

# Vegetation coverage change and associated driving forces in mountain areas of Northwestern Yunnan, China using RS and GIS

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**Abstract** The dynamics of vegetation coverage and associated driving forces are one of the key issues in global environmental change. In the study, taking Lijiang County as a case, the Normalized Difference Vegetation Index was used to quantify vegetation coverage change in mountain areas of Northwestern Yunnan, China, with the application of remote sensing data and GIS technologies. And associated driving forces of vegetation coverage change were also analyzed, with a focus on land use change and elevation. The results showed that there was high vegetation coverage with a significant increase in the whole county during 1986–2002. However, due to economic development and the implementation of environmental protection polices, vegetation coverage change in the county showed distinct spatial diversity, which mainly

behaved as the increasing in the northwest of the county with low human activities, and the decreasing in the south with high economic development. The results also showed that as a restrictive factor, elevation was of great signification on the spatial distribution of vegetation coverage in a broad scale; while in the county level, it was land use that determined the vegetation coverage, since the change of vegetation coverage grades in the study area was mainly associated with the change of land use types.

**Keywords** NDVI · Vegetation coverage change · Land use change · Elevation · Lijiang County · China

## Introduction

As a composition of plants maintaining natural ecosystem health with great sensitivity to the changes of environmental elements, vegetation is always taken as an important indicator for measuring local environmental conditions and detecting environmental changes (Yue et al. 2010), and vegetation coverage change is gaining recognitions as a key component of global environmental change (Rees et al. 2001).

Due to their temporal resolution and timely updating, time series of remotely sensed data are widely used in environmental change detection. In recent decades, with the application of remote sensing and GIS technologies, numerous case studies have been conducted to monitor and map the change of

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vegetation coverage at multi-spatial scales, especially at macro-spatial scales such as global (Myneni et al. 1997; Nemani et al. 2003; Slayback et al. 2003), national (Stapanian et al. 1997; Fang et al. 2004; Herrmann et al. 2005), and provincial scales (Cuomo et al. 2001; Burgos and Maass 2004; Weiss et al. 2004; Maselli 2004; Rull et al. 2005; Fensham et al. 2005; Lee 2005; Morawitz et al. 2006; Seabrook et al. 2007; Xu et al. 2008; Luck et al. 2009), with few studies conducted at county or lower level. On the other hand, as to temporal scales concerned in the studies, long-term change monitoring of vegetation coverage is often conducted with the application of historical or archaeological data, which usually covers hundreds to 10,000 years (Rees et al. 2001; Weiss et al. 2004; Rull et al. 2005; Lejju 2009). However, although long-term change monitoring can provide necessary information on the prediction of vegetation coverage change in the future, it may average out multiple short-term changes (Morawitz et al. 2006) and thus fails to detect the change process at fine temporal intervals in the near past decades. That is to say, short-term change detection in recent decades is also of great importance (Myneni et al. 1997; Cuomo et al. 2001; Fang et al. 2004; Maselli 2004; Morawitz et al. 2006; Liu et al. 2009), since what human beings can perceive clearly are environmental changes extending for generations.

Compared with flourish case studies on vegetation coverage change conducted in such representative areas as coastal zones (Maselli 2004; Nezlin et al. 2005; Lee 2005; Diodato and Bellocchi 2008), urban areas (Morawitz et al. 2006; Luck et al. 2009), rangelands or agricultural areas (Kraaij and Milton 2006; Seabrook et al. 2007; Meliadis et al. 2010), and arid or semiarid areas (Weiss et al. 2004; Burgos and Maass 2004; Herrmann et al. 2005; Fensham et al. 2005; Rahlao et al. 2008; Lejju 2009), few studies are focused on the change in mountain areas (Liu et al. 2009), while they are always covered with abundant vegetation and identified as globally significant regions for their rich biodiversity. In addition, it has been recognized that the change of vegetation coverage grades is also one of the key components of vegetation dynamics, which can help to assess environmental effects of vegetation coverage change more clearly. However, although distinct changes of vegetation coverage ratio have been monitored and assessed in various case studies, few are conducted to detect

detailed change processes of vegetation coverage grades, especially conversions among various grades.

Due to its global occurrence and significant environmental effects, climate change has been identified as one of the most important driving forces of vegetation coverage change with numerous case studies (Nemani et al. 2003; Roerink et al. 2003; Yu et al. 2003; Nezlin et al. 2005; Herrmann et al. 2005; Xu et al. 2008; Zeng and Yang 2008). As a crucial water source for plant growth, groundwater is also regarded as one of the key factors resulting in vegetation coverage change (Naumburg et al. 2005; Xu et al. 2007). Although human-induced land use change is always regarded as an important human factor leading to vegetation coverage change (Long et al. 2006, 2009), few are conducted to quantify such influence, whereas most of case studies on land use change monitoring and assessment are directly based on remote sensing data of vegetation coverage (De Fries and Townshend 1994; Burgos and Maass 2004; Morawitz et al. 2006). In addition, topography is always recognized as a crucial natural factor restricting environmental changes such as land use change and vegetation coverage change, especially in mountain areas with rough terrain, while it remains uncertain on how elevation gradient influences the change of vegetation coverage.

In order to enrich regional cases of global vegetation coverage change in the near past decades with a focus on mountain areas, Lijiang County in Northwestern Yunnan Province was chosen as a case study area. More specifically, the aims of this study were to monitor and map the spatio-temporal dynamics of vegetation coverage in Lijiang County during 1986–2002 with the application of remote sensing data and GIS technologies, to quantify detailed transition process among various vegetation coverage grades through the calculation of change matrix, and to detect associated driving forces of vegetation coverage change using statistical methods with a focus on land use and elevation.

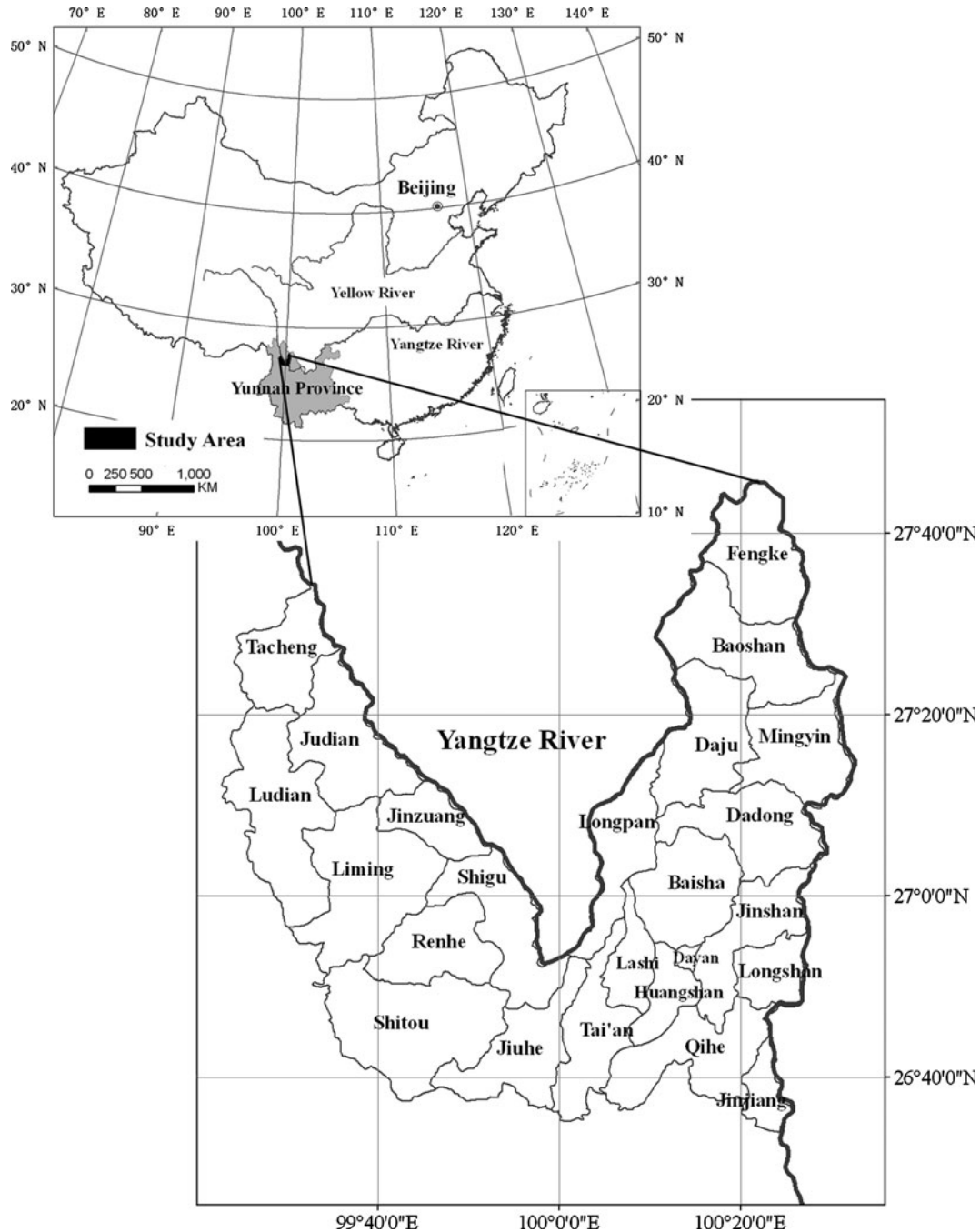
## Materials and methods

### The study area

As a typical rural minority area with fragile mountain environment and low economic development (Peng et

al. 2008), Lijiang County is located in the northwest of Yunnan Province, 99°23′–100°32′ E, 26°34′–27°46′ N, with Yangtze River flowing through (Fig. 1). The total area of the county is 7,648 km<sup>2</sup>, with 92.3% mountainous area. The length of the county is 112 km from east to west, with the width of

150.7 km from north to south, and the elevation rises from southeast to northwest. Due to the cutting process by Jinsha River and its branches, the earth surface appears fragmented. The whole county receives great solar radiation with little change of the temperature during 1 year. In addition, there are 24 towns in Lijiang



**Fig. 1** The sketch map of Lijiang County, China

County, undergoing rapid economic growth in recent years. By the end of 2002, the whole population of the county is 350,826, with 79.78% for agricultural population and ethnic minority population accounted for 83.07%.

As Lijiang County is located in the transition zone extending from the low altitude of Yunnan-Guizhou plateau to the high altitude of Qinghai-Tibet Plateau, it covers two physiognomy units, that is, Hengduan-shan Canyon and Dianxi Plateau, which make there are high mountains in the center and gorges all around with rugged terrain, lean soil, and heavy water and soil erosion. The study area has a low latitude and plateau monsoonal climate with clearly demarcated four seasons as dry in winter and spring and wet in summer and autumn. The average annual temperature is 12–20°C, and the mean annual rainfall is about 1,000 mm.

#### Remote sensing monitoring of vegetation coverage

There are two approaches in vegetation coverage detection, i.e., field survey and remote sensing. Since vegetation coverage shows significant spatial and temporal variation, it is difficult to estimate the vegetation coverage through traditional field sampling at a broad scale with high accuracy. On the contrary, in view of these defects, the approach of remote sensing is competent for its good temporal and spatial continuity (Wang et al. 2008). Along with the wide use in landscape dynamics and land use/cover change (Chen et al. 2001; Fu and Lv 2006; Fu et al. 2006, 2008), remotely sensed image has become a reliable and effective data source in vegetation dynamic studies (Zeng and Yang 2008; Liu et al. 2009; Wei et al. 2009; Hu et al. 2010), especially for rapid monitoring at global or regional scale. Furthermore, there are mainly two methods in dealing with remotely sensed images in quantifying vegetation coverage, i.e., mixed pixel decomposition and vegetation index (VI). Generally speaking, the former is based on spectral mixture model, which considers that the size of ground objective is often smaller than the spatial resolution of remotely sensed images and that the pixel characters of remotely sensed image can reflect the comprehensive information of land cover features, but the accuracy of measurement is directly restricted by the technological maturity of mixed pixel decomposition; the latter is extensively accepted

through establishing the relationship between vegetation coverage and vegetation indices.

VI is competent to characterize the distribution and quality of vegetation coverage, usually acquired through linear or nonlinear combination of red band and near-infrared band, each of which represents the photosynthesis and indicates the health status of plant leaves, respectively. There are mainly two approaches to quantify vegetation coverage with the application of VI, i.e., the empirical model and the conversion of vegetation index. On one hand, with the aid of establishing the empirical relationships between actual vegetation coverage and VI, empirical model is an effective approach to measure the vegetation coverage in the specific region with field measured data. However, the very empirical relationship established in the specific region may be ineffective along with the extending of the study area. On the other hand, the conversion of vegetation index also demands the construction of relationships between vegetation coverage and VI, while it is not based on field survey but spectral signal. Thus, the approach of VI conversion has been widely used in numerous case studies, since it is not dependent on the measured data of vegetation coverage.

At present, there are over 40 kinds of vegetation indices used in vegetation coverage monitoring, such as Ratio Vegetation Index, Difference Vegetation Index (DVI), Perpendicular Vegetation Index, Green Vegetation Index, Enhanced Vegetation Index, Soil-Adjusted Vegetation Index (SAVI), Modified SAVI (MSAVI), Normalized DVI (NDVI), etc. As it is sensitive to vegetation coverage density and plant growth condition (Tucker 1979) and is the least influenced by topography (Morawitz et al. 2006; Rastmanesh et al. 2010), NDVI is the most widely adopted vegetation index (Chen et al. 2006; Diodato and Bellocchi 2008; Zeng and Yang 2008; Rastmanesh et al. 2010). In addition, NDVI has been proven to be highly sensitive with the vegetation coverage ratio of 25–80%, and Lijiang County happens to have the similar vegetation coverage features. Thus, NDVI is used to quantify the change of vegetation coverage in the study area.

In detailed calculation as shown in Eq. 1, NDVI is defined as the difference of the spectral reflectance between near-infrared band and visible red band normalized by the summation of these two bands, where NIR is near-infrared band, R is visible red

band. In the case of Landsat TM data, NIR is represented by TM4 band with TM3 band for R. Generally speaking, NDVI ranges from  $-1$  to  $1$ . The negative value indicates land cover without chlorophyll, such as cloud, rock, water, storm, etc. The positive value represents vegetation coverage, with the higher value for the more dense coverage and healthy of green vegetation.

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

Vegetation coverage change matrix analysis

As vegetation coverage is highly dynamic due to climate change and human activities, the value of NDVI is always found to be changeable in numerous case studies. Therefore, it is significant to assess the change of vegetation coverage, besides the change detection. At present, the method of grade change is widely used, which focuses on the distinct change of vegetation coverage and ignores the small change. According to natural conditions of the study area, vegetation coverage is divided into four grades with NDVI value, i.e., full vegetation coverage (FVC,  $1 \geq NDVI \geq 0.9$ ), high vegetation coverage (HVC,  $0.9 > NDVI \geq 0.5$ ), medium vegetation coverage (MVC,  $0.5 > NDVI \geq 0.26$ ), and low vegetation coverage (LVC,  $0.26 > NDVI \geq -1$ ).

To detect the detailed process of vegetation coverage change, the change matrix of vegetation coverage grades are conducted through the spatial overlay of the two maps of vegetation coverage grade.

Generally speaking, the overlay of two maps  $A_{i \times j}$  and  $B_{i \times j}$  keeps to the map algebraic formula (2), which is valid with the number of vegetation coverage grades not more than 10. After the map algebraic operation, a map of vegetation coverage grade change  $C_{i \times j}$  is derived to represent the types of vegetation coverage change from time  $A$  to time  $B$  and associated spatial distribution.

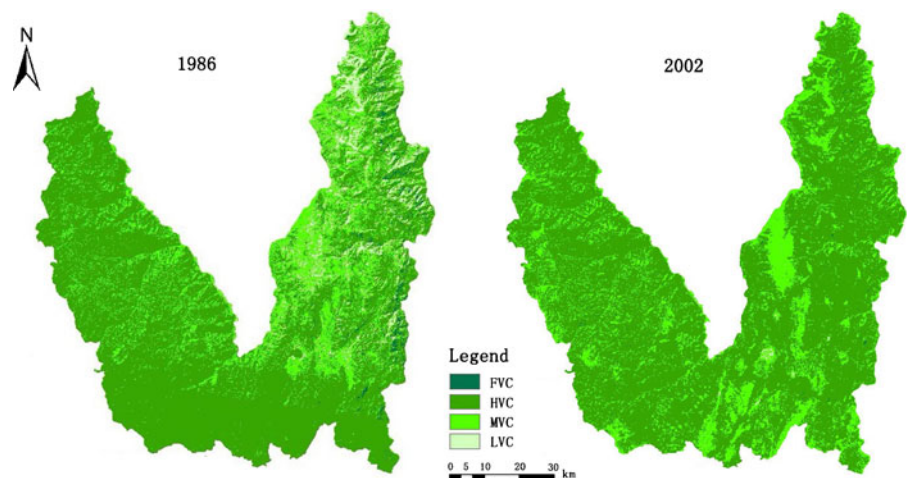
$$C_{i \times j} = A_{i \times j} \times 10 + B_{i \times j} \tag{2}$$

In this study, to avoid the uncertainty in data series resulting from different collection periods of the year (Carlsson et al. 2005), a series of cloud-free Landsat TM images (WRS path 131, row 42; path 132, row 41; path 131, row 41) with the same vegetation growing season are selected as the main data source, which are acquired on November 2, 1986 and February 7, 2002, respectively. The resolutions of the images are 30 m. With the aid of image enhancement, geometric adjustment, feature extraction, and statistical analysis, the comparable NDVI values and vegetation coverage grades are obtained (Fig. 2).

Driving forces analysis of vegetation coverage change

Both factors of land use and elevation are focused to analyze the driving forces of vegetation coverage change, with the application of spatial overlaying and statistical analysis in ArcGis 9.3. In details, land use maps in 1986 and 2002 are acquired through supervised classification and visual interpretation using the same Landsat TM images. Ten types of land use are classified (Peng et al. 2008); paddy field

**Fig. 2** Change of vegetation coverage grade during 1986–2002 in Lijiang County



(PAF, refers to arable land for rice cultivation), dry land (DRL, refers to arable land except paddy field), dense forest land (DFL, refers to the forest land with a coverage density above 30%, including natural forests and plantations), sparse forest land (SFL, includes shrub land, sparse woodland and orchard), grassland (GRL, refers to the areas with herbaceous vegetation coverage used for grazing, including natural and cultivated grassland), water body (WAB, means rivers, lakes, and reservoirs), glacier or snow-capped land (GSL, refers to land covered by glaciers or permanent snow all year round), construction land (COL, includes urban and rural settlements, industrial and mining sites, and transport sites), waste grassland (WGL, refers to unused grassland with herbage density less than 10%), and bare land (BAL, means uncovered rock gravel, sand, and other non-vegetation land).

In addition, based on the digital elevation map of Lijiang County in 2002, at a scale of 1:50,000, the whole county is divided into five elevation zones, i.e., 0–2,000, 2,000–2,500, 2,500–3,000, 3,000–3,500, and 3,500–6,000 m.

## Results

### Spatial differentiation and change of vegetation coverage

Through Fig. 2, it can be found that there is distinct spatial differentiation of vegetation coverage in the study area with distinct change during 1986–2002. In details, the main spatial pattern of vegetation coverage in the study area was the contrast between the higher south and the lower north especially the lowest northeast in 1986. While in 2002, it has been converted to the contrast between the higher west and east and the lower middle part of the county, with a distinct increase of vegetation coverage in the northeast and decrease in the south. Furthermore, vegetation restoration mainly occurred in mountain areas along with Jinsha River due to the implementation of environmental policies such as Natural Forest Protection Project and Grain-for-Green Project (Long et al. 2006). And most of basins in Lijiang County are distributed in the south where natural vegetation is easily replaced by human settlements and agricultural vegetation.

In view of the change of vegetation coverage grade, there is a positive change of vegetation coverage for the whole county during 1986–2002, as most of low vegetation coverage has disappeared with a great increase of high vegetation coverage (Table 1). In details, during the study period, a few pixels with full vegetation coverage mainly located along the Jinsha River; accounting for a majority proportion, the grade of high vegetation coverage distributed in the southern and northwestern part, with the distinct increase mainly occurring at the western and eastern part; medium vegetation coverage was mainly located in the east of the county with high spatial continuity, occupying a certain proportion with few change; and a few pixels with low vegetation coverage was mainly located in the ridge of Yulong Mountain in 1986, while there is a significant reduction during 1986–2002 with scattering of spatial distribution in the center of towns.

As shown in Table 1, the process of change for each grade of vegetation coverage is quite different, which can be characterized as follows: during the study period, almost all the full vegetation coverage has been degraded to be high vegetation coverage; high vegetation coverage is the most stable grade with 85.51% unchanged, while the rest mainly degraded to be medium vegetation coverage; there are 65.32% of medium vegetation cover turning to be high vegetation coverage with the other unchanged; and almost all the low vegetation coverage has made a positive change to the grade of high or medium vegetation coverage with the rate of 48.73% and 48.75%, respectively. Therefore, it can be concluded that there is high vegetation coverage in the study area with the process of vegetation restoration during 1986–2002.

**Table 1** Change matrix of vegetation coverage in Lijiang County during 1986–2002 (%)

Vegetation coverage grade in 1986	Vegetation coverage grade in 2002				
	FVC	HVC	MVC	LVC	Area ratio
FVC	3.55	92.45	4.00	0.00	1.09
HVC	0.11	85.51	14.25	0.14	71.95
MVC	0.02	65.32	33.91	0.74	20.72
LVC	0.02	48.73	48.75	2.51	6.24
Area ratio	0.12	79.11	20.36	0.41	100.00

Driving forces of vegetation coverage change

Land use change and vegetation coverage change

As shown in Fig. 3, in view of the average value of NDVI, there is significant difference among different land use types. In details, dense forest land has the highest value, followed by sparse forest land, grassland, dry land, paddy field, and waste grassland, construction land, and bare land, with glacier or snow-capped land and water body for the lowest value.

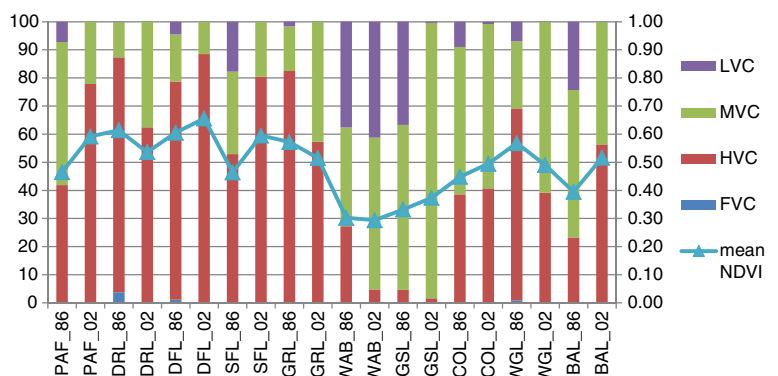
By comparing the area ratio of vegetation coverage grades in each land use type (Fig. 3), it can be found that during the study period, water body, glacier or snow-capped land, sparse forest land, and bare land are mainly occupied by medium and low vegetation coverage, while high and medium vegetation coverage accounts for more than 90% of the whole area for each of the other land use types. Due to little area ratio in the whole county, full vegetation coverage is less than 4% in each land use type. During 1986–2002, it showed vegetation improvement in paddy field, dense forest land, sparse forest land, glacier or snow-capped land, construction land, and bare land with distinct increase of area ratio for higher vegetation coverage grades, while there are vegetation degradation in dry land, grassland, water body, and waste grassland with more or less decrease. In addition, in view of area ratio of vegetation coverage grades, dense forest land, sparse forest land, paddy field, dry land, and grassland have the best grades structure of vegetation coverage, followed by bare land, construction land, and waste grassland with glacier or snow-capped land and water body for the

worst, which is accordance with the sequence of average NDVI for each land use type (Fig. 3).

Furthermore, as shown in Table 2, dense forest land accounts for a large proportion in each grade of vegetation coverage since it occupies over 67% of the whole county during the study period. Apart from the dominance of dense forest land, the grade of full vegetation coverage is also consisted of dry land, paddy field, and grassland, with the grade of high vegetation coverage equally occupied by all the other land use types. As to the grade of medium vegetation coverage, half is occupied by dense forest land, with paddy field, dry land, and waste grassland covering a certain proportion. There is a great change of the area ratio of land use types in the grade of low vegetation coverage during 1986–2002. In 1986, half of the grade was taken in charge by dense forest land, with sparse forest land followed by bare land, grassland, and glacier or snow-capped land taking a certain proportion. In 2002, the majority of the grade of low vegetation coverage was occupied by water body, with the other land use types taking equal proportion.

In addition, according to the spatial analysis of image pixel, there are 8,292,339 pixels with the change of vegetation coverage grade during 1986–2002 in the whole county, among which 99.93% experienced the change of land use types. Meanwhile, there are 8,307,230 image pixels with the change of land use types, among which 99.76% took place the change of vegetation coverage grade. Therefore, it can be concluded that regional land use change is an important factor influencing vegetation coverage. In details, the change of vegetation coverage grade in Lijiang County is mainly caused by the change of land use types, while to a certain extent the variation

**Fig. 3** Mean NDVI and area ratio of vegetation coverage grades in each land use type during 1986–2002 in Lijiang County



**Table 2** Area ratio of land use types in each vegetation coverage grade of Lijiang County during 1986–2002

		PAF	DRL	DFL	SFL	GRL	WAB	GSL	COL	WGL	BAL
FVC	1986	0.07	19.00	75.03	0.17	0.33	0.00	0.00	0.01	5.38	0.00
	2002	5.10	0.19	92.25	1.66	0.33	0.00	0.00	0.40	0.07	0.01
HVC	1986	2.32	6.32	73.90	4.54	5.36	0.26	0.08	0.37	6.20	0.66
	2002	4.78	4.91	75.38	7.38	2.86	0.05	0.02	0.70	2.08	1.83
MVC	1986	9.80	3.30	55.63	8.75	3.58	1.15	3.32	1.74	7.54	5.21
	2002	5.28	11.45	38.11	6.96	8.29	2.35	5.69	3.91	12.49	5.48
LVC	1986	4.59	0.13	49.15	17.58	1.22	4.09	6.90	0.99	7.33	8.02
	2002	0.29	0.50	3.64	0.27	0.22	89.68	1.13	2.63	1.03	0.63

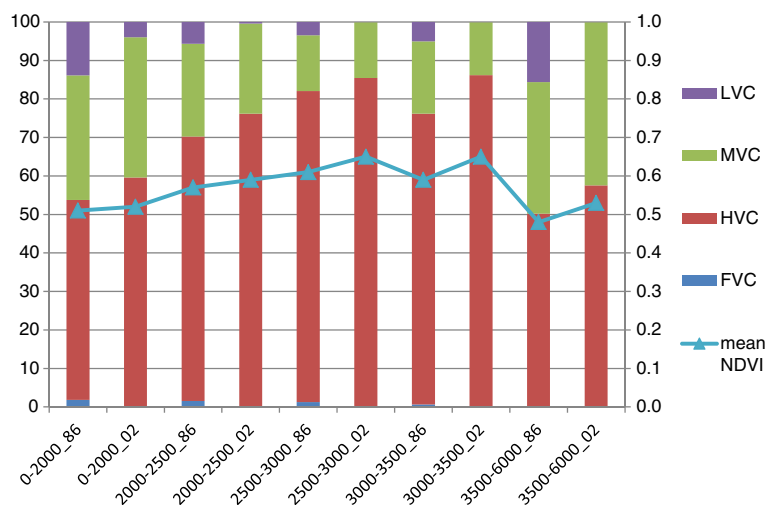
of NDVI within the same vegetation coverage grade refers to the difference of vegetation coverage in the same land use type.

#### *Elevation and vegetation coverage change*

As shown in Fig. 4, there is no distinct difference among the mean NDVI in each elevation zone, although there is high mean NDVI in the elevation zone of 2,000–3,500 m, with the low one for the elevation zone above 3,500 or below 2,000 m. And the spatial differentiation of mean NDVI in various elevation zones mainly results from spatial patterns of land use and vegetation types. In details, it is the dry-hot valley along with Jinsha River that locates below the elevation of 2,000 m in the study area, where the main land use types are bare land, waste grassland, paddy field, and construction land with a few natural vegetation coverages. And it is mountain areas under great risk of soil erosion that distribute above the elevation of 3,500 m. Although

there is more natural than cultivated vegetation in this elevation zone, it is deficient in light and heat resources, and the natural vegetation types are always coniferous forest, alpine meadow, and alpine shrub, with low level of primary productivity. On the contrary, accounting for more than 80% of the study area, the elevation zone between 2,000 and 3,500 m is full of forest and grassland with high level of primary productivity due to the compatible natural conditions of light, heat, water, and soil.

According to the composition of the area ratio of vegetation coverage grades in each elevation zone (Fig. 4), it can be found that during the study period, high vegetation coverage accounts for a large proportion (more than 50%) of area ratio in each elevation zone, with a certain proportion for medium and low vegetation coverage, and there is a few full vegetation coverages with the area ratio less than 2% in all elevation zones. During 1986–2002, there is distinct structural optimization of vegetation coverage grades

**Fig. 4** Mean NDVI and area ratio of vegetation coverage grades in each elevation zone during 1986–2002 in Lijiang County



in all elevation zones, which behaves as area ratio increase of high vegetation coverage, the fluctuation of full and medium vegetation coverage, and the significant reduction of low vegetation coverage.

Furthermore, as shown in Table 3, there are few changes of area ratio of elevation zones for the grades of full, high, and medium vegetation coverage during the study period. In details, full and high vegetation coverage mainly distributes in the elevation zone of 2,500–3,000 m, with a certain proportion in the elevation zone of 3,000–3,500 m, while the medium vegetation coverage is equally located in the elevation zones of 2,500–3,000, 2,000–2,500, and 3,000–3,500 m. However, there was distinct change of area ratio of elevation zones for low vegetation coverage, which behaves as the concentration in the elevation zone of 0–2,500 m in 2002, compared with the equally distribution in all the elevation zones in 1986.

To sum up, it is convinced that the terrain factor is an important constraint factor to NDVI and associated vegetation coverage at large scale (Fu et al. 2004). Because elevation zones are covered by the spatial mosaics of land use types, it can be concluded that the influence of topography on vegetation coverage is indirect via the impact of land use/land cover on vegetation coverage and the effect of topography on land use patterns. In this case study, in Lijiang County, it is proven that the change extent of area ratio of vegetation coverage grades in each elevation zone is less than that in each land use type. Moreover, as there is no significant change of such natural conditions as climate, soil, and hydrology at the temporal scale of decades, it results in the small variation of vegetation coverage without the human-induced change of land use types, which will ultimately lead not to the great fluctuation but small

change of the area ratio of vegetation coverage grades in different elevation zones.

### Conclusions

Taking Lijiang County of Yunnan Province, China as the case study area, vegetation coverage change and associated driving forces in mountain areas were analyzed with the application of NDVI and multi-temporal Landsat TM imagery. The results showed that vegetation coverage for the whole county was growing with high level during 1986–2002, and the most significant change of vegetation coverage was characterized as the increase in the northeast and the reduction in the south which results from environmental policy implementation and socioeconomic development, respectively. Furthermore, through the analysis of the driving factors associated with vegetation coverage change, it was proven that the terrain factor could affect NDVI as the constraint factor at large scale, while human-induced land use change was of great importance to vegetation coverage change. And the grade change of vegetation coverage in the study area was mainly due to the change of land use types.

To date, the focus on vegetation coverage change has been extended from the monitoring and mapping of vegetation coverage change (Myneni et al. 1997; Rees et al. 2001; Cuomo et al. 2001; Fang et al. 2004; Maselli 2004; Weiss et al. 2004; Burgos and Maass 2004; Rull et al. 2005; Lee 2005; Morawitz et al. 2006; Rahla0 et al. 2008; Liu et al. 2009; Meliadis et al. 2010), to the analyzing of associated driving forces (Herrmann et al. 2005; Fensham et al. 2005; Kraaij and Milton 2006; Seabrook et al. 2007; Xu et al. 2007, 2008; Wang et al. 2008; Leju 2009; Luck et al. 2009; Rastmanesh et al.

**Table 3** Area ratio of elevation zones in each vegetation coverage grade of Lijiang County during 1986–2002

		0–2,000 m	2,000–2,500 m	2,500–3,000 m	3,000–3,500 m	3,500–6,000 m
FVC	1986	11.91	28.72	43.49	15.46	0.41
	2002	4.58	6.90	49.43	38.35	0.74
HVC	1986	5.14	19.34	41.61	27.23	6.67
	2002	5.36	19.50	39.96	28.22	6.96
MVC	1986	11.11	23.59	25.99	23.52	15.79
	2002	12.76	23.34	26.45	17.52	19.93
LVC	1986	15.85	18.43	20.57	21.11	24.04
	2002	69.06	20.41	4.99	3.36	2.18

2010), to the assessing of corresponding ecological effects (Zou and Zhai 2004; Nezlin et al. 2005; Chen et al. 2007; Cheng et al. 2008; Zuo et al. 2010), and to the change modeling and predicting with different scenarios (Zhou et al. 2006; Weng and Zhou 2006; Diodato and Bellocchi 2008). All the four fields make up of a full research frame, among which the change detection and driving forces analysis are the primary steps to provide original data for the latter studies on vegetation coverage change, while the ecological effects assessment and scenario modeling are more important since they can provide environmental decisions with direct information on vegetation coverage change for sustainable development. Thus, in this case study, it is necessary to address corresponding ecological effects of vegetation coverage change in further studies. Furthermore, as surface runoff and soil erosion are of great importance to natural ecological processes, environmental protection, and regional development in mountain areas, the effects of vegetation coverage change on the very topic should be focused.

In addition, as we know, natural environmental change and human activities are the mainly two kinds driving forces associated with vegetation coverage change. In this case study, two few-noticed but important driving forces, i.e., land use change and elevation are focused, which are representatives for human and natural parts, respectively. However, although it is thought that the influence of human activities on vegetation coverage change mainly takes effect through the change of land use system, land use change cannot thoroughly represent human activities. More precision on the influences of human activities on vegetation coverage change is appreciated in further studies. Furthermore, the influences of climate change should also be added to make a full depiction of the driving process of vegetation coverage change in the study area.

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## References

- Burgos, A., & Maass, J. M. (2004). Vegetation change associated with land-use in tropical dry forest areas of Western Mexico. *Agriculture, Ecosystems and Environment*, *104*, 475–481.
- Carlsson, A. L. M., Bergfur, J., & Milberg, P. (2005). Comparison of data from two vegetation monitoring methods in semi-natural grasslands. *Environmental Monitoring and Assessment*, *100*, 235–248.
- Chen, L. D., Wang, J., Fu, B. J., & Qiu, Y. (2001). Land use change in a small catchment of northern Loess Plateau, China. *Agriculture, Ecosystems and Environment*, *86*, 163–172.
- Chen, P. Y., Fedosejevs, G., Tiscareno-Lopez, M., & Arnold, J. G. (2006). Assessment of MODIS-EVI, MODIS-NDVI and VEGETATION-NDVI composite data using agricultural measurements: an example at corn fields in western Mexico. *Environmental Monitoring and Assessment*, *119*, 69–82.
- Chen, L. D., Huang, Z. L., Gong, J., Fu, B. J., & Huang, Y. L. (2007). The effect of land cover/vegetation on soil water dynamic in the hilly area of the loess plateau, China. *Catena*, *70*, 200–208.
- Cheng, H. Y., Wang, G. X., Hu, H. C., & Wang, Y. B. (2008). The variation of soil temperature and water content of seasonal frozen soil with different vegetation coverage in the headwater region of the Yellow River, China. *Environmental Geology*, *54*, 1755–1762.
- Cuomo, V., Lanfredi, M., Lasaponara, R., Macchiato, M. F., & Simoniello, T. (2001). Detection of interannual variation of vegetation in middle and southern Italy during 1985–1999 with 1 km NOAA AVHRR NDVI data. *Journal of Geophysical Research*, *106*, 17863–17876.
- DeFries, R. S., & Townshend, J. R. G. (1994). NDVI-derived land cover classifications at a global scale. *International Journal of Remote Sensing*, *15*, 3443–3462.
- Diodato, N., & Bellocchi, G. (2008). Modelling vegetation greenness responses to climate variability in a Mediterranean terrestrial ecosystem. *Environmental Monitoring and Assessment*, *143*, 147–159.
- Fang, J. Y., Piao, S. L., He, J. S., & Ma, W. H. (2004). Increasing terrestrial vegetation activity in China, 1982–1999. *Science in China (Series C)*, *47*, 229–240.
- Fensham, R. J., Fairfax, R. J., & Archer, S. R. (2005). Rainfall, land use and woody vegetation cover change in semi-arid Australian savanna. *Journal of Ecology*, *93*, 596–606.
- Fu, B. J., & Lv, Y. H. (2006). The progress and perspectives of landscape ecology in China. *Progress in Physical Geography*, *30*, 232–244.
- Fu, B. J., Liu, S. L., Ma, K. M., & Zhu, Y. G. (2004). Relationships between soil characteristic, topography and plant diversity in a heterogeneous deciduous broad-leaved forest near Beijing, China. *Plant and Soil*, *261*, 47–54.
- Fu, B. J., Hu, C. X., Chen, L. D., Honnay, O., & Gulincx, H. (2006). Evaluating Change in agricultural landscape pattern between 1980 and 2000 in the loess hilly region of Ansai county, China. *Agriculture, Ecosystems and Environment*, *114*, 387–396.
- Fu, B. J., Lv, Y. H., & Chen, L. D. (2008). Expanding the bridging capability of landscape ecology. *Landscape Ecology*, *23*, 375–376.
- Herrmann, S. M., Anyamba, A., & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, *15*, 394–404.
- Hu, C. J., Fu, B. J., Liu, G. H., Jin, T. T., & Guo, L. (2010). Vegetation patterns influence on soil microbial biomass

- and functional diversity in a hilly area of the Loess Plateau, China. *Journal of Soils and Sediments*, 10, 1082–1091.
- Kraaij, T., & Milton, S. J. (2006). Vegetation changes (1995–2004) in semi-arid Karoo shrubland, South Africa: effects of rainfall, wild herbivores and change in land use. *Journal of Arid Environments*, 64, 174–192.
- Lee, T. M. (2005). Monitoring the dynamics of coastal vegetation in southwestern Taiwan. *Environmental Monitoring and Assessment*, 111, 307–323.
- Lejju, B. J. (2009). Vegetation dynamics in western Uganda during the last 1000 years: climate change or human induced environmental degradation? *African Journal of Ecology*, 47, 21–29.
- Liu, L. Y., Jing, X., Wang, J. H., & Zhao, C. J. (2009). Analysis of the changes of vegetation coverage of western Beijing mountainous areas using remote sensing and GIS. *Environmental Monitoring and Assessment*, 153, 339–349.
- Long, H. L., Heilig, G. K., Wang, J., Li, X. B., Luo, M., Wu, X. Q., et al. (2006). Land use and soil erosion in the upper reaches of the Yangtze River: some socio-economic considerations on China's Grain-for-green Programme. *Land Degradation & Development*, 17, 589–603.
- Long, H. L., Liu, Y. S., Wu, X. Q., & Dong, G. H. (2009). Spatio-temporal dynamic patterns of farmland and rural settlements in Su-Xi-Chang region: Implications for building a new countryside in coastal China. *Land Use Policy*, 26, 322–333.
- Luck, G. W., Smallbone, L. T., & O'Brien, R. (2009). Socio-economics and vegetation change in urban ecosystems: patterns in space and time. *Ecosystems*, 12, 604–620.
- Maselli, F. (2004). Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. *Remote Sensing of Environment*, 89, 423–433.
- Meliadis, I., Platis, P., Ainalis, A., & Meliadis, M. (2010). Monitoring and analysis of natural vegetation in a Special Protected Area of Mountain Antichasia-Meteora, central Greece. *Environmental Monitoring and Assessment*, 163, 455–465.
- Morawitz, D. F., Blewett, T. M., Cohen, A., & Alberti, M. (2006). Using NDVI to assess vegetative land cover change in central Puget Sound. *Environmental Monitoring and Assessment*, 114, 85–106.
- Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G., & Nemani, R. R. (1997). Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature*, 386, 698–701.
- Naumburg, E., Mata-Gonzalez, R., Hunter, R. G., McLendon, T., & Martin, D. W. (2005). Phreatophytic vegetation and groundwater fluctuations: a review of current research and application of ecosystem response modeling with an emphasis on great basin vegetation. *Environmental Management*, 35, 726–740.
- Nemani, R. R., Keeling, C. D., Hashimoto, H., Jolly, W. M., Piper, S. C., Tucker, C. J., et al. (2003). Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, 300, 1560–1563.
- Nezlin, N. P., Kostianoy, A. G., & Li, B. (2005). Inter-annual variability and interaction of remote-sensed vegetation index and atmospheric precipitation in the Aral Sea region. *Journal of Arid Environments*, 62, 677–700.
- Peng, J., Wu, J. S., Yin, H., Li, Z. G., Chang, Q., & Mu, T. L. (2008). Rural land use change during 1986–2002 in Lijiang, China, based on remote sensing and GIS data. *Sensors*, 8, 8201–8223.
- Rahlao, S. J., Hoffman, M. T., Todd, S. W., & McGrath, K. (2008). Long-term vegetation change in the Succulent Karoo, South Africa following 67 years of rest from grazing. *Journal of Arid Environments*, 72, 808–819.
- Rastmanesh, F., Moore, F., Kharrati-Kopaei, M., & Behrouz, M. (2010). Monitoring deterioration of vegetation cover in the vicinity of smelting industry, using statistical methods and TM and ETM+ imageries, Sarcheshmeh copper complex, Central Iran. *Environmental Monitoring and Assessment*, 163, 397–410.
- Rees, M., Condit, R., Crawley, M., Pacala, S., & Tilman, D. (2001). Long-term studies of vegetation dynamics. *Science*, 293, 650–655.
- Roerink, G. J., Menenti, M., Soepboer, W., & Su, Z. (2003). Assessment of climate impact on vegetation dynamics by using remote sensing. *Physics and Chemistry of the Earth*, 28, 103–109.
- Rull, V., Abbott, M. B., Polissar, P. J., Wolfe, A. P., Bezada, M., & Bradley, R. S. (2005). 15,000-yr pollen record of vegetation change in the high altitude tropical Andes at Laguna Verde Alta, Venezuela. *Quaternary Research*, 64, 308–317.
- Seabrook, L., McAlpine, C., & Fensham, R. (2007). Spatial and temporal analysis of vegetation change in agricultural landscapes: a case study of two brigalow (*Acacia harpophylla*) landscapes in Queensland, Australia. *Agriculture, Ecosystems and Environment*, 120, 211–228.
- Slayback, D., Pinzon, J., Los, S., & Tucker, C. (2003). Northern Hemisphere photosynthetic trends 1982–1999. *Global Change Biology*, 9, 1–15.
- Stapanian, M. A., Cline, S. P., & Cassell, D. L. (1997). Evaluation of a measurement method for forest vegetation in a large-scale ecological survey. *Environmental Monitoring and Assessment*, 45, 237–257.
- Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8, 127–150.
- Wang, J., Meng, J. J., & Cai, Y. L. (2008). Assessing vegetation dynamics impacted by climate change in the southwestern karst region of China with AVHRR NDVI and AVHRR NPP time-series. *Environmental Geology*, 54, 1185–1195.
- Wei, W., Chen, L. D., Fu, B. J., Lv, Y. H., & Gong, J. (2009). Responses of water erosion to rainfall extremes and vegetation types in a loess semiarid hilly area, NW China. *Hydrological Processes*, 23, 1780–1791.
- Weiss, J. L., Gutzler, D. S., Allred, C. J. E., & Dahm, C. N. (2004). Long-term vegetation monitoring with NDVI in a diverse semi-arid setting, central New Mexico, USA. *Journal of Arid Environments*, 58, 249–272.
- Weng, E. S., & Zhou, G. S. (2006). Modeling distribution changes of vegetation in China under future climate change. *Environmental Modeling and Assessment*, 11, 45–58.
- Xu, H. L., Ye, M., Song, Y. D., & Chen, Y. N. (2007). The natural vegetation responses to the groundwater change resulting from ecological water conveyances to the lower Tarim River. *Environmental Monitoring and Assessment*, 131, 37–48.
- Xu, X. K., Chen, H., & Levy, J. K. (2008). Spatiotemporal vegetation cover variations in the Qinghai-Tibet Plateau

- under global climate change. *Chinese Science Bulletin*, 53, 915–922.
- Yu, F. F., Price, K. P., Ellis, J., & Shi, P. J. (2003). Response of seasonal vegetation development to climatic variations in eastern central Asia. *Remote Sensing of Environment*, 87, 42–54.
- Yue, Y., Wang, K., Zhang, B., Chen, Z., Jiao, Q., Liu, B., et al. (2010). Exploring the relationship between vegetation spectra and eco-geo-environmental conditions in karst region, Southwest China. *Environmental Monitoring and Assessment*, 160, 157–168.
- Zeng, B., & Yang, T. B. (2008). Impacts of climate warming on vegetation in Qaidam Area from 1990 to 2003. *Environmental Monitoring and Assessment*, 144, 403–417.
- Zhou, Z. C., Shanguan, Z. P., & Zhao, D. (2006). Modeling vegetation coverage and soil erosion in the Loess Plateau Area of China. *Ecological Modelling*, 198, 263–268.
- Zou, X. K., & Zhai, P. M. (2004). Relationship between vegetation coverage and spring dust storms over northern China. *Journal of Geophysical Research*, 109, D03104. doi:10.1029/2003JD003913.
- Zuo, X. A., Zhao, X. Y., Zhao, H. L., Guo, Y. R., Zhang, T. H., & Cui, J. Y. (2010). Spatial pattern and heterogeneity of soil organic carbon and nitrogen in sand dunes related to vegetation change and geomorphic position in Horqin Sandy Land, Northern China. *Environmental Monitoring and Assessment*, 164, 29–42.