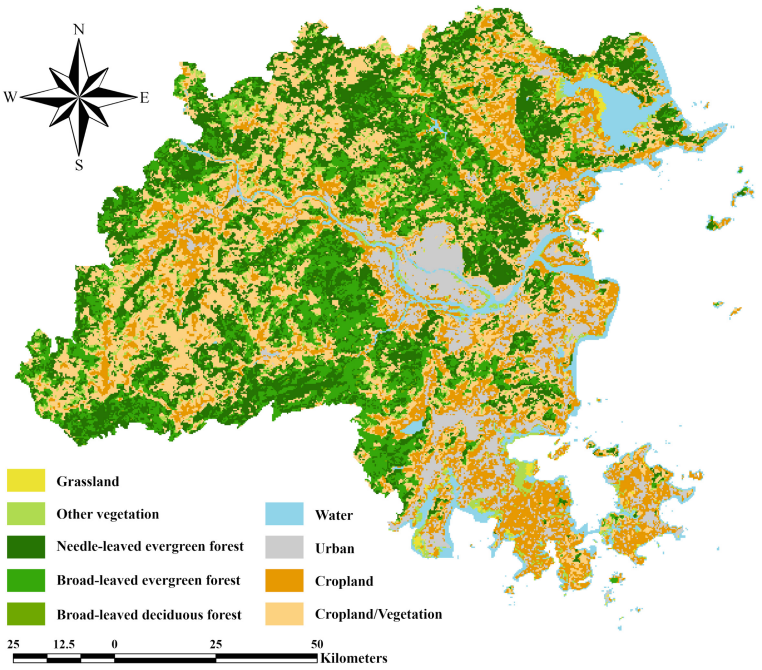

Fig. 2. Land cover types of the study area.

[8]. In 2000, when Xi Jinping was the governor of Fujian Province, he proposed the idea of an "ecological province", with a clear vision of ecological development within 20 years [9]. Fuzhou, as the capital of Fujian Province, is an important study area and its ecological quality of vegetation is an important representative of the whole region. Fuzhou City has six districts (Gulou district etc., red), six counties (Minhou county etc., green) and one county-level city (Fuqing City, yellow) (Fig. 1b).

The land cover types in Fuzhou City are mainly forest and farmland, occupying 39.84% and 39.75% of the total area, respectively. Forests include needle-leaved evergreen forest, broad-leaved evergreen forest and broad-leaved deciduous forest. In addition, the proportion of urban, water bodies and other vegetation land areas ais 8.74%, 5.76% and 5.91%. The urban areas are located in the eastern coastal areas and along the rivers, while the forests are mainly located in the inland areas. The districts are dominated by urban land, the county-level city is mainly urban and farmland, while the counties are mainly forest and farmland (Fig. 2).

2.2 Data

In this study, we used the Normalized Difference Vegetation Index (NDVI) to calculate Vegetation Fraction Cover (VFC) and the Net Primary Productivity (NPP) to calculate vegetation area carbon sequestration, and then comprehensively assessed the changes of ecological quality of vegetation in Fuzhou. In addition, we used the landcover data for

urban areas' identification and their connection to the ecological quality of vegetation. NDVI and NPP data from 2000 to 2020 were collected for this study.

NDVI (MOD13A1) is a data that response to vegetation cover by measuring the difference between near infrared (strong vegetation reflection) and red light (vegetation absorption) [10]. NPP (MOD17A2H) is the difference between the energy fixed by plants and their respiration, i.e., the biotic gain of plants, which is also equivalent to the net carbon absorbed by plants through photosynthesis [11, 12]. Both of them achieved from NASA (https://ladsweb.modaps.eosdis.nasa.gov/).

Landcover dataset used in this study is from the Land cover classification gridded maps (v2.1.1 - 2020) obtained from Copernicus Climate Change Service Climate Data Store (https://cds.climate.copernicus.eu/).

2.3 Method

For the downloaded raw NDVI data, the data for the study area was firstly obtained by region clipping using the Fuzhou city administrative map. The data for the study area was then processed using cloud mask to remove nulls and invalid values. For null values due to data acquisition quality issues, the null values were filled using sliding window averaging. In this paper, Vegetation Fraction Cover (VFC) was approximated using a vegetation index. VFC is a quantitative measure of the extent of ecological greening and is the percentage of the vertical projection of the above-ground portion of vegetation over the ground area. VFC model:

$$\mathrm{VFC} = (\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{soil}}) / (\mathrm{NDVI}_{\mathrm{veg}} - \mathrm{NDVI}_{\mathrm{soil}}) \quad (1)$$

NDVI soil is the NDVI value of an area that is completely bare soil or without vegetation cover, and NDVI veg represents the NDVI value of the image element that is completely covered by vegetation, i.e., the NDVI value of the pure vegetation image element [13]. In this paper, by sorting NDVI by size, the largest and smallest 1% data were extracted and averaged separately to obtain NDVI min and NDVI max of 0.0221 and 0.8811, respectively. They were used to represent NDVI soil and NDVI veg, respectively. Finally, we used the process of sliding smoothing which is averaging the data before and after the singular value, for proxying of extreme singular values.

For the downloaded raw NPP data, the same region clipping, cloud mask and sliding window averaging as for NDVI were used to obtain more accurate and valid data. Finally, median sliding smoothing was performed, which is the median value taken from data in a month, for replacing the extreme singular values. This is because the use of the mean value is more likely to be influenced by singular values, whereas the median value gives a more reasonable result.

3 Result

The result shows that the multi-year average VFC in Fuzhou City is 68%, showing a significant increasing trend. VFC is relatively low in the districts and county-level city, while relatively high in the county. It shows a growth trend in most regions for

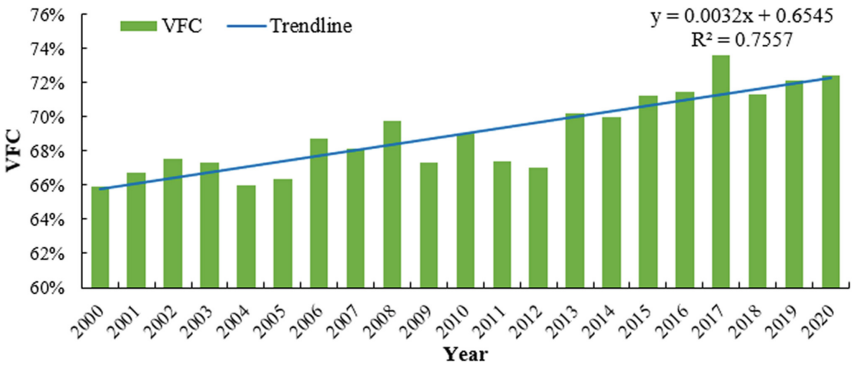

Fig. 3. Timing variation of VFC from 2000 to 2020.

the statistics of administrative divisions. The multi-year average NPP of 14.6×10^3 kg $C \cdot m^{-2} \cdot yr^{-1}$ is relatively stable, showing a slightly increasing trend. NPP shows similar spatial pattern to VFC. It has remained relatively stable in most regions with small variations. The distribution of VFC and NPP shows consistency with the distribution of land cover types (Fig. 2). The overall vegetation cover of the area is high and plants showed continuously carbon sequestration at a high level.

3.1 High and Significant Increase in VFC

The temporal changes and spatial distribution of VFC are shown in Figs. 3 and 4. The result shows that the VFC increased significantly in the 20 years since 2000, with a total increase of 6.54% and an average annual increase of about 0.32%. Among them, the lowest and highest VFC were 66.01% in 2004 and 73.60% in 2017, respectively.

The spatial distribution shows that 60% of the area with VFC above 70%, mainly located in the northern, southern and western principal urban inland areas. The areas with less than 50% VFC account for about 14% of the total area, mainly in the riverine and eastern coastal areas. In general, VFC is low in urban and coastal areas and high for other areas. It can be seen that VFC is lower in areas with more abundant human activities.

The overall VFC in Fuzhou is likely to continue to grow in the future as the emphasis on the environment grows and the introduction of environmental policies. However, with urban expansion and the development of coastal areas, VFC in these areas is likely to continue to decline.

3.2 NPP is Stable for Vegetation Carbon Sequestration

NPP indicates carbon sequestration with value greater than 0. It does not show a significant increasing trend like VFC. Even, NPP is stable at a high level that indicate the plant is in good growth condition for carbon sequestration.

The temporal variation and spatial distribution of NPP are shown in Figs. 5 and 6 respectively. The result shows that over the 20 years starting from 2000, NPP fluctuated

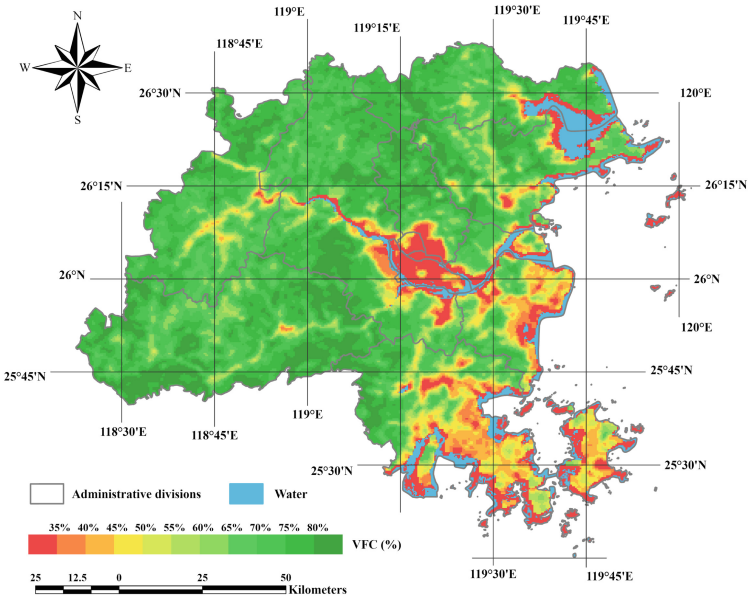

Fig. 4. Total average spatial distribution of VFC from 2000 to 2020.

but was relatively stable, with no significant increasing or decreasing trend, ranging from about $14.6 \pm 1.0 \times 10^3$ kg C·m^{-2}·yr^{-1}. Among them, the highest NPP was in 2003, at 16.8×10^3 kg C·m^{-2}·yr^{-1}. It may be due to the severe impact of meteorological hazards including cold wave, high temperature and typhoon in Fuzhou in 2015 [14].

The spatial distribution shows that about 38% of the area in Fuzhou City has NPP above 14.0×10^3 kg C·m^{-2}·yr^{-1}, mainly in the northern and southern areas, while the area below 8.0×10^3 kg C·m^{-2}·yr^{-1} accounts for about 10% of the total area, mainly in the urban areas along the rivers and the eastern coast. NPP is lower in urban areas and coastal regions, but higher in areas away from cities. It shows a high consistency with VFC and land cover distribution.

It can be predicted that Fuzhou City will continue to maintain an overall stable and minor increase in NPP at a high level in the future. Also, the vegetation will be continually working in carbon sequestration. However, the expansion of urban areas and the development of coastal areas may cause a continued decline in NPP in these areas.

3.3 Different Variations from Statistics in Districts and Counties

The counties generally have a higher VFC than districts and county-level city (Table 1). Among them, Yongtai county has the highest VFC with 74.80%. Taijiang district, on the other hand, has the lowest VFC at 23.59%. The overall VFC all showed an increasing trend, with only Cangshan and Changle districts decreasing over the 20 years, which may be affected by urbanization.

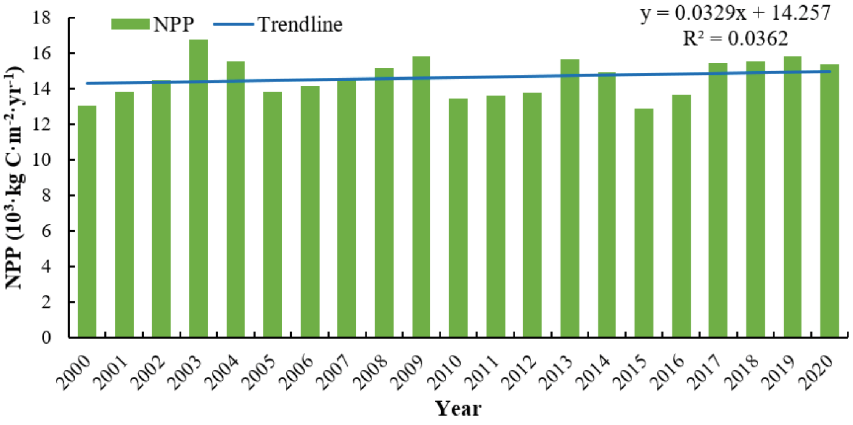

Fig. 5. Timing variation of NPP from 2000 to 2020.

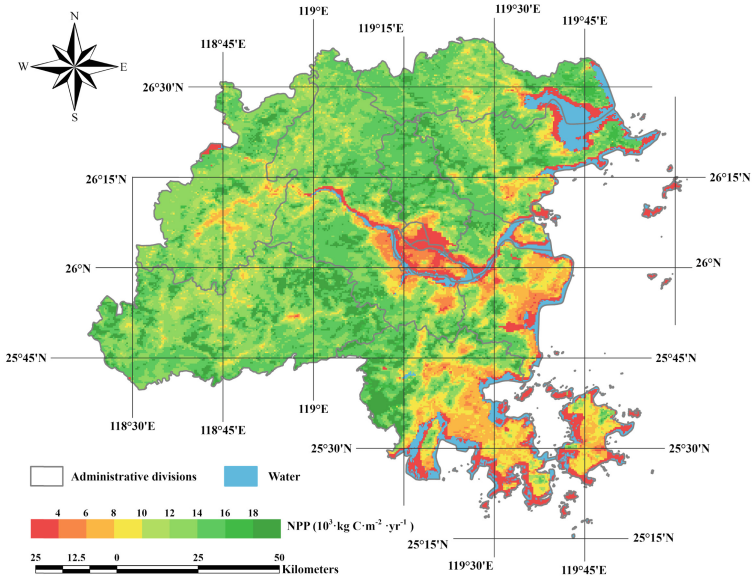

Fig. 6. Total average spatial distribution of NPP from 2000 to 2020.

In addition, NPP of counties are generally higher than districts and county-level city areas. Among them, Jin'an district has the highest NPP at 14.6 × 10^3 kg C·m^{-2}·yr^{-1}, while the NPP in Taijiang district is also the lowest at 2.8 × 10^3 kg C·m^{-2}·yr^{-1}. The overall change in NPP over the 20 years is small, mostly slight or largely unchanged, with only Cangshan district showing a significant decline.

In general, VFC and NPP are higher in the counties and lower in the districts close to the cities. Among districts, Jin'an and Mawei districts have noteworthy high levels

Table 1. Total average VFC and NPP from 2000 to 2020 and trend in each administrative division of Fuzhou City.

Administrative divisions	VFC (%)		NPP (103·kg C·m-2·yr-1)	
	Average	Trend	Average	Trend
Fuqing	58.80%	G	11.6	U
Cangshan	32.87%	SD	5.2	SD
Gulou	34.93%	SG	7.2	MG
Jin'an	70.78%	G	14.6	MD
Taijiang	23.59%	SG	2.8	MG
Changle	54.73%	MD	10.2	MD
Mawei	63.75%	G	12.5	MD
Lianjiang	68.24%	G	13.4	MD
Luoyuan	72.57%	G	13.7	MD
Minhou	70.19%	G	13.0	MD
Minqing	71.32%	SG	12.8	U
Pingtan	47.05%	U	8.7	MG
Yongtai	74.80%	SG	14.2	MD

Note: G = Growth, SG = Significant Growth, MG = Minor Growth, U = Almost Unchanged, D = Decline, SD = Significant Decline, MD = Minor Decline

of VFC and NPP, while these two districts are also relatively far from the urban centers. While among counties, the two figures for Pingtan county are significantly lower than other counties, which may be influenced by its geographical location (island) and tourism.

4 Discussion and Conclusion

The study found that the ecological quality of vegetation in Fuzhou City is high but unevenly distributed. The multi-year average VFC in Fuzhou City is 68%, showing a significant growth trend with an average growth rate of 0.32% yr^{-1}. The multi-year average NPP is 14.6 × 10^3 kg $C{\cdot}m^{-2}{\cdot}yr^{-1}$ and continues to fluctuate steadily, accompanied by a slightly increasing trend. VFC and NPP are relatively low in districts and county-level city, but relatively high in counties. The overall distribution shows a high consistency with land cover types.

The study in this paper found that VFC in Fuzhou City shows an increasing trend, which is consistent with the provincial and national research results [6, 15]. The continuous and stable photosynthetic carbon sequestration (NPP) of vegetation is one of the reasons for the growth of VFC. Meanwhile, the impact of cities on vegetation coverage is reflected in two aspects. Total vegetation coverage was increased due to the implementation of environmental protection and greening policies. However, in some urban

areas, vegetation coverage has decreased due to the influence of urban development. This phenomenon is consistent with the findings of studies on the effects of urban development on vegetation change [15]. How to protect and develop regional forest cover while developing cities is a direction for further research.

As for the spatial distribution, vegetation coverage increases with decreasing urbanization levels, which is consistent with the national distribution [15]. The VFC is relatively low in areas close to water bodies and NPP showed a similar distribution. In general, the VFC and NPP are much higher in the inland counties than in the districts of urban areas and coastal areas. In addition, this paper only shows the results of the changes in VFC and NPP and does not explore the driving factors in depth. However, according to existing studies, vegetation is correlated with various factors such as temperature, precipitation, sunshine and human activities [1, 13, 16]. In contrast, Fuzhou may be mainly influenced by precipitation and human activities.

In this study, NDVI and NPP data were used to assess the regional ecological environment of Fuzhou City in terms of vegetation coverage and carbon sequestration. The methodology of this study is generalizable and can reflect the ecological changes in the region, serving as a basis for regional vegetation ecology researches.

References

1. Gu, Z., Duan, X., Shi Y., Li, Y., Pan, X. (2018) Spatiotemporal variation in vegetation coverage and its response to climatic factors in the Red River Basin, China. Ecological Indicators, 93: 54–64.
2. Pan, Q., Zheng, H., Wang, Z., Wen, Z., Yang, Y. (2021) Effects of plant functional traits on ecosystem services: a review. Chinese Journal of Plant Ecology, 45(10): 1–15.
3. Zheng, K., Wei, J., Pei, J., Cheng, H., Zhang, X., Huang, F., Li, F., Ye, J. (2019) Impacts of climate change and human activities on grassland vegetation variation in the Chinese Loess Plateau. Science of the Total Environment, 660: 236–244.
4. Huang, L., Tian, P., Shuai, S., Liao, Y., Liu, Y. (2018) Analysis of Eco - Environment quality variation of vegetation in Chishui river basin from 2000 to 2016. Mid - low Latitude Mountain Meteorology, 42(5): 20–24.
5. Ma, Q., Long, Y., Jia, X., Wang, H., Li, Y. (2019) Vegetation response to climatic variation and human activities on the Ordos Plateau from 2000 to 2016. Environmental Earth Sciences, 78: 709.
6. Li, Y., Wang, X., Chen, Y., Wang, M. (2019) Land surface temperature variations and their relationship to fractional vegetation coverage in subtropical regions: A case study in Fujian Province, China. International Journal of Remote Sensing, 41(6): 2081–2097.
7. Yang, H., Xu, H. (2020) Assessing fractional vegetation cover changes and ecological quality of the Wuyi Mountain National Nature Reserve based on remote sensing spatial information. Chinese Journal of Applied Ecology, 31(2): 533–542.
8. Zhou, R., Lin, S. (2021) Exploration and practice of promoting ecological civilization in Fuzhou. Journal of Fuzhou Party School, 1: 60–64.
9. Zheng, Z., (2021) The Development of Xi Jinping's Thought on Ecological Civilization and its Evolutionary Logic. Journal of Central South University of Forestry & Technology (Social Sciences), 15(2): 1–7+13.
10. Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., Ferreira, L.G. (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sensing of Environment, 83: 195–213.

11. Wang, L., Niu, Z., Kuang, D. (2010) Analysis of China's terrestrial NPP from 2002 to 2006 based on MODIS data. Remote Sensing for Land & Resources, 4:113–116.
12. Heinsch, F.A., Reeves, M., Kang, S., Milesi, C., Zhao, M., Glassy, J., Jolly, W.M., Loehman, R., Bowker, C.F., Kimball, J.S., Nemani, R.R., Running, S.W. (2003) User's Guide GPP and NPP (MOD17A2/A3) Products NASA MODIS Land Algorithm.
13. Zhang, Y., Li, L., Wang, H., Zhang, Y., Wang, N., Chen, J. (2017) Land surface phenology of Northeast China during 2000–2015: temporal changes and relationships with climate changes. Environmental Monitoring and Assessment, 189: 531.
14. Ma, Z., Peng, J., Li, L., Duan, Z., Yang, K., Lin, J. (2016) Analysis of climate characteristics and agricultural meteorological disasters in the winter of 2015 - 2016 in Fujian Province. Subtropical Agriculture Research, 12(2): 108–112.
15. Yang, K., Sun, W.Z., Luo, Y., Zhao, L., (2021) Impact of urban expansion on vegetation: The case of China (2000–2018). Journal of Environmental Management, 291: 112598.
16. He, Z., Zhang, Y., He, Y., Zhang, X., Cai, J., Lei, L. (2020) Trends of vegetation change and driving factor analysis in recent 20 years over Zhejiang province. Ecology and Environmental Sciences, 29(8): 1530–1539.