Spatio-temporal variation of fractional vegetation coverage and response to climatic factors in Three Gorges Reservoir area from 2010 to 2014

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Abstract. Current study investigated the spatio-temporal distribution of fractional vegetation coverage (FVC) and climatic factors response in Three Gorges Reservoir area from 2000 to 2014 using a dimidiate pixel model. Several data sets were used including the MODIS NDVI data, land use/cover change (LUCC) data and past 15 years of FVC data. Our results suggested that, except 2006 the annual maximum FVC were stable from 2000 to 2014. Extremely arid climate in 2006 influences FVC of Three Gorges area. The annual average FVC of the study area was 91.28%. The monthly mean FVC showed a regular fluctuation, where mean higher FVC values were found from May to August and from December to March of the following years FVC was lower. Overall study area showed an upward trend of FVC from 2000 to 2014, basic invariant areas, slight increased areas and obvious increased areas were accounted for 84.70%, 8.75%, and 0.78% respectively, whereas significantly reduced areas and mild reduction areas were accounted for 1.52% and 4.25% FVC, respectively. The FVC growth areas were mainly distributed in the eastern part of the Three Gorges Reservoir area whereas degraded areas were mainly distributed in the hilly areas of the West and middle of the Three Gorges area. Greater than 2000 meters high mountains the FVC value reached 98.47%, and the slope greater than 25° the regional FVC value reached 92.60%. Strong correlations were observed between monthly mean temperature and FVC (R=0.88), precipitation and FVC (R=0.77), and growth season lag 1 month of FVC values and temperature (R=0.85).

1. Introduction
The Fractional Vegetation Coverage (FVC) refers to the vegetation (including leaf, branch and stem) percentage of the total statistical area in the vertical projection of the ground where the changes are related to biomass, net primary productivity, leaf area index of vegetation, ecological index, reflectivity and emissivity of soil moisture and surface parameters. It is a comprehensive quantitative
index covering the surface condition of plant communities which is also an important indicator of regional environmental changes [1,2]. A remote sensing technique which can reflect the vegetation cover information and its changing tendency in different time and space. It is an important technical method to obtain the parameters of FVC and have been applied in numerous studies in different regions of the world [3-6]. In China, researchers studied in various ecological functional zones of different spatial scales of County-City-Province-National levels, and the change trend, climatic factors and human activities [7-11]. Deng et al. (2014) [11] studied extensively on the climate change impact on Yangtze River Basin vegetation cover using MODIS Enhanced vegetation index (EVI) 2000-2010 and climate data. Liu et al. (2013) [12] have studied on vegetation coverage change (2000-2011) and its relationship with climate in Chongqing, China using MODIS normalized difference vegetation index (NDVI) and climatic data (temperature and precipitation). Similar studies have also been conducted by other researchers considering different time periods in different areas [13-16]. Previous researches commonly used NDVI and EVI data to estimate the changes in regional vegetation whereas FVC is more simple and can easily be accepted by the scientific community [17]. The time series image was insufficient which could not explain the overall variation characteristics of vegetation in Three Gorges Reservoir area. Moreover, the study area high-resolution TM/ETM and SPOT images effected by cloud might be difficult to establish long time series data analysis. Therefore, we applied FVC index to monitor dynamic changes in vegetation coverage in Three Gorges Reservoir area. The Three Gorges Reservoir as an important strategic reserves for China's freshwater resources. The reservoir basin area of $5.7 \times 10^4$ km$^2$, covering 26 counties in Hubei Province and Chongqing Municipality (Fig.1). It is typically humid subtropical monsoon climate zone. The annual average temperature is 17-19℃, average annual rainfall 1045-1140 mm with heavy rainfall in the July to September. The objective of this study was to analyse the characteristics of temporal and spatial variation of FVC in recent 15 years in Three Gorges Reservoir area using time series MODIS NDVI data, combined with land use/land cover (LUCC) data of two pixel model of FVC based on data sources. Moreover, changes in vegetation cover in response to the climatic factors was also considered during this study.

2. Methodology

2.1 Data sources

FVC MODIS basic data: Using MODIS vegetation index products developed by NASA, which are widely used in the world. This product adopted the maximum synthesis method where the time series filtering and post processing was conducted in order to greatly reduce the influence of the clouds, the sun angle, the sensor sensitivity changes with time and other effects. The MODIS vegetation index product time span was 2000-2014 of the total 179 scenes, resolution is 1 km.

Vegetation coverage data: Obtained combining the total three land use data of the years 2000, 2005 and 2010, using the two-pixel model to generate 1 km FVC precision MODIS between 2000 to 2014 monthly FVC data, then post-processed with clipping, fusion, etc.

Monthly climate data: Collected from the monthly average temperature, precipitation and sunshine of the percent data during 2000-2014 from China meteorological data network (http://data.cma.cn), where the area weighted method was adopted [18].

2.2 Data analysis techniques

(a) Maximum synthesis (MVC)

The general method of maximizing the MVC (Maximum Value Composites), to maximize the processing by using GIS software on MODIS FVC data, to maximize annual FVC data, the calculation formula is as follows:

$$MFVC = \text{MaxFVCij} \quad (1)$$

In the formula, MFVC is the maximum value of FVC in I, FVCij is the FVC value of j month in i.

(b) Dimidiate pixel model
There are many methods about the inversion of FVC that can be found in the literature, such as NDVI-FVC empirical model, dimidiate pixel model [19,20] and others. However, in this study dimidiate pixel model was used for the NDVI data to calculate FVC and land cover type data. The principle of this model is a hypothesis that a pixel in a two endmembers, namely FVC area and bare area, the pixel FVC depends on the two endmember area ratio of the pixel, and the area weighted index to replace available NDVI.

\[
 f_{\text{veg}} = \frac{(\text{NDVI} - \text{NDVI}_{\text{soil}})}{(\text{NDVI}_{\text{veg}} - \text{NDVI}_{\text{soil}})} \quad (2)
\]

Where NDVI_{soil} is the bare land NDVI, NDVI_{veg} is a full coverage area of the vegetation NDVI value, according to the experience of selecting statistical NDVI value as 90\% NDVI_{veg}, 5\% NDVI value as NDVI_{soil}; different land cover types, the corresponding NDVI characteristics is also different, land use/cover change (LUCC) data used in the study and vegetation cover types related to the farmland, woodland and grassland. Except construction on land, land use/ cover type spatial distribution is relatively stable, little change in the year can be used for FVC analysis and statistics.

(c) Trend analysis

Trend analysis using monadic linear regression analysis can simulate the change trend of each raster unite, characterization of vegetation cover change and spatial characteristics of trends. Changes in the magnitude were obtained by each year's data eliminating the influence of abnormal factors incidental in the study period of vegetation growth, more scientific reflect the evolution trend of long time series FVC [21-22]. Relevant formula is:

\[
 \text{Slope} = \frac{n \times \sum_{i=1}^{n} \left( i \times F_{\text{max}}^{\text{veg}} \right) - \sum_{i=1}^{n} \sum_{i=1}^{n} F_{\text{max}}^{\text{veg}}}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}
\]

Type FVC_{maxi} : coverage value for the first I years of vegetation; n : the study period of length from 2000 to 2014, and total of 15 years, the time step is 1 years; Slope is the gradient of the linear fitting; when Slope>0, showed that the FVC increased, change trend, and vice versa for reduction or degradation.

(d) Correlation analysis

The response of vegetation cover is composed of several common elements of climatic factors, topography and human activities. Correlation analysis was used to identify the relationship between specific variables [12]. The pixel based on the spatial analysis of FVC in correlation with the climatic factors such as rainfall, temperature, percentage of sunshine. In addition, correlation analysis is also applied to study the relationship between climatic factors, the time lag (monthly and lag 1 (January)) FVC and growth season (April - August) FVC.

3. Results and discussion

3.1. Time variation characteristics of FVC

3.1.1. Monthly Changes in FVC

A total of 179 long sequences of FVC data from 2000 to 2014 of the Three Gorges Reservoir area were analyzed and presented. Compared with other months, low FVC values were obtained during January-April and December in 2006 and the lowest FVC was found in January 2006 due to the abnormal data. Monthly mean distribution of FVC represent large changes in vegetation coverage where high FVC values were appeared in June and August, reached the highest coverage in July. Main growth period of vegetation was found from March to June. After October, the evergreen broad-leaved forest, deciduous, seasonal factors such as farmland vegetation gradually reduced, and therefore decreased FVC value. From December to the following year of March the FVC value was found lower and the lowest FVC value was obtained in January.

3.1.2. Annual variation of FVC

Except 2006, the annual FVC was almost stable during study period (Fig. 2) and average annual FVC was estimated about 91.3\%. The present study area suffered a severe drought during May to
September 2006, the average temperature was higher than 2-3°C than the same periods of other studied years and 90% less rainfall. The annual FVC during 2006 was 80.04%, the lowest in 15 years. However, annual FVC improved in 2007 to 94.15%, reached the highest value.

In order to further understand the FVC change trend in the Three Gorges reservoir, GIS software was used for trend slope mapping. This reflected the changing tendency of vegetation growth and the slope was found to be positive. The vegetation had the trend of degradation, the opposite slope was positive where the vegetation cover increased. The degree of trend analysis slope value for the 0.00057coverage from 2000 to 2014, the vegetation in the study area was very small, slightly rising trend. We classified our study area into 5 categories as similar to the previous study on Southwest Lancang river basin [22] significantly reduced area, slightly reduced area, basically an invariant area, slight increase area and obvious increase area. Statistical analysis of coverage trends can be obtained in the study area of 15a vegetation representing the basic invariant area of three classes: basically invariant, slightly reduced and slight increase areas covered 97.7% (Fig. 3, Table 1). However, significantly reduced area and obvious growth area of Three Gorges Reservoir was found a small proportion which estimated, a total of nearly 2.3%. FVC significantly varied within the administrative regions of our study area. Chongqing urban is the main city in Three Gorges Reservoir area, rapid urbanization and industrialization development, occupy a lot of lands and therefore FVC decreased significantly whereas the growth trend is more obvious in eastern and central regions due to sowing afforestation, natural forest protection and ecological protection in recent years.

3.2 Spatial variation characteristics of FVC in Three Gorges

Overall spatial distribution of FVC increased from west to East in Three Gorges reservoir area from 2000 to 2014. According to Wuhan city vegetation cover classification [23], coverage from low to high can be divided into: low vegetation coverage (<30%), Medium-low vegetation coverage (30-45%), medium vegetation coverage (46-60%), medium-high vegetation coverage (61-75%) and high vegetation coverage (>75%). Based on this vegetation coverage classification we divided our study area and showed in different color in Fig. 4. High vegetation coverage accounted for 97.47% of the total studied area whereas reaming 2.53% vegetation coverage fall under the low, medium-low, medium, and medium-high class. A large number of forest and grassland are distributed in the East part of the Three Gorges Reservoir where high FVC values were obtained. In contrary urban areas and the Three Gorges Reservoir area of Pengxi River and Daning River riparian zone showed high or medium FVC that have been studied by other researchers [12,24].

In order to study the effect of altitude and slope of vegetation growth and vegetation index under different terrain conditions characterized by elevation, we divided into four classes as similar to the previous study by Qi et al. (2015) [25], such as low mountain (<500 m), Middle mountain (500-1000 m), Middle high mountain (1500-2000 m) and high mountain (>2000 m), the slope was divided into <5°, 5-15°, 15-25° and >25° respectively (Table 2). Vertical differentiation was obvious in FVC of the study area, the higher the altitude, the greater the slope, degree of vegetation cover was high. This was due to low regional population density and less disturbed by human activities in high mountain areas.

3.3 Correlation analysis

Based on monthly climatic data analysis of Three Gorges Reservoir from 2000 to 2014 in, we observed average highest and lowest temperature in July and January respectively. Precipitation and percent of sunshine, was highest in July and August whereas the lowest value was appeared in December and January respectively. Table 3 represent the relationship between FVC and climatic factors. The monthly mean FVC and temperature of the study was found highly correlated with correlation coefficient $R = 0.881$ (P<0.01, n = 172) whereas moderate relationship was observed between monthly mean FVC and precipitation ($R = 0.770$). Relationship between FVC and percentage of sunshine was found low suggesting that sunshine had little effect on the vegetation cover. Growing season lag 1 month FVC was highly correlated with the monthly average temperature with correlation coefficient $R = 0.761^{**}$ (P<0.01, n = 74). This indicates that the temperature played a major role to
improve FVC in the study area. Three Gorges is located in subtropical monsoon region, and abundant rainfall, the vegetation growth was affected by temperature and precipitation. This finding is consistent with the previous results on vegetation coverage changes in Chongqing from 2000 to 2011 as reported by Liu et al (2013) [12] but different from the results reported by Braswell et al (1997) in other places [26].

4. Conclusions
Except 2006, average annual FVC was almost stable during 2000 to 2014. Low FVC in 2006 was found due to extreme drought condition. Average annual FVC of the study was found 91.28% and among them high FVC accounted for 97.47% of the total area. Monthly FVC analysis showed an increasing trend in FVC from June to August, with the highest in July, whereas from December to March the following year showed a decreasing trend in FVC, with lowest value in January. FVC increased from west to east part of the study area. The higher the altitude, the greater the slope, the FVC is higher than the mean value. More than 2000 m height the FVC value reaches 98.47%, the vegetation area greater than 25° covered 92.60% of FVC. Highest FVC was found in Xingshan County (94.62%) whereas lowest value was observed in Yuzhong Districts (55.74%). Temperature was found highly correlated with both monthly and growing season FVC. Further research on the temporal and spatial variation, combined with human activities especially the relationship between the vegetation coverage change, industrialization and urbanization, to provide technical support for the Three Gorges Reservoir area and the upper reaches of the Yangtze River Ecological Restoration and reconstruction of scientific decision-making.

5. Tables

| Table 1 Statistical result of trend of MaxFVC change simulated from 2001-2014 |
|---|
| slope | trend | area (Km²) | area ratio (%) |
| (-∞, -0.009] | Significantly reduced area | 771.3 | 1.52 |
| (-0.009, -0.0045] | Mild reduction zone | 2160 | 4.25 |
| (-0.0045, 0.0045] | Basic invariant region | 43100.1 | 84.70 |
| [0.0045, 0.009) | Slight increase area | 4450.5 | 8.75 |
| [0.009, ∞) | Obvious increase area | 397.8 | 0.78 |

| Table 2 Distribution statistics of multi-year mean FVC and elevation and slope in Three Gorges (%)
height (m) | <500 | 500-1000 | 1000-2000 | >2000 |
|---|---|---|---|---|
| FVC | 86.97 | 91.24 | 95.97 | 98.47 |
| Slope (°) | <5 | 5–15 | 15–25 | >25 |
| FVC | 88.48 | 90.36 | 91.38 | 92.60 |

| Table 3 The correlation coefficient between average monthly FVC and influencing factors |
|---|
| FCV | monthly mean temperature | monthly mean precipitation | monthly mean percentage of sunshine |
|---|---|---|---|
| monthly | Lag 1 month | monthly | Lag 1 month | monthly | Lag 1 month |
| R | 0.881** | 0.664** | 0.77** | 0.524** | 0.576** | 0.441** |
| R (Growing season) | 0.761** | 0.847** | 0.467* | 0.352** | 0.213 | 0.424** |

**at the 0.01 level (bilateral) significantly related. *at the 0.05 level (bilateral) significant correlation
6. Figures

**Fig. 1** Location map of the study area

**Fig. 2** The monthly and annual mean FVC from 2000 to 2014

**Fig. 3** Annual average FVC trend from 2000 to 2014
Fig. 4 Annual mean FVC from 2000 to 2014

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