

# Evaluate the spatio-temporal changes of vegetation and human activities in China's Wulingyuan Natural World Heritage Site

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**Abstract.** The Wulingyuan area, in Zhangjiajie, China, is a world natural heritage site famous for quartz sand and rock peak landscape. The assessment of vegetation dynamics and human activities are conducive to protecting the heritage value and to formulating sustainable development plans. Here, we use long-term MODIS data to quantify the spatiotemporal changes of vegetation and the response to environmental variables through three NDVI processing methods. We also analyze human activities and policy changes. The results indicated the following. (i) The vegetation in Wu has been in good condition on average for the past 18 years, with a high vegetation index and high vegetation productivity. (ii) The vegetation in Wu and each subarea shows an overall improvement trend, 71.00% (60.03%, 46.80%), and shows an increase in AM-NDVI (SG-NDVI and STI). Spatially, the vegetation increase area is mainly located in the buffer area, and a very small vegetation decrease area is in the development region. (iii) There are correlations between vegetation and temperature and precipitation, but neither of them passed the significance test. (iv) To comply with the World Heritage Convention, establishing national scenic areas and supplementing woodland protection planning may be the key policies having a positive effect on the vegetation change.

## 1 INTRODUCTION

Natural World Heritage Sites (NWHS), via their formal designation through the United Nations, are globally recognized as containing some of the Earth's most valuable natural assets. Understanding changes in their ecological condition is essential for their ongoing preservation<sup>[1]</sup>. The Wulingyuan (Wu) area, in Zhangjiajie, Hunan Province, is not only a national scenic spot in China but also a world natural heritage site famous for its quartz sand and rock peak forest landscape. Geomorphologic landscapes, diverse ecological systems and rare animal and plant resources give Wu unique aesthetic and biodiversity value. In recent years, with the rapid development of tourism, human activities have been affecting nature profoundly. Therefore, an understanding of how to scientifically protect and rationally utilize its natural heritage is an important subject for Wu.

As a kind of resource, a plant landscape is an indispensable carrier of a heritage sites' value. Vegetation, as a macroscopic form of plant landscape, not only closely combines with geology and topography to present landscape aesthetics but also reflects the authenticity and ecological integrity of a heritage site. To understand the historical dynamic changes of the vegetation in the region is of great significance to the protection and cultivation of plant resources and sustainable development, the improvement of

management systems and the planning of scenic spots in the future.

Current monitoring of NWHS is summarised in site-level reports and surveys. This includes periodic reporting on progress and condition by States Parties on a 6-year regional cycle, reactive monitoring led by UNESCO and the Advisory Bodies in response to current issues, and site-level monitoring and evaluation systems<sup>[2]</sup> Satellite remote sensing provides the best practical means to monitor vegetation dynamics at both regional and global scales<sup>[3-6]</sup>. NDVI is widely recognized as an effective index to use to monitor regional and global vegetation changes, because it can compensate for changes caused by differences in lighting conditions, soil color, slope, and observational orientation<sup>[7]</sup>. By using vegetation index, scholars have done a great deal of research on the dynamic change of regional vegetation and its influencing factors, with most of them focusing on large scale areas significantly affected by climate change and other factors<sup>[8-11]</sup>. However, there are few studies on the temporal-spatial dynamic changes of vegetation across natural reserves<sup>[12]</sup>, scenic areas, and heritage sites. Driving factors of vegetation change include climate, human activities and so on. Temperature and precipitation are considered as important climate factors affecting vegetation growth and distribution<sup>[13, 14]</sup>, while human factors mainly involve urban expansion, and are measured by the proportion of impervious surface<sup>[15]</sup> and to a lesser extent combined with specific policies and human behavior. More

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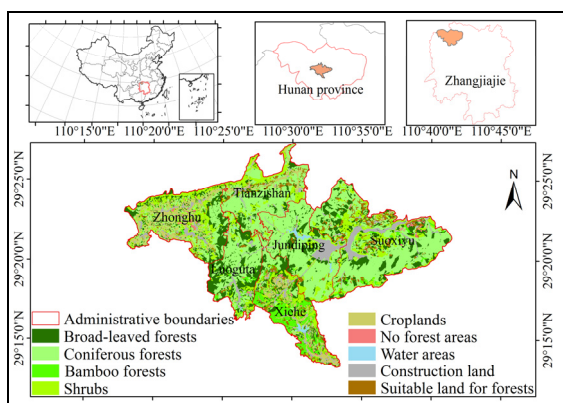
comprehensive indicators of human pressure on the environment need to be developed and applied, and more reasonable assessments of the impact of changes in human activities on sustainable development of heritage sites need to be performed. Trend analysis of vegetation functioning and human pressure is central to understand the environmental dynamics associated to global change, and requires new and improved tools to assess dynamic processes associated to spatial patterns in a cost effective manner<sup>[16]</sup>.

Here, using a long-term remotely sensed normalized difference vegetation index (NDVI) dataset, we quantified the vegetation changes and performed an evaluation from different subareas in Wu over the last two decades (2001–2018) in three ways: the annual mean NDVI (AM-NDVI), the growing season mean NDVI (SM-NDVI) and the seasonal total integral (STI). We then used the human footprint data to assist in the analysis of human activities, and explore the possibility of impacts of human activities and policy changes on vegetation.

## 2 Materials and methods

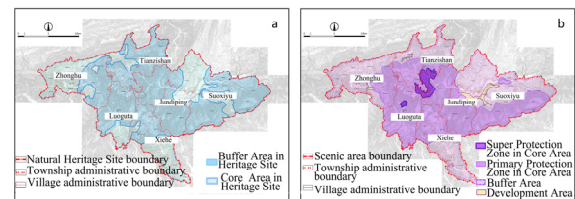
### 2.1. Study Area

Wu is located in the northwest of Hunan Province (110° 20' 30"E-110° 41' 15"E, 29°16' 25"N-29° 24' 25"N) and covers an area of approximately 397 square kilometers (Fig. 1). It is a world natural heritage site featured by the world's most rare quartz sand rock peak forest landscape. The terrain is generally high in the northwest and low in the southeast, with the mountainous portion accounting for 76% of the total area. The region has a typical subtropical mountain archetype monsoon humid climate, with obvious diversity and vertical differences. The annual average frost-free period is 274.6 days, and average annual precipitation ranges from 1380.0 - 1450.0 mm. The types of land cover mainly include trees, shrubs, cultivated land, water areas and construction land. The natural heritage area is rich in plant diversity, with an obvious vertical band spectrum of plants, complete community structure and stable ecosystem.



**Fig. 1.** Location and land cover type of Wulingyuan area (2015) (Data source: the survey data of Wu forest planning).

In 1988, Wu was rated as a national scenic spot. In 1992, it was listed on the world natural heritage list by UNESCO and became one of China's first three world natural heritage sites. The core area and buffer area of the heritage site are shown in Fig. 2-a. In 2004, it was awarded the title of "world geological park", which was one of the first parks selected by China in 2004. In 2005, the overall planning of Wu scenic spot (2005-2020) was revised and compiled by Peking University, and four scenic areas were defined in the plan: the Super Protection Zone in the Core Area and the Primary Protection Zone in the Core Area, Buffer Area and Development Area (Fig. 2-b).



**Fig. 2.** Core area and buffer zone area of Wu world natural heritage (1992) (a) the overall planning of Wu scenic spot (2005-2020) partition scope (b). (Reference data: scenic and historic interest area world natural heritage core area and buffer area scope map of Wu world natural heritage site (1992), the overall planning of Wu scenic spot (2005-2020), administrative zoning map of Wu area (2017), topography map of Wu area(2017)).

### 2.2 Data collection

We used 16-day composites (MOD13Q1) Normalized Difference Vegetation Index (NDVI) estimated from Moderate Resolution Imaging Spectroradiometer (MODIS) images from 2001 to 2018 to describe temporal patterns of vegetation in Wu. The spatial resolution is 250 × 250 m and the time interval is 16 days. Albers projection is adopted and the coordinate system is Xian-80. Data is from NASA's website ( <http://ladsweb.nascom.nasa.gov/> ). MODIS, an optical sensor on Terra and Aqua satellites, is part of NASA's earth observation system and has the advantages of high spatial and spectral resolution compared to NOAA and landsat satellites.

To measure human pressure on the natural environment we used the recently updated Human Footprint<sup>[17, 18]</sup>, which is a globally-standardised measure of cumulative human pressure on the terrestrial environment. At a 1km<sup>2</sup> resolution, the Human Footprint includes global data on: built environments, crop lands, pasture lands, population density, night lights, railways, major roadways and navigable waterways. This makes the Human Footprint the most comprehensive cumulative threat map available<sup>[19]</sup>. Still, it is important to note that it does not include data on all the possible threats and pressures facing NWHS. Other threats, including invasive species<sup>[20]</sup>, overabundant species<sup>[21]</sup>, wildlife poaching<sup>[22,23]</sup>, tourism pressure<sup>[24]</sup>, and rapid climate change<sup>[25]</sup>, are not directly accounted for in the Human Footprint data.

Meteorological data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn>). The boundary data of Wu area scenic spot and heritage site were obtained from the overall planning of Wu scenic spot (2005-2020).

## 2.3 Data analysis

### 2.3.1 NDVI processing methods

For every year studied, three processing methods were used to estimate vegetation quality from 23 composite images of NDVI with values rescaled from 0 to 1: the annual mean NDVI (AM-NDVI), the growing season mean NDVI (SM-NDVI) and the seasonal total integral (STI). The annual mean NDVI refers to the average value of 23 NDVI images per year; the growing season mean NDVI refers to the average value of 18 images taken between March 6 and December 3 (the growing season) per year; the seasonal total integral refers to the use of Timesat software<sup>[26]</sup> to estimate vegetation phenology. Timesat software (<http://www.nateko.lu.se/TIMESAT/timesat.asp>) provides Savitzky–Golay filtering, asymmetric Gaussian fitting, and double-logistic fitting to reconstruct time series datasets and extract phenological information on vegetation growth<sup>[27]</sup>. TIMESAT quantifies phenological signals from time series of satellite data, adjusts local functions for each point and combines these functions in a model of phenological patterns<sup>[16]</sup>. Although smoothing methods applied to satellite NDVI could generally capture vegetation phenology, no method was universally better than the others<sup>[28]</sup>. In this study, we adopted the asymmetric Gaussian fitting method to extract the total seasonal integral (STI), which can be used as an index to measure the annual dynamics of vegetation in the growth season and reflect the level of photosynthetic productivity.

### 2.3.2 Spatio-temporal variations vegetation analysis

The linear regression method was used to determine the trend of the spatially averaged NDVI in the Wu. An F test was used to examine the statistical significance of the trends.

The nonparametric Mann-Kendall (M-K) test<sup>[29, 30]</sup> was used to determine the trends and to quantify their statistical significance at the pixel scale. According to the Z-values from M-K test, the NDVI pixels were divided into seven classes: significant decrease (Z-value < -2.32, with  $p < 0.01$ ); medium decrease (Z-value < -1.96, with  $p < 0.05$ ); decrease (Z-value < 1.65, with  $p < 0.1$ ); not significant ( $|Z\text{-value}| < 1.65$ ); increase (Z-value > 1.65, with  $p < 0.1$ ); medium increase (Z-value > 1.96, with  $p < 0.05$ ); and significant increase (Z-value > 2.32, with  $p < 0.01$ )<sup>[8, 31]</sup>. The statistics was quantified and the vegetation spatial variation was analyzed. Next, every pixel was assigned to one of the four protection levels of the scenic spot: (1) Super protection zone in the core area; (2) Primary protection zone in the core area; (3)

buffer zone; (4) development area, as well as one of the Wu natural heritage sites: (1) core area; (2) buffer area. Pixels were clumped depending on the partition of scenic spots and natural heritage sites, and the change slopes statistic in different partitions was counted and then the proportion of protection area of each scenic spot classified by different vegetation changes was calculated.

### 2.3.3 The response of vegetation cover to climatic factors

To discuss the dynamic response of vegetation to climate change, we calculated the partial correlation coefficient between AM-NDVI and the climatic variables (average annual temperature and annual precipitation) for each pixel from 2001 to 2015, and carried out a significance test. A regional discussion was conducted according to the positive and negative correlation of vegetation with temperature and precipitation.

### 2.3.4 Human activity

Here, we use Human Footprint data from 1994 to 2010 to help understand human pressure changes in the Wu area and analyze the possibility of impacts of human activities and policy changes on vegetation and the environment.

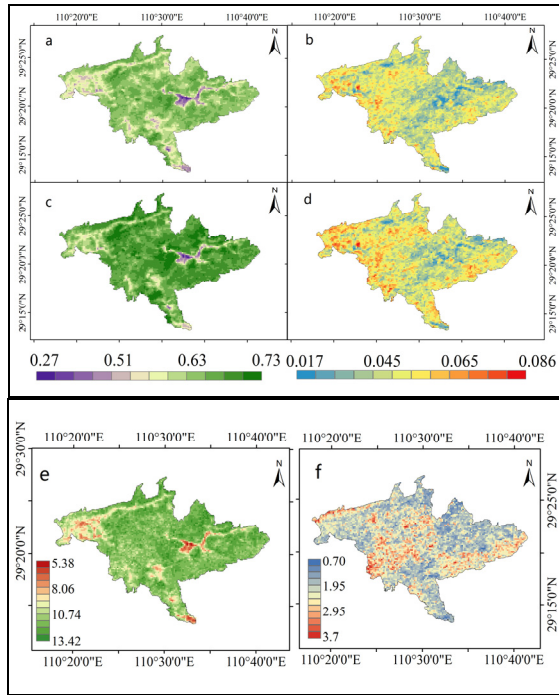
## 3 Results

### 3.1 Three vegetation processing method

From the 18-year average values of the AM-NDVI, SM-NDVI and STI from 2001 to 2018 (Fig. 3-a,b, c), we can see that the vegetation in Wu is in good condition on average for these 18 years, with high vegetation index and high vegetation productivity. Spatially, the vegetation in the core area of Wu is relatively good as the climate in these areas is humid with sufficient precipitation, and the vegetation type is mostly arbor forest. In contrast, the vegetation in Zhonghu village and Xiehe village located in the buffer zone is inferior. However, the vegetation of the Jundiping community in the development area is poor, the land use type of which is mainly urban with high development intensity and less vegetation cover. Among the three vegetation processing methods, the AM-NDVI and GS-NDVI respectively ranged from 0.27 to 0.68, and from 0.3 to 0.72, while the STI ranged from 5.39 to 13.41. The GS-NDVI is slightly higher than AM-NDVI, which conforms to the characteristics of vegetation growth.

As the SD distribution of the AM-NDVI (Fig. 3-d), SM-NDVI (Fig. 3-e) and STI (Fig. 3-f), the spatial variation of vegetation in Wu is greater among the three patterns methods, and the variability degree in the central and eastern zoon is greater than that in the northwest (Zhonghu township, Yangjiajie forest park) and the southwest (Zhangjiajie forest park), which is consistent with the land use type (Fig. 1). Compared with shrubs and construction land, croplands, broad-

leaved forest and coniferous and broad-leaved mixed areas show greater interannual variability. The variation degree of SM-NDVI was slightly greater than that in the GS-NDVI. According to the SD distribution of STI (Fig. 3-f), the interannual fluctuation of vegetation in Zhangjiajie forest park and other places was the strongest, indicating that NDVI in the growth season could better capture the interannual fluctuation of vegetation than that of the annual fluctuation, as the species in Zhangjiajie forest park and other places were abundant and presented stronger interannual variation.



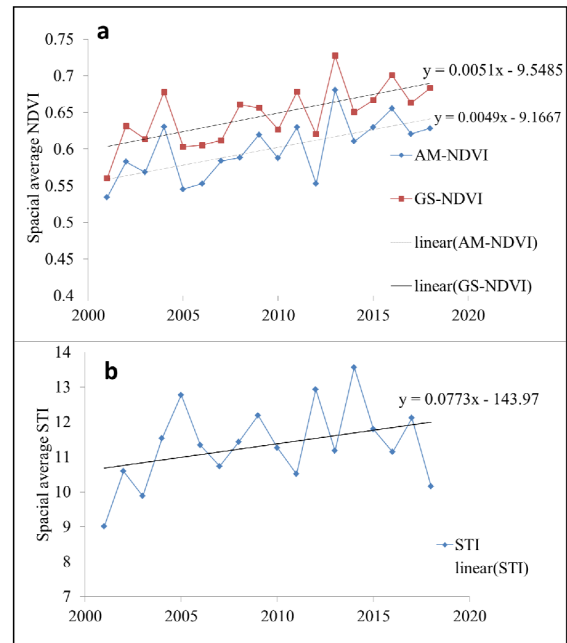
**Fig. 3.** The spatial distributions of the 18-year average values and the SD of the AM-NDVI (a,b), SM-NDVI (c,d) and STI (e,f).

### 3.2 Spatio-temporal variations of vegetation in Wu

#### 3.2.1 Temporal variations of vegetation

The temporal variations of vegetation are shown in Fig. 4, which indicates that the interannual change of vegetation in Wu from 2001 to 2018 is obvious and shows an overall growth trend, among which the productivity of vegetation increased from 2001 to 2015. Linear trend analysis shows that the spatial means of the AM-NDVI and GS-NDVI are significantly positively correlated with time ( $p < 0.05$ ), and the slope is  $4.9 \times 10^{-3}$  and  $5.1 \times 10^{-3}$ /year. Each area class of natural heritage sites and scenic spots are also significantly positively correlated with time ( $p < 0.05$ ). The spatial mean of STI in Wu was not significantly positively correlated from 2001 to 2018 but was significantly positively correlated with the period from 2001 to 2015 ( $p < 0.05$ ), and the slope was 0.16/year. Except for the primary protection zone in the core area ( $p < 0.05$ ), other areas are significantly positively correlated with time ( $p > 0.05$ ).

From 2001 to 2018, especially from 2001 to 2015, the vegetation in the Wu area and each subarea showed an overall improvement trend, and the vegetation enhancement was significant.



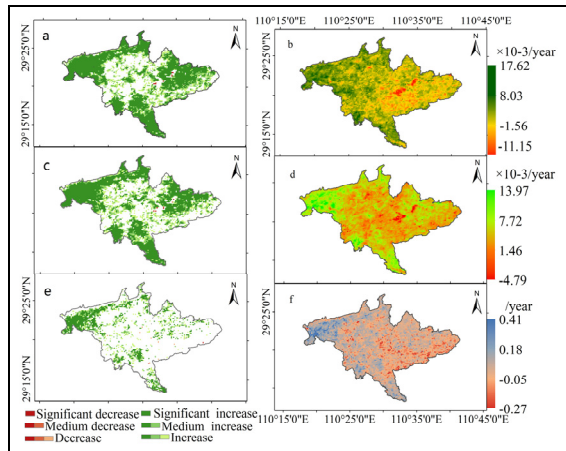
**Fig. 4.** The time trend of mean value of annual AM-NDVI spatial mean and GS-NDVI spatial mean (a) and STI spatial mean (b) in Wu area.

According to the survey data of forest resources, compared with 2004, Wu progressed through nearly a decade of artificial afforestation, afforestation, forest management and use measures such as cutting, to realize a forestland area of 4719.6 hectares in 2014 (19%) and forest growing stock increase of 952810 m<sup>3</sup> (46.8%); the forest coverage rate increased from 74.75% to 84.55%, up 9.8%, and tree coverage from 78.58% to 85%, up 6.42%. The results of this paper are consistent with the forest resources survey data, which indicate that the measures of mountain closure and forest cultivation have achieved obvious results and the regional forest vegetation changed significantly.

#### 3.2.2 Spatial variation of vegetation

The M-K test (Fig. 5) shows that the buffer area has increased significantly, and areas where vegetation shows a decreasing trend are very small. Among the three methods, 71.00% (67.20%, 26.77%), 60.03% (55.44%, 19.59%), and 46.80% (42.75%, 12.97%) of regions showed an increase, medium increase, and significant increase in AM-NDVI (GS-NDVI and STI). However, only 0.17% (0.13%, 0.16%), 0.17% (0.11%, 0.03%), and 0.13% (0.08%, 0%) of regions showed a decrease, medium decrease, and significant decrease in AM-NDVI (GS-NDVI, STI). Among three models, AM-NDVI (Fig. 5-a) and GS-NDVI (Fig. 5-b) showed the increase area is larger, while the STI (Fig. 5-c) is small. The AM-NDVI and GS-NDVI variation range from  $11.15 \times 10^{-3}$  / year to  $17.62 \times 10^{-3}$  / year, from  $4.79 \times 10^{-3}$  to

13.97×10<sup>-3</sup>/year, and STI range from 0.27 to 0.47 / year. The variation range of AM-NDVI is greater than that of GS-NDVI, and combining the reality of Wu, AM-NDVI and STI can better reflect the real situation of interannual changes of vegetation.

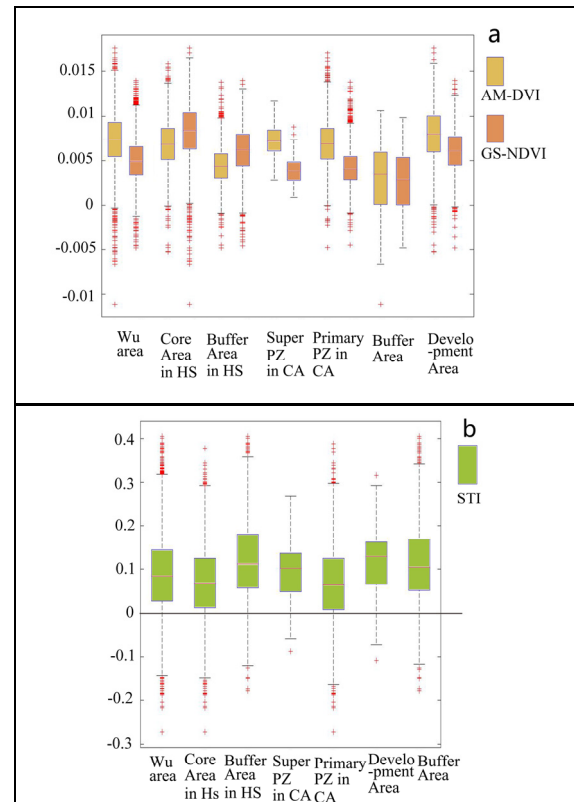


**Fig. 5.** Spatial distribution of vegetation change classes and change slope in Wu from 2001 to 2018 obtained by three methods.

The statistics of vegetation slope in different districts (Fig. 6) revealed that the vegetation in each zone showed an overall trend of enhancement. Statistics of vegetation change classes (table 1), the area where AM-NDVI (GS-NDVI, STI) in the core area and buffer area in heritage site, super protection zone in the core area, primary protection zone in the core area, buffer area and development area in the scenic spot significantly increased, accounting for 34.72% (70.79%, 30.79%), 66.57% (7.28%, 23.99%), 33.71% (11.6%, 0%), 25.7% (22.5%, 6.2%), 74.5% (68.8%, 21.2%), and 37.5% (38.4%, 22.3%), and a moderate increase of 25.2% (27.7%, 4.5%), 41.6% (36.6%, 10.9%), 84.5% (79.9%, 30.2%), and 46.4% (48.2%, 33.0%). Spatially the vegetation increasing area is mainly located in the buffer area in the scenic spot, followed by the primary protection zone and super protection zone in core area, and a very small vegetation decrease area is located in the development area such as the Jundiping community, and the AM-NDVI and GS-NDVI in the core area and buffer area of the heritage site increases more than the STI.

In 2005, the heritage protection and landscape conservation planning components of the overall planning of the Wu scenic spot scenic area were implemented to clear all permitted and prohibited projects in different subarea; they put forward the maintenance of natural vegetation through natural recovery and natural regeneration and increasing the evergreen-broadleaf mixed forest area, which provides a variety of biological habitats and other measures to protect and restore natural vegetation and landscapes. This may be the reason why the vegetation in the core remained stable and the enhancement was not significant. The woodland protection and utilization plan of the Wu area (2010-2020), in 2010 proposed that local government and relevant departments strictly control the

use of woodlands, carry out afforestation and forest quality projects and other measures, with an expectation to achieve moderate increase of woodland areas, continuous forest area growth and substantial improvement of woodland productivity. The artificial forest in Wu is mainly located in the buffer zone, which may be one of the reasons for the remarkable restoration and enhancement of vegetation there.



**Fig. 6.** Statistical box chart of change slope of AM-NDVI and GS-NDVI(a) and STI(b) in Wulingyuan area and each partition.

**Table. 1.** Statistical table of vegetation change classes in three methods.

	The proportion	Significant increase (%)	Medium decrease (%)	Increase (%)	Decrease (%)	Medium decrease (%)	Significant decrease (%)
Super PZ in CA	1	7.10	25.16	37.42	0.00	0.00	0.00
	2	11.61	27.74	42.58	0.00	0.00	0.00
	3	0.00	4.52	0.65	0.00	0.00	0.00
Primary PZ in CA	1	25.70	41.60	56.39	0.09	0.09	0.09
	2	22.46	36.57	51.81	0.09	0.06	0.06
	3	6.20	10.90	16.74	0.24	0.03	0.00
Buffer Area	1	74.51	84.49	91.01	0.04	0.04	0.04
	2	68.79	79.94	87.48	0.04	0.04	0.04
	3	21.19	30.15	0.07	0.07	0.04	0.00
Development Area	1	37.50	46.43	50.00	7.14	7.14	4.46
	2	38.39	48.21	52.68	4.46	4.46	2.68
	3	22.32	33.04	50.00	0.00	0.00	0.00
Core Area in HS	1	34.72	49.74	62.36	0.09	0.09	0.07
	2	30.79	44.40	58.35	0.07	0.05	0.05
	3	7.28	12.33	18.36	0.19	0.02	0.00
Buffer Area	1	70.79	80.51	88.17	0.34	0.34	0.24

r area	2	66.57	77.35	84.91	0.24	0.24	0.14
in Hs	3	23.99	33.67	42.86	0.10	0.05	0.00

(Note: 1,2,3 respectively represent AM-NDVI,GS-NDVI and STL.)

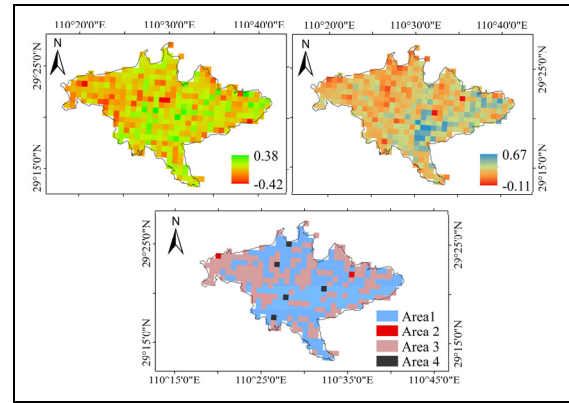
### 3.3 Responses of NDVI to climate-related variables

According to the partial correlation coefficient between average annual temperature and average annual precipitation from 2001 to 2014 (Fig. 6), the partial correlation coefficient between average annual temperature and average annual NDVI ranged from -0.41 to 0.38 (Fig. 6-a), and the partial correlation coefficient between annual precipitation and NDVI ranged from -0.11 to 0.67 (Fig. 6-b), neither of which passed the significance test. According to these statistics, the area vegetation in positive correlation with average annual temperature accounted for 98.24%, and the area in positive correlation with annual precipitation accounted for 55.78%.

Spatial heterogeneity of vegetation response to temperature and precipitation is stronger. Different regions show different dynamic responses (Fig. 7), and can be divided into two main areas: (i) The annual NDVI is in positive partial correlation with both the annual average temperature and precipitation, and the correlation is higher. It accounts for 54.52% and is mainly in high altitude areas, composed of mainly shrub and coniferous forest, with low temperature and minimal human activities, so vegetation growth is greatly affected by climate. (ii) The annual NDVI is in positive partial correlation with the annual average temperature and negative correlation with precipitation, and the correlation is lower. It accounted for 43.72% and is mainly in the northwest and high mountains. For one thing, the main land use types are urban or irrigated farmland, and most vegetation is crops. In the growing season of crops, groundwater is mainly used for irrigation, resulting in a weak correlation between vegetation cover and precipitation. In addition, most drought-tolerant plants, such as Wuling pines, are found in the area of rock peaks and pillars. Increasing precipitation will decrease the light conditions and weaken plant photosynthesis<sup>[32, 33]</sup>. In addition, there are a small number of areas with poor site conditions and large topographic fluctuation, in which an increase in precipitation will increase soil leaching, and natural disasters such as debris flows and landslides may occur, aggravating soil erosion and making precipitation negatively correlated with vegetation cover change.

**Table 2.** Response zones and statistics of mean annual NDVI to annual temperature and precipitation changes.

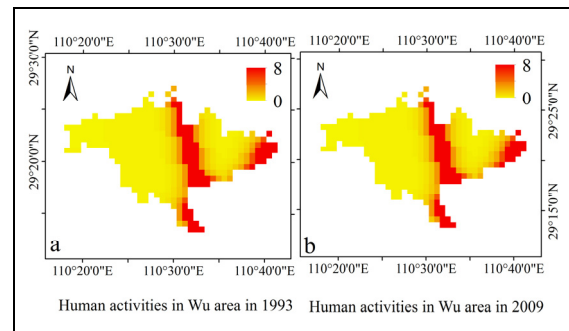
Partition	Temperature	Precipitation	Proportion (%)
partition 1	+	+	54.52%
partition 2	-	-	0.50%
partition 3	+	-	43.72%
partition 4	-	+	1.26%



**Fig. 7.** Partial correlation coefficient and response zoning diagram of average annual temperature, annual precipitation and average annual NDVI change from 2001 to 2015.

### 3.4 Human activity and policy

Human footprint data (Fig. 8) show that the human footprint index of Wu natural heritage site from 1993 to 2009 is very low, and there is no increasing trend, indicating that human activities had little negative impact on the heritage site from 1993 to 2009.



**Fig. 8.** Human activities in Wu area in 1993(a) and 2009(b).

Due to natural and human activity, the natural vegetation landscape is always in change. In nature, sandstone rock peaks and pillar group landforms are constantly subjected to slow weathering erosion, gravity collapse and water cutting deformation so that rock pillars, dykes, and mesas will decrease and lower day by day, and mountain torrents, freezing, fires, and pests cause varying degrees of damage to vegetation. In addition, the slow endogenous succession of vegetation is also an important factor. For human activities, deforestation accelerated in the 1960s. Human destruction was mainly caused by deforestation in the early 1960s. The existing trees in the natural heritage site are all artificial forests and secondary forests restored by nature after destruction, except those trees in stone pillars, rock-wall peaks, part of the tops of mesas and the barrier valley. At the same time, the development of tourism brings certain pressure to the environment, and human activities affect biodiversity. However, through dynamic evaluation of vegetation and analysis of human activities, it is shown that the human activities in the Wu natural heritage site are controlled at a lower level, and

the overall level of vegetation is high and shows an increasing trend with time.

To maintain the dynamic balance between tourism development and environmental protection, according to relevant international conventions and national laws and regulations, Wu has set up a special institution among natural heritage sites to monitor the quartz sandstone landscape, the number of tourists and their impact, air quality, water quality, environmental quality, electromagnetic radiation, noise, animal habitat and other aspects. In addition to routine protection and management measures, Wu also set a limit of 5.56 million visitors by 2020. These management measures are conducive to the sustainable development of heritage sites and scenic spots and the implementation of the world natural heritage convention. To comply with The World Heritage Convention, to establish Wu national scenic area, to delimit protection zones and to supplement and complete woodland protection planning may be the key policies having a positive effect on the vegetation change in Wu.

#### 4 Discussion and conclusion

In this paper, by using a long-term MODIS NDVI dataset, we monitored and evaluated vegetation from three processing methods: interannual, growing season (03/06-12/03) and seasonal total integral. Among them, interannual and growing season average or sum are commonly used vegetation index processing methods in existing studies, while STI has been used in relatively few studies. STI considers the interannual fluctuation and the seasonal fluctuation of vegetation activity, and the accumulation of photosynthetic activity as a kind of comprehensive measures to quantify<sup>[16]</sup>. In this paper, three NDVI models were used for evaluation and comparison, to make a more comprehensive and objective analysis of vegetation changes over the years. The vegetation change trend of the Wu area and each subarea in the most recent two decades was evaluated, and the spatial response of the climatic factors, temperature and precipitation to NDVI was analyzed by using the partial correlation coefficient. Finally, according to human activities and relevant policies the factors of vegetation change in Wu were analyzed. The results showed that:

i) The vegetation in Wu has been in good condition on average for these 18 years, with both high vegetation index and high vegetation productivity. The linear trend method shows that over nearly 20 years, vegetation increased significantly in Wu. These results were consistent with forest survey data and the previous studies of Liu<sup>[34]</sup> et al.

ii) The M-K test and spatial statistics show that the vegetation in many areas, especially the buffer area, has increased significantly, and areas where vegetation shows a decreasing trend are very small. The vegetation increase area is mainly located in the buffer area in the scenic spot, followed by the primary protection zone and super protection zone in the core area, and a very small portion is located in the development area such as

Jundiping community. Many studies<sup>[35-37]</sup> indicate that there have been alarming rates of forest loss in the buffer zones surrounding nationally designated protected areas over the last three decades. Fortunately, the situation in Wu is the opposite.

iii) There was positive correlation between vegetation and temperature, while either positive or negative correlation with precipitation, but the correlation was not significant. This paper only selects the data of annual precipitation and temperature. Analyses should also be conducted at the growing-season scale rather than only at the annual scale, since vegetation is more sensitive to changes of climate during the growing season than through the year as a whole<sup>[8]</sup>.

iv) Human footprint analysis indicates that human activities had little impact on the heritage site from 1993 to 2009. Considering the actual management and protection situation of Wu, we believe that to comply with The World Heritage Convention, to establish Wu national scenic area, to delimit protection zones and to supplement and complete woodland protection planning may be the key policies and projects having positive effects on the vegetation change in Wu. Currently studies applying the dynamic monitoring of vegetation to scenic spots and natural heritage sites are few, as the scenic area is relatively small, and remote sensing images are more suitable for larger regional and global area. The remote sensing data used in this study is 250 m, and some details may be ignored in the analysis. There are also limitations with satellite-derived estimates of global forest change; for example, it is impossible to infer the causes of forest loss without the use of site-level data<sup>[1]</sup>. In addition, human footprint data need to be updated to help analyze human activity over the last decade.

Despite the complexity of NDVI index interpretation and the limitations of seasonal integral processing, this paper applies it to the Wu area and conducts different subarea analyses. Meanwhile, we combine the latest human footprint data, local actual policies and human actions to analyze the changes in the ecological environment of Wu. The results are helpful to understand the changes of vegetation in Wu in the past 20 years; provide scientific guidance for vegetation detection, protection and conservation in scenic areas; and provide reference for other natural heritage sites to implement protection and management measures.

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