Hindawi Publishing Corporation
Advances in Meteorology
Volume 2013, Article ID 235378, 11 pages
http://dx.doi.org/10.1155/2013/235378

Research Article

Vegetation Activity Trend and Its Relationship with Climate Change in the Three Gorges Area, China

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Received 21 July 2013; Revised 27 October 2013; Accepted 30 October 2013

Academic Editor: Harry D. Kambezidis

Based on SPOT/VGT NDVI time series images from 1999 to 2009 in the Three Gorges Area (TGA), we detected vegetation activity and trends using two methods, the Mann-Kendall and Slope tests. The relationships between vegetation activity trends and annual average temperature and annual total precipitation were analyzed using observational data in seven typical meteorological stations. Vegetation activity presents a distinctive uptrend during the study period, especially in Fengjie, Yunyang, Wushan, Wuxi, and Badong counties located in the midstream of the Three Gorges Reservoir. However, in the Chongqing major area (CMA) and its surrounding areas and Fuling, Yichang, and part of Wanzhou, vegetation activity shows a decreasing trend as a result of urban expansion. The NDVI has two fluctuation troughs in 2004 and 2006. The annual mean temperature presents a slight overall upward trend, but the annual total precipitation does not present a significant trend. And they almost have no significant correlations with the NDVI. Therefore, temperature and precipitation are not major influences on vegetation activity change. Instead, increasing vegetation cover benefits from a number of environment protection policies and management, and ecological construction is a major factor resulting in the upward trend. In addition, resettlement schemes mitigate the impact of human activity on vegetation activity.

1. Introduction

The Three Gorges Project (TGP), located at Sandouping Village, Yichang City, on the Yangtze River, China, began in 1994 and ended in 2009. Currently, the water level in the reservoir has increased up to 175 m; the total storage capacity of the reservoir is approximately 39.3 billion m^3, and the reservoir stretches 660 km upstream, is on average 1.1 km wide, and encompasses a total area of 1084 km^2. It has become the World's largest man-made reservoir. The Dam generates up to 18,000 MW of hydroelectric power, establishes flood control along the river basin, and improves the economic stability of the upper reaches of the Yangtze through improved navigation capabilities [1]. The reservoir is operated in a seasonal mode: low water level (145 m) in summer and high water level (175 m) in winter. As the largest water conservation project in the world, the TGP has attracted worldwide attention. This attention has been not only for its comprehensive social and economic benefits but also for the potential impacts on the security of the natural environment, potential geological disasters, and impacts on biological diversity in the surrounding reservoir area. The adverse impacts of reservoir construction on ecosystems and climate change have attracted more public concern because of similar cases including the influence of Egypt's Aswan High Dam on water and soil quality and human health 20 years after its completion [2] and the influence of the Itaipu Project on vegetation, animals, water quality, and soil pollution [3]. Although the TGP was successfully completed in 2009, the controversy still continues [4–6]. The TGP will

exert both positive and negative impacts on the environment and ecological systems [7]. One positive impact is that it will bring about significant benefits in electric power generation, flood control, and shipping traffic; a negative aspect is that it will produce adverse impacts on migration, environmental and cultural issues, and so forth [8]. Positive impacts will be felt mainly in the middle and lower reaches of the Yangtze, and negative impacts will be concentrated in the reservoir area.

Ecosystem and climate changes and the resettlement of over 1 million people (mostly farmers) resulting from the TGP may all have a direct impact on vegetation growth dynamics and their geographic distribution. Terrestrial vegetation, both native and cultivated, is often viewed as the most overt evidence of biological response to climatic and other environmental factors. So changes in vegetation cover and activity are well recognized as some of the most important indicators for regional environmental changes in the Three Gorges Reservoir area (TGA) [9]. Because data from satellites provide our first opportunity to monitor vegetation on the earth's surface in a systematic, repetitive manner, a common way to derive indicators of ecosystem dynamics is the use of spectral vegetation indices related to the photosynthetic capacity of vegetation canopies, such as the Normalized Difference Vegetation Index (NDVI) [10–13]. The NDVI can capture seasonal and interannual changes in vegetation status and is widely used as an indicator of vegetation activity [14, 15], which can be used to detect and classify changes in the condition of vegetation over time and capture the effects of multiple processes that cause changes, including natural and anthropogenic (e.g., deforestation, urbanization, and farming) disturbances. The high temporal resolution and global coverage of some satellite sensors (e.g., AVHRR, SPOT/VGT and MODIS) have been widely used to monitor vegetation at different spatial and temporal resolutions [16, 17]. Recently, many studies have successfully used NDVI time series data to gain novel insights into the direct and indirect effects of environmental change [18, 19], and these studies have proven to be adequate for the detection of long-term land use/land cover changes and for modeling terrestrial ecosystems on global, continental and regional scales [20–22]. At present, the impact of climate change caused by the TGP on vegetation activity, net primary productivity (NPP), vegetation leaf area index (LAI), and fraction of photosynthetically active radiation (FPAR) are not well understood [23], although many studies have been centered on environmental issues surrounding the TGP such as biodiversity, water quality, fisheries, sediment flows in the river, reservoir-induced seismicity, and geological instability and social issues including population health risks, displacement, and resettlement.

The aim of this study is to examine vegetation activity trend and its relationship with climate change in the TGA from 1999 to 2009 using NDVI time series data. Our study focused on the following three aspects: (1) to estimate vegetation activity changes during the period, (2) to analyze relationships between vegetation activity and temperature and precipitation, and (3) to reveal the cause of vegetation activity change.

2. Data and Method

2.1. Study Area. The Three Gorges Area (TGA) is situated in the lower section of the upper reaches of the Yangtze River, within E106°–115°50′, N29°16′–31°25′, with a population of almost 20 million [17] (Figure 1). It consists of 21 counties or cities of Chongqing municipalities (including Jiangjin district, Banan district, Chongqing major area (CMA), Yubei district, Changshou district, Fuling district, Wulong county, Fengdu county, Zhongxian county, Shizhu county, Wanzhou district, Kaixian county, Yunyang county, Fengjie county, Wuxi county, and Wushan county) and the Hubei province (including Badong county, Xingshan county, Zigui county, and Yichang city), with various geographic conditions: 74% of the region is mountainous, 4.3% is plains, and 21.7% is hilly. The long waterway extends approximately 660 km from the Three Gorges Project Dam to Chongqing municipality. The TGA has a humid subtropical monsoon. The TGA is mostly covered by secondary vegetation and farmland that contribute approximately 92% of the total area as a result of long-term human activity [24, 25]. The forested areas are dominated by coniferous, deciduous broadleaved, and subtropical evergreen broadleaved species.

2.2. Data. We used the NDVI dataset for the period 1999–2009 derived from the vegetation instrument of the Système Pour l'Observation de la Terre (SPOT) 4 and 5 satellites. The NDVI dataset of the SPOT satellites was at a spatial resolution of 1 km. We downloaded SPOT/VGT-NDVI (S10) and Satus Maps (SM) from the VGT website (http://free.vgt.vito.be/) for the period from January 1999 to December 2009 (396 total NDVI images and 396 total SM images). A subset was extracted using VGTExreact (version 2.1.0), a free vegetation extraction tool produced by VITO. The temporal resolution of the SPOT NDVI was 10 days, which made 36 composites in a one-year cycle and was corrected to remove the effects of satellite shift and sensor degradation. Atmospheric contamination from water vapor, ozone, and aerosols was also corrected through a simplified method for atmospheric corrections. In addition, the maximum value composite (MVC) for each 10-day interval was applied to further minimize nonvegetation effects [26, 27]. Despite all of these efforts to improve data quality, the remaining disturbances caused by cloud contamination, atmospheric variability, and bidirectional effects in the NDVI dataset may still result in spurious variations in the vegetation indexes [20]. Thus, we used the following two methods to further reduce potential noise.

Firstly, the NDVI is derived from the digital number (DN) via the formulation: $\mathrm{NDVI} = 0.004 * \mathrm{DN} - 0.1$. The false low value is identified on the SM where a pixel contaminated by a cloud or scan strip is assigned a special value. The false high value is where the difference in the NDVI between continuous two decades is more than 0.6 at the same location because this difference disobeys the gradual natural process of vegetating [20]. And the false low and false high values are treated as missing values and replaced by the moving average using the adjacent points. A period of four decades is selected as the best window size in the moving average based on the

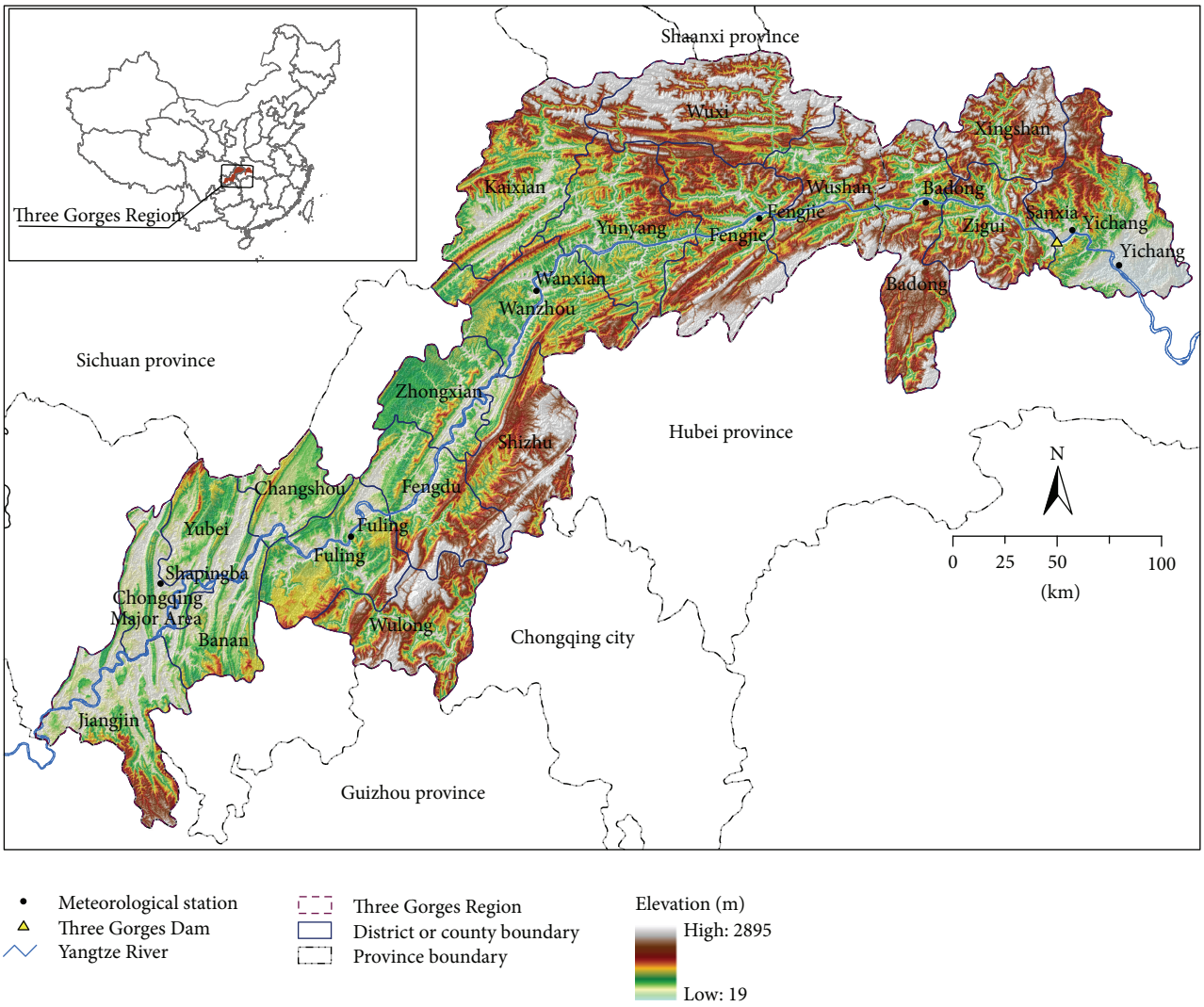

Figure 1: Location of the Three Gorges Area.

autocorrelation analysis of 100 random samples; thus, the raw NDVI value of an abnormal cell is removed and replaced by the mean value of the following 20 days and the preceding 20 days. Then, a Savitzky-Golay (SG) filter is used to smooth and reconstruct the NDVI time series data. We select seven SPANs (5, 7, 11, 13, 15, 19, and 25) and three DEGREEs (2, 3, and 4) for 10 random sample points and gain 21 span-degree combinations. Based on the fitting effect index (FI) [20], the best parameters are identified as a SPAN equal to 7 and a DEGREE equal to 4. We wrote programs to perform these tasks in ArcGIS and Matlab software.

In addition, temperature and precipitation data from seven weather stations were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). Other auxiliary data include GDP and population obtained from Chongqing and Hubei Statistical Yearbooks (1999–2011).

2.3. Method

2.3.1. Annual Maximal NDVI. Based on MVC, the annual maximal NDVI (AMNDVI) corresponds to high photosynthetic activity during a year; that is, it can indicate the best status of vegetation activity under the best weather conditions in a year [28]. In this way, the AMNDVI can be extracted from 36 images, which indicate the best status of vegetation activity in one year.

2.3.2. Mann-Kendall Test. The Mann-Kendall test is a widely used nonparametric test to detect significant trends in time series [29, 30]. The Mann-Kendall test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers. The Mann-Kendall test is based on the correlation between the ranks of a time series and their time

order. For a time series $X = \{x_1, x_2, \ldots, x_n\}$, the test statistic is given by

$$S = \sum_{i<j} a_{ij}, \tag{1}$$

where

$$\begin{aligned} a_{ij} &= \operatorname{sign}\left(x_j - x_j\right) \\ &= \operatorname{sign}\left(r_j - r_i\right) = \begin{cases} 1 & x_i < x_j \\ 0 & x_i \geq x_j \end{cases} \end{aligned} \tag{2}$$

and r_i and r_j are the ranks of observations x_i and x_j of the time series, respectively. As seen from (2), the test statistic depends only on the ranks of the observations rather than their actual values, resulting in a distribution-free test statistic. This is true because if data were to be transformed to any distribution, the ranks of the observations would remain the same. Distribution-free tests have the advantage that their power and significance are not affected by the actual distribution of the data. This is in contrast to parametric trend tests, such as the regression coefficient test, which assume that the data follow the normal distribution and whose power can be greatly reduced in the case of skewed data [31].

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in (1) above are given by

$$\begin{aligned} E(S) &= \frac{n(n+1)}{4}, \\ V(S) &= \frac{n(n-1)(2n+5)}{72}, \end{aligned} \tag{3}$$

where n is the number of observations. We assume that there is a statistic variance UF_k defined below ($k = 1, 2, \ldots, n$) that follows the standard normal distribution, so

$$UF_k = \frac{\left(S_k - E\left(S_k\right)\right)}{\sqrt{V\left(S_k\right)}}, \quad (k = 1, 2, \ldots, n). \tag{4}$$

When k is 1, UF_1 is zero. The significance of trends can be tested by comparing the standardized variable UF with the standard normal variate at the desired significance level a. When a is 0.1, if $UF \geq 1.282$, there is a significant increasing trend and if $UF \leq -1.282$, there is significant decreasing trend.

2.3.3. Slope Test. For a pixel, linear regressions are fitted between the NDVI values and the year number on the time series, and the slopes can illuminate the vegetation activity trend. And the F test is applied in every location (pixel) after the linear regression equation was fitted. Similarly, the significant level is set to 0.1. And the slope of the regression equation with the F value over the critical value ($a = 0.1$) is considered as significant trend. The positive significant slope indicates the significant increasing trend of vegetation activity; the negative significant slope indicates the significant decreasing trend of vegetation activity; if the significant slope is zero, there is little change in vegetation activity as a whole [32]. The slope of the regression equation with the F value less than the critical value ($a = 0.1$) is considered as insignificant trend. Every pixel's slope in the image is calculated by (5)

$$\begin{aligned} &\text{SLOPE} \\ &= \frac{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)\left(\text{AMNDVI}_i - \overline{\text{AMNDVI}}\right)}{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2} \\ &= \frac{\sum_{i=1}^{n}\left(y_i\,\text{AMNDVI}_i\right) - \left(\sum_{i=1}^{n} y_i\right)\left(\sum_{i=1}^{n}\text{AMNDVI}_i\right)/n}{\sum_{i=1}^{n} {y_i}^2 - \left(\sum_{i=1}^{n} y_i\right)^2/n}, \end{aligned} \tag{5}$$

where n is the number of the sample (from 1999 to 2009), $n = 1, 2, \ldots, 11$. AMNDVI_i is the maximum value compositing NDVI of the year j; $\overline{\text{AMNDVI}}$ is the average of the NDVI over 11 years. The y_i is the year ($i = 1, 2, \ldots, 11$).

3. Results and Analysis

3.1. Vegetation Activity Detected by the Mann-Kendall Test. The vegetation activity trend is identified in every pixel using the Mann-Kendall trend test method. The UF value ranges from −4.67 to 3.27 (Figure 2). It is conspicuous that higher values of UF are found in Yunyang, Fengjie, Kaixian, Wanzhou, Shizhu, Banan, and Jiangjin. This shows that vegetation activity has an obvious increasing trend benefitting from a series of eco-environment protection policies implemented during this period. On the contrary, other counties and districts present low UFs, especially in the CMA and its surrounding areas in Yubei and Banan as a result of rapid urban expansion. The area with an obvious increasing trend ($UF \geq 1.282$) is roughly 26,963 km^2 (approximately 39.22 percent of the total TGA); the area with an obvious decreasing trend ($UF \leq -1.282$) is only 1351 km^2 (approximately 1.79 percent of the total TGA), and in an area roughly 40,432 km^2 in size (approximately 58.81 percent of the total TGA), vegetation activity does not present any obvious change ($-1.282 < UF < 1.282$).

There are distinct differences in vegetation activity among 20 districts and counties in the TGA (Figure 3). Vegetation activity with an obvious increasing trend mainly occurs in less developed areas such as Yunyang, Fengjie, and Kaixian in which some residents have emigrated to other provinces or cities and others have settled in newly built buildings higher along the Yangtze River and its branches since the beginning of the project. Emigration mitigates the pressure on land use, especially cropped land, and eco-environment protection policies have been effectively implemented in the TGA, which helped to increase or restore vegetation. Since it became a municipality city in 1997, Chongqing city has quickly spread to a great extent into the suburbs due to a series of preferential policies by the central government, particularly in major areas where most of the immigrants from the TGA have been settled. Thus, rapid economic development has resulted in the obvious downtrend of vegetation activity in the CMA. In addition, the main secondary cities,

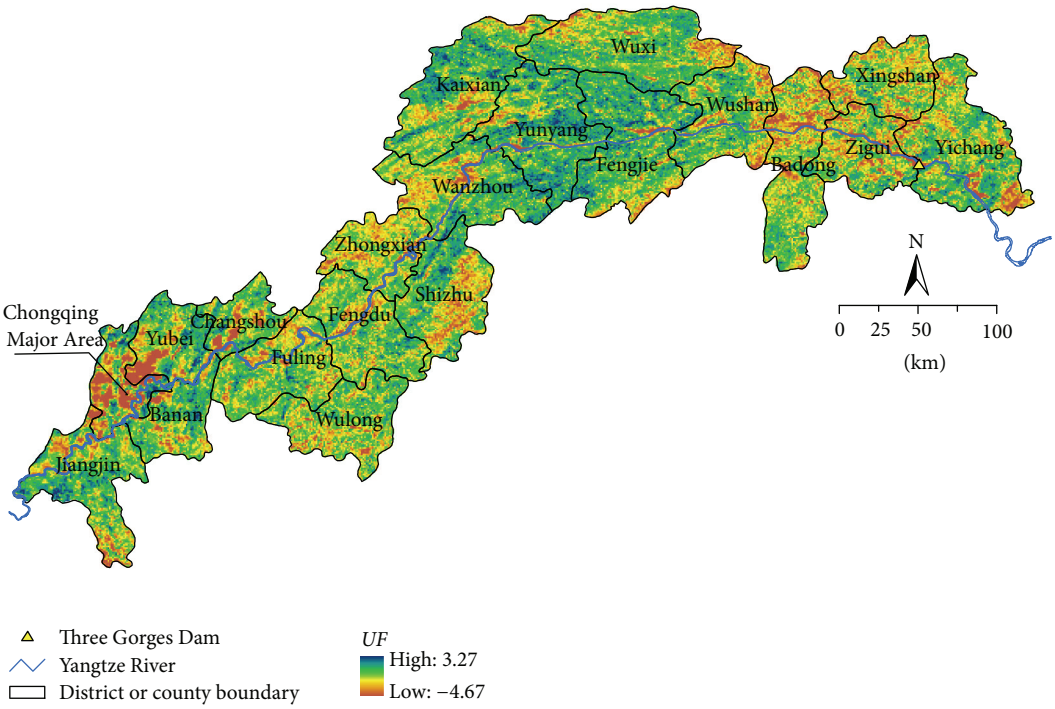

Figure 2: The Mann-Kendall trend test (absolute value of *UF*) of vegetation activity in TGA.

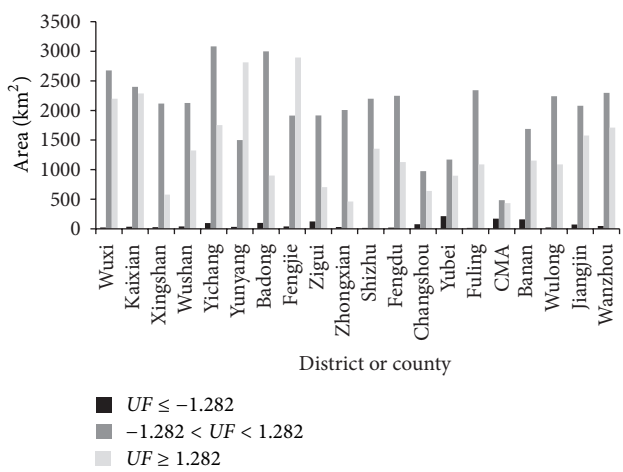

Figure 3: The area with significant trend based on classified *UF*.

Fuling, Wanzhou, and Changshou, have undergone rapid economic and social development where vegetation activity presents a significant downtrend. In Badong and Zigui near the Three Gorges Dam, lower in elevation and with flatter topography than Chongqing city, most of the immigrants have settled in the new, higher elevation urban area near the old urban area. To obtain new land for construction and cultivation to compensate for the loss of land submerged by the Three Gorges Reservoir, cleaning or deforesting is inescapable, especially on both banks of the rivers and near the large residential area. Although the impounding of the Three Gorges Reservoir may change local climate in the TGA, vegetation activity has still shown an obvious increasing trend since 1999.

3.2. Vegetation Activity Detected by the Slope Test. Figure 4 shows the spatiotemporal distribution of the significant trends of vegetation activity detected by the Slope trend method from 1999 to 2009 in the TGA. The significant slope ranges from −0.048 to 0.029. The area with a significant increasing slope is about 23951 km^2 (approximately 34.84 percent of the total area), and the area with a significant decreasing is only 309 km^2 (approximately 0.45 percent of

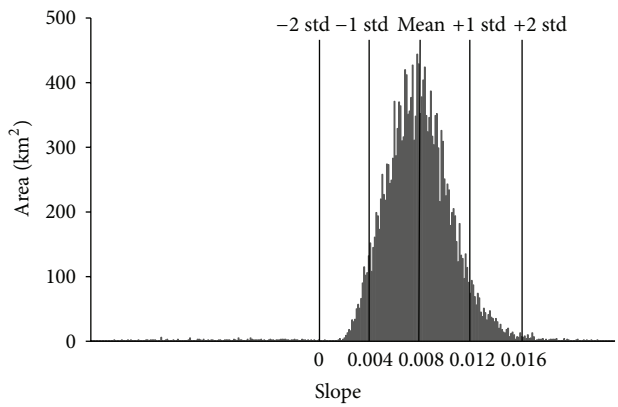

Figure 4: The statistical distribution of the significant slope. (The std stands for standard deviation.)

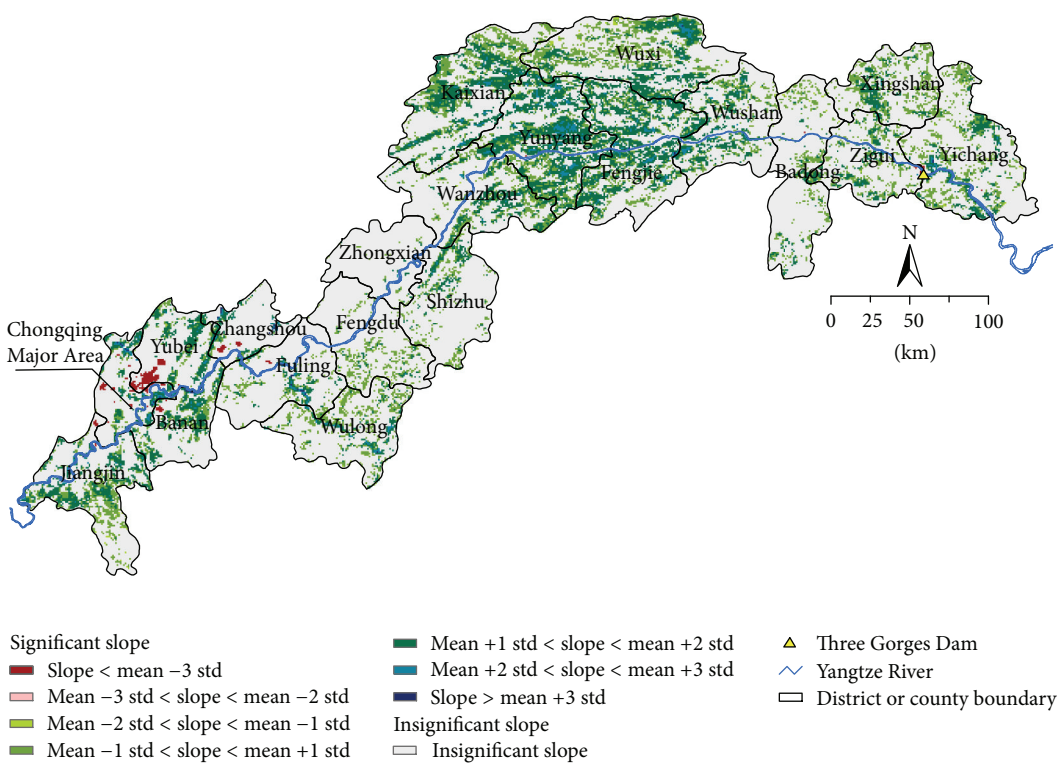

Figure 5: The slope of vegetation activity trend in TGA.

the total TGA). And the area with insignificant slope is roughly 44,486 km^2 in size (approximately 64.71 percent of the total TGA). The mean value of significant slope is approximately 0.008, which indicates a rising tendency as a whole. In Figure 4, we can find that the 99% of the significant slopes fall within two standard deviations range, that is, between 0 and 0.016. The pixels falling within the two standard deviations range cover approximately 34.68% of the total study area, and the slopes of these pixels are all greater than zero. Overall, we can say with certainty that one-third of land surface vegetation activity presents a rising tendency in the TGA during the period.

These results are in agreement with the trends detected by the Mann-Kendall test (Figure 2). The spatial distribution of significant slope (Figure 5) is also consistent with the *UF* results. Similarly, the pixels with significant slope within one standard deviation range are found in most of the TGA except for the CMA, Yubei, and Changshou and part of Badong,

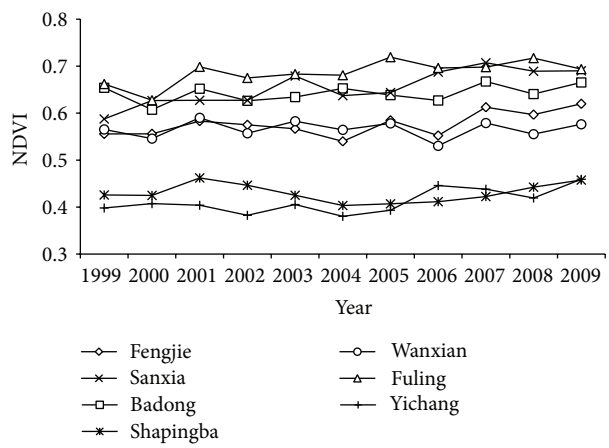

Figure 6: The slope of vegetation activity trend in each weather station during the period.

Zigui, and Shizhu counties and their surrounding areas. A research by Fang et al. (2003) showed that vegetation activity is improving in China [33], especially in center and western China, in recent 20 years (1982–1999). Our finding of an increasing vegetation activity trend in the TGA shows that this increasing trend found by Fang et al. continues in the following ten years.

Although the trends of vegetation activity detected by the two methods (Mann-Kendall and Slope tests) are similar, the area with significant trend detected by Mann-Kendall test (39.22%) is slightly larger than the area with significant trend detected by slope test (34.84%). As a matter of fact, these two methods have their own advantages and shortcomings. The Mann-Kendall trend test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers. However, some researches demonstrated that the method of Mann-Kendall may lead to a higher probability of rejecting the null hypothesis of no trend while it is actually true [31]. Of course, as a parametric trend test (regression coefficient test), slope test assumes that the data follow the normal distribution, and its power could be reduced in the case of time series data contaminated with outliers. To sum up, the percentage of land area with obvious increasing trend of vegetation activity is more than one-third of TGA; the percentage of land area with obvious decreasing trend of vegetation activity is very small, 0.45% from slope test and 1.79% from Mann-Kendall test; and the percentage of land area with insignificant trend is more than half of the TGA.

3.3. Relationship between Vegetation Activity and Temperature and Precipitation. Gosz et al. used a 3 km radius circle to study the relationship between summer rainfall and lightning at the Sevilleta [34]. The size of each area was limited to account for localized rainfall from convective thunderstorms during the summer. Sensitivity analyses to determine the effects of analysis area size on NDVI mean values were performed for this study, comparing diameters of 3, 4, and 5 km, and mean NDVI values for each were comparable [35]. Considering significant differences in land cover and local climate in the mountain area, the 3 km diameter circle surrounding a meteorological station was chosen to analyze relationships between the NDVI trend and temperature and precipitation trends during the analysis period. Firstly, the mean NDVI in each 3 km radius area was extracted, and the scatter diagram between the mean NDVI and year is shown in Figure 6. The NDVIs of Shapingba and Yichang stations for the entire period are lower than those of the other stations because the two stations are located in urbanized areas. Vegetation growth shows high levels in Fuling, Badong, and Sanxia stations through the period. Vegetation growth is slightly lower in Wanxian and Fengjie stations. Then, the linear regression is fitted between mean NDVI and year during the period in each 3 km radius area. All slopes in six 3 km radius areas are more than zero except Shapingba whose slope is zero. Then the F test is applied. Finally, we can find that the slopes (coefficients) of the regression equations in Fengjie, Yichang, Sanxia, and Fuling are significant with F value higher than the critical value ($a = 0.05$). However, the slopes (coefficients) of the regression equations in Badong, Wanxian, and Shapingba are insignificant with F value less than the critical value ($a = 0.05$). These trends are consistent with results analyzed by the Mann-Kendall and slope tests.

There are two important events in 2003 and 2006 during this period of the impoundments of Three Gorges reservoir. We think that inundation result from impoundment may lead to low NDVI. When the reservoir was firstly filled to 135 m in June 2003, land inundation involved 101.6 km^2 of cropland, 59.9 km^2 of grassland, and 29.3 km^2 of forest [23]. The inundated land lost vegetation covered on the land surface, which may lead to low NDVI especially in the next year. By 2006, when the water level reached 156 m, the inundation may also lead to low NDVI accompanied by urban relocation and a continuous drought in the TGA. In fact, although there are obvious fluctuations in all lines in Figure 6, we can still find

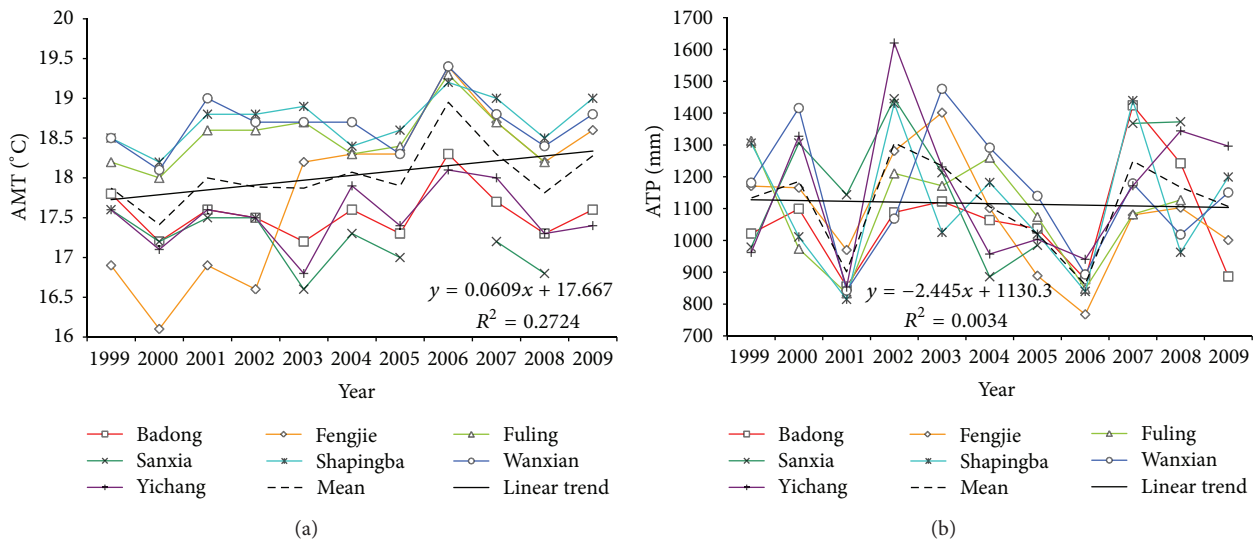

Figure 7: AMT and ATP trends in weather stations during the period.

that NDVIs in 2004 become lower than that in adjacent years except for Badong, and NDVIs in 2006 also become lower than that in adjacent years except for Sanxia, Yichang, and Shapingba.

Figures 7(a) and 7(b) show annual mean temperature (AMT) and annual total precipitation (ATP) in each meteorological station during the period. Similarly, every line of each station showed in Figure 7 was fitted by linear regression during the period, and the F test was applied. When the significant level is set to 0.1, AMTs in five stations also present insignificant trends except for Fengjie and Sanxia stations, and ATPs in all seven stations present insignificant trends. The AMT in Fengjie station presents significant increasing trend (slope = 0.254, $R^2 = 0.662$); however, the AMT in Sanxia station presents significant decreasing trend (slope = −0.063, $R^2 = 0.332$).

There are great differences among the seven stations. In Sanxia station with decreasing AMT is located near the Three Gorges Project Dam, it may be heavily affected by the changing local climate resulting from the grand reservoir water surface, although the impacts of the Three Gorges Reservoir on local climate are still unclear. The stations with insignificant AMT trends (Shapingba, Wanxian, Fuling, Yichang, and Badong) are located in urbanized areas and may be affected by urbanization accompanied by with region climate change. In Fengjie station, the AMT may be mainly influenced by the local topography. For all stations, the fluctuation of ATP is large than the AMT which may lead to insignificant trends. And the cyclical fluctuation pattern is also observable in ATP trends (about a 5-year cycle). For example, serious drought appears in 2002 and 2006; however, heavy precipitation appears in 2002-2003 and 2007.

The mean AMT of seven stations presents an overall significant increasing trend (slope = 0.06, $R^2 = 0.272$). The mean ATP of seven stations presents an insignificant trend, although the slope is −2.455. From 1999 to 2009, the mean AMT for seven stations increased from 17.87°C to 18.28°C, approximately 0.04°C per year, which is consistent with finding by Fang et al., 2010 [36].

For each station, a Pearson correlation test of its mean NDVI in the 3 km circle against AMT and ATP on the time series is carried out in SPSS. Then, we find that there are no significant positive or negative correlations between the NDVI and AMT except at Sanxia station, and the same is true of correlations between NDVI and ATP in all seven stations. In Sanxia station, Pearson correlation coefficient is −0.712 between the NDVI and AMT which is significant at the 0.05 level (2-tailed). And the regression analyses reveal that only the relationship between the NDVI and AMT in Sanxia station has a significant linear relation (slope = −0.079, $R^2 = 0.507$), and in the remaining stations there are no significant linear relations like the relationship between NDVI and ATP. No significant correlations and linear relations in most stations may indicate that vegetation growth is controlled by many factors including natural factors (e.g., temperature, precipitation, soil type and moisture, vegetation communities and species) and human activity (e.g., deforestation, urbanization, and vegetation restoration, and agriculture), although temperature and precipitation are two important factors impacting vegetation growth conditions. In Sanxia station near the Three Gorges Reservoir water surface, the significant negative correlation may indicate that declining temperature is an important factor on vegetation activity resulting from the Three Gorges Reservoir.

4. Discussion

4.1. Difference in the Vegetation Activity Trends Detected by Two Methods. In fact, these two methods have their own

advantages and disadvantages. On the one hand, the Mann-Kendall trend test is one of the widely used nonparametric tests to detect significant trends in time series. The method is not affected by the actual distribution of the data and is less sensitive to outliers, because it is a function of the ranks of the observations rather than their actual values. Therefore, the Mann-Kendall test is more suitable for detecting trends in NDVI time series which are usually be contaminated with outliers despite smoothing. However, temporal (serial) correlation and/or spatial (cross) correlation always present in data sets, which will affect the ability of the Mann-Kendall test to assess the significance of trends. For example, the presence of positive serial correlation can lead to a higher trend, even in the absence of a trend [29, 31]. As a gradual natural process, vegetation growth is clearly suited to the Tobler's First Law of Geography. That is to say that spatial correlation exists in NDVI data. Furthermore, there exists a temporal correlation in NDVI time series data because vegetation growth in a year could be influenced from the coverage and growth state in previous year. Consequently, the vegetation activity trend detected by the Mann-Kendall test may be overvalued in TGA.

On the other hand, as a parametric test, slope of regression equation fitted by the least squares method may be more powerful than the Mann-Kendall [29]. However, the parametric test requires independent and normally distributed data and is more sensitive to outliers. Mountain and hill covering the most of TGA and mist resulting from mountains and large water surface often reduce the NDVI signal. And very few outliers still remain in NDVI data sets in spite of smoothing. These factors may contribute to underestimating the vegetation activity trend.

As a whole, the spatial distributions of vegetation activity trend detected, respectively, by the two methods are similar, and the area with significant trend is also similar. That is to say that the significant increasing trend with approximately one-third of TGA does exist.

4.2. Driving Forces of Vegetation Activity Change. We consider vegetation activity a result of comprehensive effects of geographical environment factors and human activity. One major reason is that vegetation growth conditions involve temperature, precipitation, sunlight, humidity, soil conditions, and consequent vegetation phenology (e.g., start and end of the growing season, growing season length and peak activity and its duration). An increasing trend of AMT is consistent with the study by Lin et al. [37]: the annual mean temperature in the TGA had a markedly upward trend with a warming rate of 0.13°C/10 year during a recent 50-year time period (from 1960 to 2006). However, AMT and ATP trends are not significantly correlated with the trend of the NDVI in most stations, which indicates that temperature and precipitation changes have no significant effects on vegetation growth. Until now, the degree of the impact of the construction of the Three Gorges Project on climate change in the entire reservoir area has not been clearly defined. Early assessments raised the possibility that the massive new reservoir might affect temperatures and other climatic variables locally, on the scale of tens of kilometers [38]. Further research is necessary to reveal the impact of the Three Gorges Project on vegetation growth in the TGA for longer time series, especially after the project was completed because such a large water surface is expected to alter regional weather and climate patterns [2], which can change vegetation growth conditions.

Another major reason is an increasing area of vegetation cover. The NDVI has a high correlation with the vegetation area in the TGA [39]. Zhang et al. found that there is an overall small increase in vegetation cover from 2000 to 2006 in the TGA [17]. High vegetation cover increased obviously in mountain areas, especially in Yunyang, Fengjie, Wushan, Wuxi, and Badong counties, although urban areas rapidly increased due to relocation and resettlement for submerged urban areas' immigrants, resulting in major loss of natural vegetation on slopes between 0 and 35° [22]. Therefore, increasing vegetation cover can be a major factor resulting in increasing vegetation activity. In fact, to rehabilitate ecological functions in the reservoir area, policies and management projects have been carried out in recent years. As a consequence, the forest coverage rate in the reservoir area increased from 21.9% in 1997 to 34.5% in 2008, greater than the national averages of 13.9% in 1997 and 20.4% in 2008 [40]. Approximately 1,020 km^2 of cropland distributed on steep slopes with gradients of 25° or more was returned to forest or grassland through implementation of the Grain for Green Project in the reservoir region over the 2000–2008 period. At the same time, to strengthen ecological and environmental construction in the TGA and the surrounding area, the State Council approved the "Greenbelt Around the Three Gorges Reservoir Construction Project Planning" in July 2004 with a construction period from 2004 to 2007. The work includes returning farmland to forest, planting trees on barren hills and wastelands, closing hillsides to facilitate afforestation and construction of basic farmland, other measures to protect the existing forest resources, and creating water conservation and soil conservation forests, ensuring the ecological safety of the Three Gorges Reservoir [17]. Major national ecological projects have clearly played a fundamental role in offsetting the negative impacts of the TGP on vegetation loss across the resettlement region. The findings of this research provide empirical support for the proposition that ecological projects can effectively improve vegetation activity and ecological services of vulnerable ecosystems in the TGA [23].

The third reason is relevant to mitigating human activity resulting from resettlement schemes. By the end of 2008, approximately 1.25 million people were displaced [41]. Over one-fifth (20.3%) of the displaced population were rural residents who were resettled within their original county via nearby resettlement schemes. Many old county seats or township centers in 11 counties and districts alongside the reservoir bank were completely or substantially submerged, and new urban centers were subsequently reconstructed at new sites uphill or further away from the new shoreline. Urban dwellers, accounting for 64.7% of the total displaced population, were relocated to new urban areas via urban resettlement schemes. In addition, approximately 190,000 rural residents (15.0% of the total displaced) have been moved out of their original counties and resettled in distant places

beyond the reservoir area via distant resettlement schemes [23]. Many resettled residents are no longer dependent on farming and stockbreeding due to a shortage of agricultural land. The abandoned cultivated land gradually restores vegetation, especially in sloping areas. Simultaneously, residents resettled in distant places beyond the TGA. There is a significant negative correlation between the NDVI and population [42]. Consequently, resettlement schemes mitigate the impact of human activity on vegetation activity.

5. Conclusion

Using two methods, the Mann-Kendall and slope tests, we find that vegetation activity presents distinctive uptrends during the period, especially in Fengjie, Yunyang, Wangzhou, and Wushan located in the midstream of the Three Gorges Reservoir and far from urban area. Our finding of an increasing vegetation activity trend in the TGA shows that this increasing trend found by Fang et al., 2003 [33] continues in the following ten years. And the area with distinctive uptrends is about one-third of the total TGA. On the contrary, in the CMA and its surrounding area in Yubei and Banan and Fuling and Yichang, vegetation activity shows significant decreasing trends as a result of urban expansion, intense human activities, and submerged land related to Three Gorges Project. However, the area with significant decreasing trend is quite small. It is highly likely that the reservoir impoundment resulted in two fluctuation troughs of the NDVI in 2004 and 2006. Over 11 years, the mean AMT of all seven stations presents a slight increasing trend, but AMTs in most stations present insignificant trends except for Fengjie and Sanxia stations. However, the mean ATP of all seven stations does not present a significant trend, and ATPs in seven stations have not shown significant trends either. Although temperature and precipitation are the two most important factors for vegetation growth, vegetation activity shows no significant correlation with annual mean temperature and annual total precipitation except for Sanxia station. By comparison, increasing vegetation cover benefited from a number of environmental protection and ecological construction polices and projects, with more of an impact on upward vegetation activity than local climate change. Although the impact of the Three Gorges Project on vegetation growth conditions via climate change on local and regional scales is still not perfectly clear, we consider that such a large water surface must have far-reaching effects on the ecosystem. There is a large amount of work needed to study how the TGA changes regional climate and then to understand how it indirectly impacts vegetation activity, distribution, and phenology.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The study was supported by the Natural Science Foundation Project of CQ CSTC (Grant No. CSTC2011jjA00025). The authors thank Dr. Z. W. Sun for his constructive comments and suggestions on their paper. We also thank the two anonymous reviewers of the paper for their many excellent comments and suggestions.

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