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Dynamic Monitoring of Fractional Vegetation Cover in Fuxian Lake Watershed based on Multi-Temporal Landsat 5/8 Images

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Abstract: Fractional vegetation cover (FVC) is an important indicator of terrestrial vegetation density and provides basic dynamic information of regional eco-environment for research on global change. This paper uses dimidiate pixel model and 11 scenes of Landsat 5/8 images from 1974 to 2-14 and DEM data for monitoring of FVC in Fuxian Lake watershed. Combining geographical information, administrative division and industrial sectors data, vegetation cover for different slope gradients is analyzed. Results show that (1) in the past 40 years, the area of grade Ⅰ FVC fluctuates very little in Fuxian Lake watershed, as opposed to large fluctuation of area of grade II-IV FVC; (2) Bare land and extremely low vegetation cover are mainly distributed in areas with small slope gradient and mild terrain. In steep terrain, moderate, moderate-to-high, and high vegetation cover are dominant; (3) Across the years, the area of grade I FVC is the largest. In 1974, 1977, 1989 and 1996, the area of grade II and III FVC is larger, and that of grade IV and V FVC is smaller. After 2000, the area of grade II, III and IV FVC is smaller. In 2006, 2009, 2012 and 2014, the area of grade IV and V FVC is larger, while that of grade II and III is smaller.

Keywords: *Fractional vegetation cover, dimidiate pixel model, spatial-temporal variation, Fuxian Lake watershed*

1. Introduction

Vegetation, a principle component of terrestrial ecosystem, forms the natural basis for human survival and development. Vegetation cover not only reflects the differentiation of natural environment and temporal and spatial evolution of the climate, but also influences the energy balance of the earth system. Vegetation changes have large impacts on regional surface air temperature, precipitation and biological circulation [1-3]. Fractional vegetation cover (FVC) is an important indicator of terrestrial vegetation cover and ecosystem change [4]. It occupies a special position in atmosphere, pedosphere, hydrosphere and biosphere [5]. Regional and global FVC estimation is a crucial part of vegetation research [5] and global change research [6]. Among numerous studies on FVC [1-2,7-11], the commonly used methods include empirical model, vegetation index (NDVI), mixed pixel decomposition and spectral gradient difference method. Empirical model and NDVI are the most frequently used, but no standard procedures are available for FVC estimation [5]. Mixed pixel decomposition estimates the proportion of vegetation pixels using the spectral mixture model, without the need for modelling from measured FVC data. This method is simple, reliable and easily applicable [6]. Many existing researches largely focus on the reasons behind FVC change and less on the characteristics of temporal and spatial evolution of FVC.

Yunnan Plateau is studded with lakes. The total area of watershed of 9 major plateau lakes in Yunnan approaches 8000km2, accounting for 2% of provincial land area. The population in the watershed accounts for 9.3% of total population of the province, but its contribution to provincial GDP is about 34% [12]. Sustainable development of watershed of 9 major plateau lakes in Yunnan is crucial for regional social and economic development [12]. Fuxian Lake in Yunnan is the second deepest lake in China, and its area and water capacity ranks the 8th and 3rd nationwide. Reputed as the “plateau pearl” in middle Yunnan, Fuxian Lake is also a recreational site and water source area for pan-Pearl-River delta region and even for Southwest China [13]. But due to intensifying human activities and climate warming, the water level of Fuxian Lake has been declining with shrinkage of water area. Vegetation in the watershed is deteriorating because of reclaiming farmland from lakes, deforestation, over-exploitation of tourist resources and construction activities [14]. Monitoring of temporal and spatial variations of FVC in Fuxian Lake watershed is of high importance to the utilization and management of local water circulation and water resources. Moreover, it will provide basic data for climate change prediction, ecological

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assessment and decision making on macro-control. This study uses 10 scenes of Landsat 5/8 images of Fuxian Lake watershed from 1974 to 2014 as the data source and applies dimidiate pixel model, remote sensing technology and GIS to FVC monitoring. The aim is to reveal the spatial and temporal characteristics of FVC evolution in Fuxian Lake watershed.

2. An Overview of the Study Area

Fuxian Lake is the largest lake in the source of Pearl River and belongs to Pearl River system. Located at the boundary between Chengjiang, Jiangchuan and Huaning County of Yuxi City, Yunnan Province (24°13′N - 24°46N, 102°39′E- 103°00′E) (Figure. 1). Fuxian Lake has a water area of 216.6 square kilometers. The maximum depth of water is 158.9m, average depth of water 95.2m and transparency 5-6m. It is China's second deepest freshwater lake and also the lake with the largest water capacity in Yunnan (18.93 billion km^3). The lake water quality belongs to class Ⅰ on the whole. Fuxian Lake, running in south-north direction, is formed by faulting and corrosion and surrounded by mountains on three sides. Precipitation is the main source of water for the lake. Xingyun Lake in the south and Liangwang River and Xilong Pool in the north supply water to Fuxian Lake, and the lake water runs into Nanpan River through Haikou River in the east. Forest and waters are the two major land use types in Fuxian Lake watershed. In recent years, local vegetation has undergone dramatic changes due to reclaiming farmland from lakes, deforestation, over-exploitation of tourist resources and construction activities.

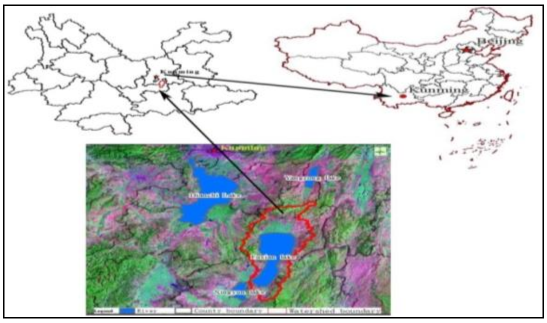

Figure 1: *The location of Fuxian lake watershed*

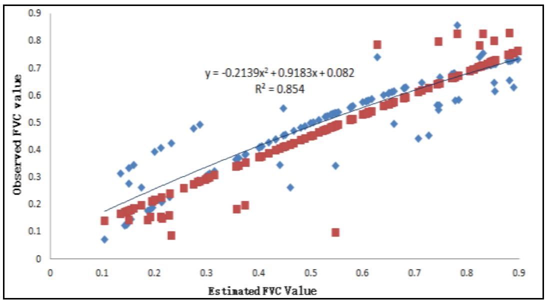

Figure 2: *The correlation analysis of the estimated fractional vegetation cover (FVC) and observed value in study area*

3. Data Source and Method

3.1. Data Source and Pretreatment

3.1.1 Data source

Remote sensing data and GIS data are used. Specifically, the remote sensing data are Landsat MSS images of 1974 (138/44) and 1977 (139/43), Landsat TM images of 1987, 1990, 1996, 2000, 2006, 2009 and 2012 and Landsat OLI images of 2014 and 2015, totaling 11 scenes. The orbit numbers are 138/44, 139/43, 129/43, 129/44 and 130/44. Satellite images are downloaded from the website of United States Geological Survey (http://glovis.usgs.gov/). The images of dry season from December to April of the following year are chosen for the sake of comparability. Other data are boundaries of watershed, 1:10000 DLG data of the watershed, DEM data with 2m grid spacing, and field survey data from October to December in 2014.

3.1.2 Pretreatment

(1) Geometric registration of the remote sensing data: Geometric registration is performed using ENVI 4.8 on 2 MSS scenes of 1974 and 1977 and 7 Landsat TM5 scenes of 1987, 1990, 1996, 2000, 2006, 2009 and 2012. ENVI 5.1 is used for registration of 8 Landsat 8 scenes of 2014 and 2015. The images used for registration are WorldView-2 images of 2012 after orthogonal projection correction. The fitting error is below 0.5 pixel and the resolution of resampling is 30m; (2) Atmospheric correlation of remote sensing data: Atmospheric conditions vary with the weather and the solar elevation angle, and the surface spectral reflectance will change correspondingly. Thus atmospheric correction is necessary to reduce atmospheric effect. ENVI 4.8 and ENVI5.1 are used for atmospheric correction and radiometric correction, respectively. For atmospheric correction, parameters of header files for TM images are used, including time of data reception (hour, day, month, year), solar elevation angle, and longitude and altitude. By atmospheric correction, the effect of atmosphere and illumination on surface spectral reflectance is partially removed; (3) coordinate conversion. Coordinate conversion is performed for auxiliary data. That is, the vector and raster data are converted to CGCS2000 coordinate system. The pretreated remote sensing data are clipped based on boundaries of watershed.

3.2. Method

3.2.1 NDVI estimation and outlier removal

Normalized difference vegetation index (NDVI) is the most widely used indicator of vegetation coverage [15], calculated by dividing the difference of reflectance in the near-infrared (NIR) and red color bands by the sum of reflectance in the NIR and red colors bands for each pixel [11]. Due to atmospheric correction, some pixels may have negative NDVI values. For the shadow regions, NDVI beyond the interval [-1,1] are outliers. For the sake of convenience, these outliers are turned to background values of 0, by using the following method:

$$(NDVI\ lt\ -1)*0+(NDVIgt\ 1)*0+(NDVIge\text{-}1\ and\ NDVIle\ 1)*\ NDVI \tag{1}$$

Using formula 1, NDVI values are calculated with the outliers removed.

3.2.2 FVC calculation

Then FVC is calculated using dimidiate pixel model, assuming that the pixel is composed of vegetation cover and bare land and that FVC of the pixel is the percentage of vegetation cover [16].According to relevant study [17], FVC and NDVI are linearly correlated in an extremely significant manner, based on which the formula of mutual conversion can be established. By substituting NDVI into formula (2), the formula of FVC is derived [17]:

$$FVC = (NDVI - NDVI_{soil}) / (NDVI_{veg} - NDVI_{soil}) \tag{2}$$

where $NDVI_{veg}$ is NDVI value of vegetation cover, and $NDVI_{soil}$ is NDVI value of bare land.

However, the NDVIsoil and NDVIveg values changes temporally and spatially under different atmospheric and surface conditions and with seasons and years in different regions [11,18]. To obtain more accurate NDVI values, the cumulative probability distribution or histogram is plotted for regional NDVI values, and 5% and 95% confidence intervals are computed. The NDVIsoil and NDVIveg values based on statistical estimation are shown in Table 1.

Table 1: *The value of $NDVI_{soil}$ and $NDVI_{veg}$ in study area*

Year	$NDVI_{soil}$	$NDVI_{veg}$	Year	$NDVI_{soil}$	$NDVI_{veg}$	Year	$NDVI_{soil}$	$NDVI_{veg}$
1974	0.0712	0.7236	1996	0.0748	0.7576	2012	0.0867	0.8891
1977	0.0684	0.7067	2000	0.0679	0.7238	2014	0.0842	0.8682
1987	0.0887	0.8956	2006	0.0806	0.8481	2015	0.0885	0.8996
1990	0.0789	0.8874	2009	0.0695	0.6954			

3.2.3 Grading of FVC

At present there is uniform standard for the grading of FVC and varying critical values for grading may be used [9,19]. Grading of FVC depends on specific circumstances of the study area and vegetation characteristics. Here, based on existing literature and the values of FVC calculated from 11 scenes of images from 1974 to 2014, FVC values are divided into 5 grades. Grade Ⅰ FVC is defined bare land cover in the interval [0,10%]; grade Ⅱ, low vegetation cover, in the interval [10%-30%]; grade Ⅲ, low to moderate vegetation cover, in the interval [30%-45%]; grade Ⅳ, moderate to high vegetation cover, in the interval [45%-60%]; grade Ⅴ, high vegetation cover, in the interval [60%-100%]. By density slicing, the FVC grade map (Figure. 3) is generated along with the areas of each grade (Table 1).

3.2.4 Density slicing and calculation of difference images

According to actual conditions of the study area and field survey, FVC values are extracted by density slicing and calculation of different images. In previous studies, the threshold for grading is set as 10%, which is a negligence of the area with reduction of FVC by 0-10% [8]. We treat the negative values of FVC different as information of vegetation damage, positive values as information of vegetation restoration, and zero as extremely small or no change of vegetation cover.

3.2.5 Precision validation

For precision validation, FVC was surveyed in the study area from June to September 2014 when the vegetation cover was higher. Data were collected from 132 sampling points, and the correlation between FVC estimated from remote sensing images and measured FVC is analyzed, as shown in Figure 2. It is easy to see that the estimated and measured FVC values have significant correlation, with R^2=0.81, indicating remote sensing-based FVC estimation has high precision and reliability (Figure. 2).

4. Result and Analysis

In the past 40 years, the area of grade Ⅰ FVC is the largest in all years in the watershed. The area of grade Ⅱ and Ⅲ FVC accounts for a larger proportion in 1974, 1977, 1989 and 1996, as opposed to small area of grade Ⅳ and Ⅴ FVC. After 2000, the area of grade Ⅱ, Ⅲ, Ⅳ and Ⅴ is similar. In 2006, 2009, 2012 and 2014, the area of grade Ⅳ and Ⅴ FVC is larger than that of grade Ⅱ and Ⅲ (Table 1).

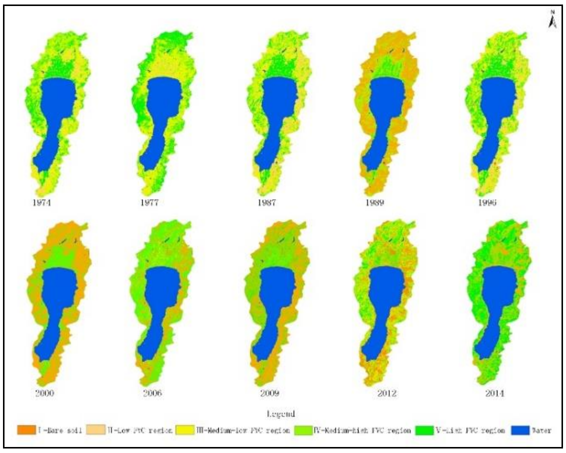

Figure 3: *FVC value distribution*

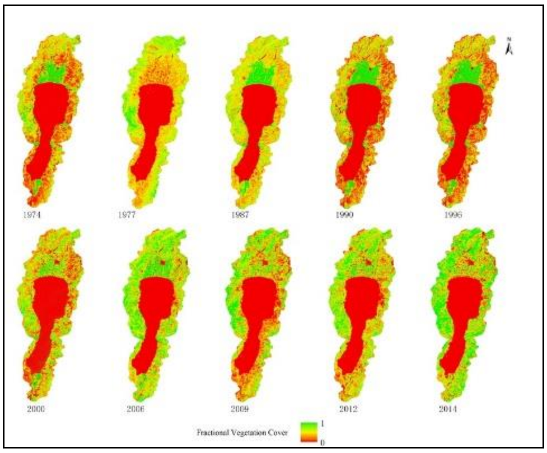

Figure 4: *Changes of FVC in each grade*

The changes of FVC in each grade in the watershed are shown in Figure. 4. According to Figure. 3, the area of grade Ⅰ remains basically stable since 1974 except in 1977 and 1987, with the peak occurring in 1996. The area of grade Ⅱ FVC fluctuates more dramatically in the watershed, with trough values appearing in 1989 and 2006 and 3 peaks in 1989, 2000 and 2009. The area of grade Ⅲ FVC is increasing from 1974 to 1977 but decreasing from 1977 to 2014, though the total area of grade Ⅲ FVC changes only mildly. The area of grade Ⅳ FVC starts to increase from 1974 until reaching a peak in 1977. From 1974 to 1989, the area of grade Ⅳ FVC decreases, but increases again after 1989. It shows a stably increasing trend from 2009 to 2014. The area of grade Ⅴ FVC is increasing monotonically from 1974 to 2014. FVC of Fuxian Lake watershed has generally increased in the past 40 years.

However, areas of each grade of FVC across the years cannot reflect the conversion between different grades of FVC, but only provide a general picture of changes. Transition matrix deals with the transition of factors in a system, where the result of time point n is only affected by the state of time point n-1. That is to say, the result is only related to the current state and not to the past states. Thus transition matrix can be used to quantify the conversion between different grades of FVC and to reveal the probability of transition between grades of FVC across time and space [12]. Using the FVC map of Fuxian Lake watershed, the transition matrices of FVC are constructed for 1974-1977, 1977-1987, 1987-1989, 1989-1996, 1996-2000, 2000-2006, 2006-2009, 2009-2012, 2012-2014, and 1974-2014, respectively (Table 2). On this basis, the conversion and transition of area of different grades of FVC can be known.

Table 2: *Transition matrices of FVC in the watershed across the years (hectares)*

Item	1974	1977	1987	1989	1996	2000	2006	2009	2012	2014
Ⅰ	27458.0	21990.0	22232.7	29225.9	29815.8	26346.2	25424.2	26420.1	25127.1	25015.0
Ⅱ	11965.0	6512.7	4796.9	11205.6	9411.0	10464.3	5994.4	9508.2	6711.6	5843.2
Ⅲ	12143.6	17524.3	15835.7	10794.0	9711.0	10346.8	10665.3	10113.7	10556.1	9793.0
Ⅳ	6736.2	13723.4	13045.4	6321.7	7509.0	8642.1	11723.0	8194.0	9693.3	9950.3
Ⅴ	9175.5	7220.6	10072.2	9931.1	11031.6	11678.8	13671.2	13242.4	15390.2	16877.0

In Table 2, the percentage of area of grade I FVC converted into other grades is 4.64%, 5.36%, 3.90% and 4.92%, respectively, from 1974 to 2014; the remaining 81.18% of the area of grade I FVC remains constant. The percentage of area of grade II FVC converted into other grades is 7.48%, 26.68%, 21.57% and 27.15%, respectively; the remaining 17.12% of the area of grade II FVC remains constant. The percentage of area of grade III FVC converted into other grades is 4.74%, 10.31%, 23.12% and 38.88%, respectively; the remaining 22.94% remains constant. The percentage of area of grade Ⅳ FVC converted into other grades is 4.65%, 6.11%, 13.83% and 54.52%, respectively; the remaining 20.89% remains constant. The percentage of area of grade Ⅴ FVC converted into other grades is 10.24%, 9.34%, 15.37% and 22.71%, respectively; the remaining 42.32% remains constant. From 1974 to 2014, the area of grade I FVC remains basically unchanged, with 81.18% being constant. The variation trend of area of grade II, III and IV is consistent. Comparatively, the area of grade I FVC changes more dramatically, and only 20.32% of the area remains constant on average. Compared to grade II, III and IV, the area of grade V FVC changes less significantly, and 42.32% of the area remains constant on average.

4. Conclusion and Discussion

(1) Temporal and spatial evolution of area of each grade of FVC in Fuxian Lake watershed show significant differences. The area of grade I FVC is the largest across the years, and the area of other grades shows significant interannual variation. In 1974, 1977, 1989 and 1996, the area of grade II and III FVC is the largest, and that of grade IV and V FVC is the smallest. After 2000, the area of grade II, III and IV FVC fluctuates mildly. In 2006, 2009, 2012 and 2014, the area of grade Ⅳ and V FVC is the largest, while that of grade II and III FVC is the smallest. Regions with lower slope gradient generally have low vegetation cover (grade Ⅰ). Steeper regions mostly have low (grade III), moderate to high (grade IV) and high (grade V) FVC. In the past

years, the area of grade I FVC in Fuxian Lake watershed changes very little, as opposed to large fluctuation of area of grade II-IV FVC, with appearance of several trough and peak values. The area of grade Ⅴ FVC shows an increasing trend, indicating vegetation restoration under the ecological protection policy for the watershed. With the implementation of the policy of returning cultivated land to forest since 2003, the area of grade Ⅴ FVC in Fuxian Lake watershed has been increasing.

(2) Given the complicity and diversity of vegetation type and growth and underlying surface, the vegetation and bare land NDVI values are completely extracted from then remote sensing images. However, the cloud cover in some regions is above 5%. Although the precision requirement is met, the estimated and measured FVC values can be hardly consistent. For this reason, precision of the retrieved FVC values needs to be tested. Besides, the non-density and mixed density subpixels are not considered.

(3) Due to global warming and intense human activities, the water body of Fuxian Lake has been dwindling in recent years. With dramatic changes of land use types in the watershed, water and soil erosion and soil deterioration have become the main concerns. FVC monitoring based on multi-temporal remote sensing data and GIS technology can provide basic data for ecological protection and restoration of Fuxian Lake watershed.

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