Detecting and attributing vegetation changes in Taihang Mountain, China

HU Shi[1] https://orcid.org/0000-0002-3550-4538; e-mail: hus.08b@igsnrr.ac.cn

WANG Fei-yu[2] https://orcid.org/0000-0001-9373-0990; e-mail: wangfy123@snnu.edu.cn

ZHAN Che-sheng[1*] https://orcid.org/0000-0001-5014-1723; e-mail: zhancs@igsnrr.ac.cn

ZHAO Ru-xin[3] https://orcid.org/0000-0002-1658-6662; e-mail: zhaorx324@163.com

MO Xiong-guo[1] https://orcid.org/0000-0003-3830-6083; e-mail: moxg@igsnrr.ac.cn

LIU Liang-mei-zi[1,4] https://orcid.org/0000-0002-9333-5058; e-mail: 814186331@qq.com

**Corresponding author*

1 Key Laboratory of Water Cycle & Related Land Surface Processes, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

2 School of Geography and Tourism, Shaanxi Normal University, Xi'an 710119, China

3 College of Water Sciences, Beijing Normal University, Beijing 100875, China

4 University of Chinese Academy of Sciences, Beijing 100049, China

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Abstract: Attributing vegetation changes provide fundamental information for ecosystem management, especially in mountainous areas which has vulnerable ecosystems. Based on the Normalized Difference Vegetation Index (NDVI) data, the spatial-temporal change of vegetation was detected in Taihang Mountain (THM) from 2000 to 2014. The topographical factors were introduced to interpret the response of vegetation variation to climate change and human activities. Results showed that the avegaged NDVI during growing season showed a single-peak curve distribution, with the largest value (0.628) among 1600-1800 m. A significant greening trend was detected in THM, with the largest increasing rate (0.0078 yr^{-1}) among the elevation of 1600-1800 m and slope gradient between 3~5°. The partial correlation and multiple correlation analyses indicated that vegetation variation in more than 81.8% pixels of the THM was mainly impacted by human activities. In the low elevation zones less than 1000 m, increasing precipitation is the principle factor promoting vegetation restoration, whereas in the high elevation zones of THM, temperature is the restricted factors impacting vegetation variation. Considering the dramatic climate change in the future, further studies should be conducted to explore inherent mechanism of vegetation growth to dynamic environment changes.

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Introduction

Characterized by the variations of temperature and precipitation, climate change exerted profound effect on vegetation growth (Piao et al. 2006; Gottfried et al. 2012; Richardson et al. 2013). Compared with other ecosystem, mountainous ecosystem is more sensitive to climate change due to its complex ecosystem structure. Generally, the supply of water and energy determines the large-scale spatial variations in vegetation (Cramer et al. 2001; Theurillat and Guisan 2001); meanwhile, due to variations in elevation and slopes, it has great impacts on small-scale vegetation pattern (Fu et al. 2006; Zhang et al. 2013a). The complex interactions between regional climate and other topography factors caused spatial heterogeneity in plant species (Lenoir et al. 2008) and biodiversity (Eisenlohr et al. 2013), thus eventually influence ecological structure (Zapata-Rios et al. 2015) and ecosystem stability. Therefore, understanding the mechanism of vegetation growing process due to environmental changes is critical to promote ecological construction management in mountainous areas.

Vegetation dynamic can be attributed to natural and anthropogenic effects (Zhang et al. 2013a; Alexander et al. 2016; Tao et al. 2017). On one hand, land use/cover change resulted from human activities such as afforestation, ecological restoration, and urban construction has great influence on vegetation growing process (Xin et al. 2008; Zhang et al. 2016), by changing land surface conditions. For example, the most well-known Grain for Green Program (GGP) launched in 1999 by China, which focused on the return of steep farmlands to forests or grasslands, has greatly changed the spatiotemporal characteristics of land use/land cover (Zhang et al. 2013a; Sun et al. 2015; Li et al. 2016) and vegetation variation (Li et al. 2017). On the other hand, the response of vegetation to climate change is complex and shows huge spatial heterogeneity. Generally speaking, in the arid and semi-arid areas, precipitation is the limiting factor for plant growth (Kawabata et al. 2001; Fensholt et al. 2012), while temperature is the restricted factor in the high latitudes of north hemisphere and Qinghai-Tibet Plateau (Zhou et al. 2001; Li et al. 2015). For mountainous ecosystem, the effects of temperature and precipitation on vegetation are closely related to elevation and slopes, topography-induced redistribution of climate change, represented by changes of humidity (Johansson and Chen 2003; Deng et al. 2013), energy (Zapata-Rios et al. 2015), temperature (Pepin et al. 2015), soil properties (Li et al. 2017), leads to vegetation differentiation (Eisenlohr et al. 2013). Therefore, to deeply understand the response of vegetation variation to climate change in mountainous area, the specific case study is still necessary.

Previous studies have analyzed changes of plant communities and species diversities influenced by local climate change, based on field investigations in different spatial scales, such as plot (Chytrý et al. 2014), slope transect (Gutiérrez-Girón et al. 2015) and small catchment (Wang et al. 2013; Zapata-Rios et al. 2015). It is helpful to acquire firsthand information concerning vegetation growth through such studies at local scales. However, due to a lack of spatially continuous data along vertical gradient in mountainous areas, the mechanism of vegetation changes under topographic impacts at regional scale remains less understood. Satellite imagery is now considered to be a useful tool to study the relationship between vegetation dynamics and climate change, due to its ability to capture the characteristics of temporal dynamics and spatial heterogeneity of vegetation response to climate change (Kerr and Ostrovsky 2003). Remotely sensed NDVI, which can provide spatially continuous maps of the vegetation growth status (Gutman and Ignatov 1998; Yang et al. 1998), has been widely used to detect the vegetation dynamics (Kinyanjui 2011; Wylie et al. 2012) and its response to climate change (Olsson et al. 2005; Cui et al. 2012) at regional or global scales (Gouveia et al. 2016; Zhou et al. 2016), in spite of limitations caused by hindrance of atmosphere and disturbance from electromagnetic signals (Jin and Sader 2005).

As the eco-barrier of Beijing-Tianjin-Hebei region, an irreplaceable center of politics, economy and culture in North China, Taihang Mountain (THM) plays a crucial role in natural resources supply, water-soil conservation and climate regulation for surrounding regions and the residents. However, most areas in THM have suffered from infertile soil and water shortage, thus severely weaken the function of agro-forestry system (Moiwo et al. 2010). Up to now, a general pattern of vegetation distribution in THM has been known, based on field investigations and experiments (Yang et al. 2006; Zhang et al. 2012), but little is learnt about vegetation-climate interactions over the entire study region. Given extensive global changes in the near future, understanding and attributing vegetation changes is a critical but challengeable issue for sustainable development in mountainous regions. The objectives of this study are thus to (1) investigate the spatiotemporal changes in vegetation with MODIS NDVI, and (2) attribute the vegetation changes with the aid of partial correlation and multiple correlation analysis.

1 Materials and Methods

1.1 Study area

Taihang Mountain (THM) is located between the western margin of the North China Plain and the eastern margin of the Loess Plateau, with an area of 13×10^4 km^2 and elevation ranges from 50 to 3057 m (Figure 1). THM extends from 34°14' N to 41°6' N and from 110°13' E to 116°34' E. It has a warm temperate and semi-humid continental monsoon climate, with a mean annual temperature ranging from -9.1°C to 21.6°C and an annual precipitation ranging from 318 to 817 mm (Zhang et al. 2006). Most of the region is occupied by cropland, shrub, deciduous broadleaved forest and grassland (Figure 1). The dominant species are *Quercus liaotungensis* and *Betula platyphylla* for forest communities, and *Spiraea trilobata*, *Corylus heterophylla*, *Vitex negundo var. heterophylla*, and *Hippophae rhamnoides* for shrub (Zhang et al. 2008a).

1.2 Data Sources

The data used in this study including

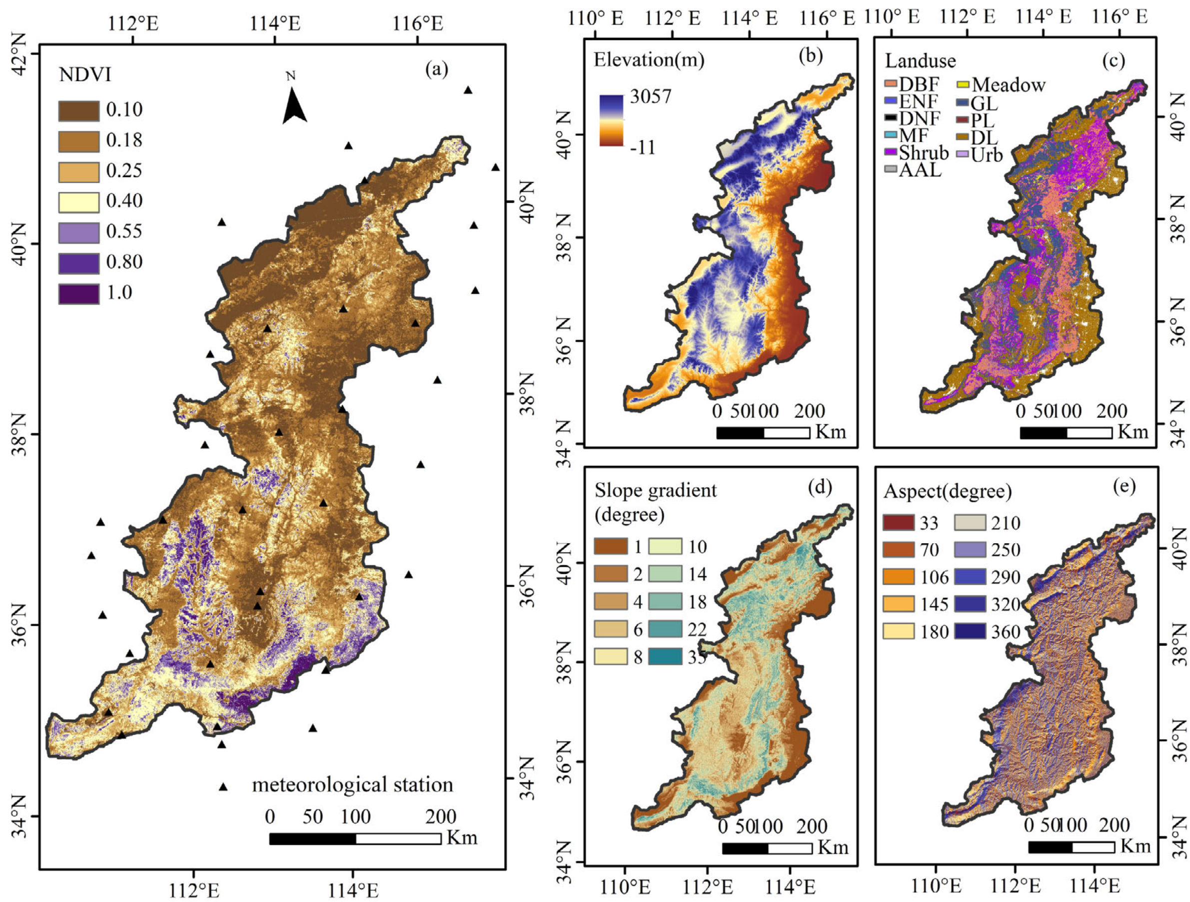

Figure 1 Background information of the study area: (a) averaged NDVI from 2000 to 2014 and the locations of meteorological stations in and around the Taihang Mountain (b) Digital Elevation Model (DEM); (c) land use types. DBF, ENF, DNF, MF, Shrub, Meadow, GL, PL, DL and Urb are short for deciduous broadleaved forest, evergreen coniferous forest, deciduous coniferous forest, mixed broadleaved coniferous forest, shrub land, meadow land, grassland, paddy land, dry land, and urban land, respectively; (d) slope gradient; (e) slope aspect, north is 0˚.

topographic map, land use map, remote sensing, and meteorological data. The digital elevation model (DEM) dataset was provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn), with a spatial resolution of 90 m×90 m. Based on the DEM, the slope gradients and aspect were calculated via ArcGIS software. Land-use data for 2005 and 2010 were obtained from the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (http://www.resdc.cn/), with a spatial resolution of 30 m×30 m. These data were re-sampled to 250×250 m using the nearest neighbor resampling method (Goyal et al. 2018).

The daily meteorological data (precipitation and air temperature) of 34 national meteorological stations (2000-2014) in and around THM were acquired from the National Climatic Center of the China Meteorological Administration (http://data.cma.cn/). In order to improve the accuracy of spatial distribution of precipitation, a specialized rainfall dataset of 128 rainfall stations from 2000 to 2014 was collected from Water Year Book. All the data were interpolated to the whole region with Gradient Inverse Distance Square Method (GIDS) (Nalder and Wein 1998).

The remote sensing data was 16-day composite 250m NDVI data from 2000 to 2014, which was derived from MOD13Q1 NASA science data (http://modis.gsfc.nasa.gov/data/datapro/mod13.php). In order to eliminate the influence of non-vegetation regions, all areas with non-vegetation land in the two land-use dataset (2005 and 2010) were masked out, and NDVI values were extracted for only those areas containing crops and natural vegetation. In addition, regions where the absolute range of NDVI value (maximum - minimum of the annual NDVI) was less than 0.1 were excluded, because most of these pixels belong to built-up land. Regions where the NDVI values were beyond the scope of 0~1 were also excluded, as most of these pixels indicate surface water areas. The Savitzky-Golay filter (Chen et al. 2004) was used to reduce noisy from cloud cover, solve geometry problems of satellite data, and to construct high-quality NDVI time series.

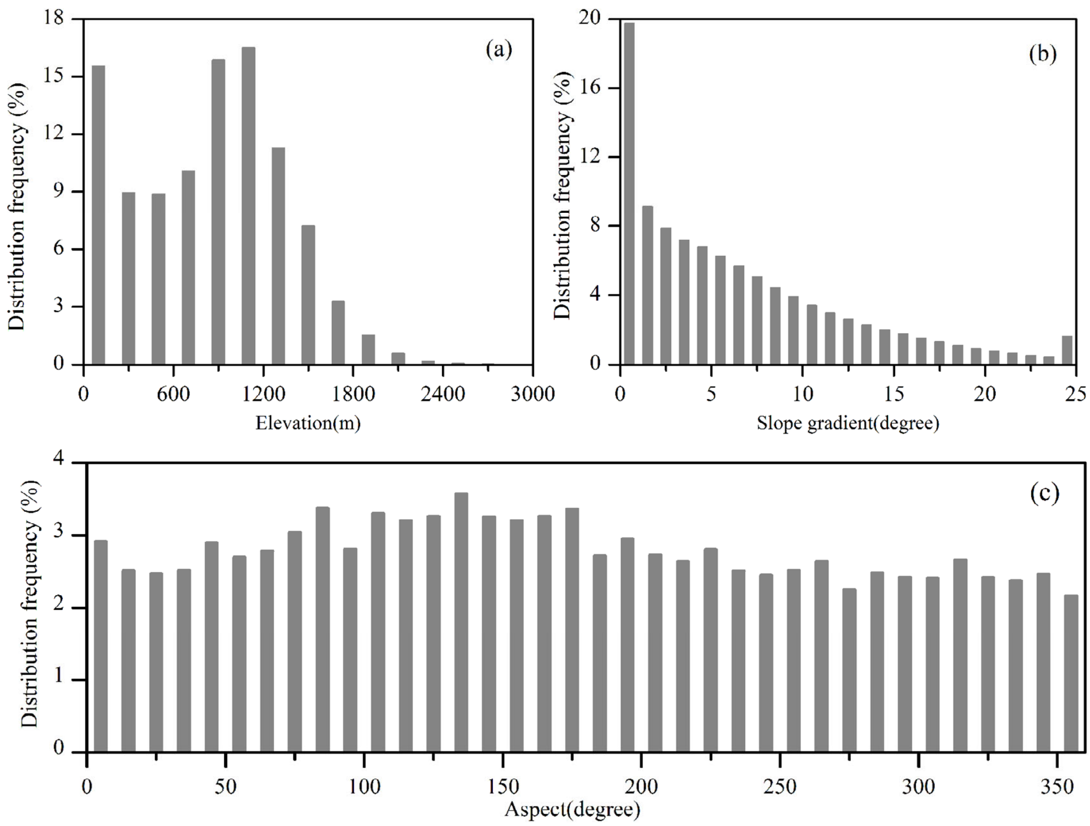

Figure 2 The distribution frequency of pixel in different DEM, slope gradient and aspect.

1.3 Methods

1.3.1 Analyzing vegetation variation

The temporal trend of mean NDVI (March to October) at pixel scale from 2000 to 2014 was calculated by the least-square linear regression, the F-test was used to detect whether the linear regression function of temporal NDVI series is significant or not at pixel scale during growing season. If the null hypothesis is rejected, it indicated that the increasing or decreasing trend of NDVI was significant. The abrupt change of growing season mean NDVI was explored based on the sequential version of Mann-Kendall test.

To better understand the effect of topographical factors on vegetation spatial pattern, the histogram of elevation, slope gradient and aspect were calculated to obtain the overall characteristics of topography (Figure 2). The elevation was divided into 15 sub-ranges by 200 m interval (except for the last one), slope gradient was classified into 25 sub-ranges by 1° interval and slope aspect was divided into 36 sub-ranges by 10° interval. The above classifications for topographical factors will be subsequently used to analyze the spatial-temporal variation of vegetation by overlaying NDVI maps with DEM, slope gradient and aspect maps.

1.3.2 Effect of precipitation and temperature on NDVI

To explore the response of vegetation variation to climate change, simple correlation analysis, partial correlation analysis and multiple correlation analysis were used (Appendix 1). Compared with simple correlation coefficient, partial correlation coefficient reflected more inherent relationship between two variables, by removing the effects of random variables which numerically related to both variables (Lipsitz et al. 2010). In this paper, the partial correlation coefficient between NDVI and precipitation, NDVI and temperature were calculated at the pixel scale. The significance of partial correlation coefficient was tested by *t* statistics. The multiple correlation analysis could analyze the relationship between several factors and one certain factor. The growing season mean NDVI is the dependent variable in multiple correlation analysis, and the corresponding mean precipitation and temperature are the independent variable. The significance of multiple correlation coefficient was tested by *F* statistics. Based on the *t* statistics in partial correlation analysis and *F* statistics in multiple correlation analysis, the regionalization of NDVI change by climate factors can be determined through the scheme proposed by Chen et al. (2001) (Table 1).

Table 1 The rules of regionalization

Types of NDVI change		Rules		
		$r_{NDVI\ P{\cdot}T}$	$r_{NDVI\ T{\cdot}P}$	$r_{NDVI{\cdot}T\ P}$
Change driven by	precipitation	$t>t_{0.01}$		$F>F_{0.01}$
	temperature		$t>t_{0.01}$	$F>F_{0.01}$
	precipitation and temperature	$t<t_{0.01}$	$t<t_{0.01}$	$F>F_{0.01}$
	non-climate factors			$F<F_{0.01}$

Notes: $r_{NDVI\ P{\cdot}T}$ is the partial correlation coefficient between NDVI and precipitation; $r_{NDVI\ T{\cdot}P}$ is the partial correlation coefficient between NDVI and temperature; $r_{NDVI{\cdot}T\ P}$ is the multiple correlation coefficient between NDVI, precipitation and temperature.

2 Results

2.1 Spatial pattern of NDVI

The average value of mean NDVI during growing season (refer to as MGNDVI) from 2000 to 2014 was 0.57, with a decreasing trend from south to north (Figure 1a). The pixel with averaged MGNDVI value larger than 0.7 took up 34% of the study, which most located at south part of the THM, while the pixel with averaged MGNDVI value smaller than 0.3 took up 23% of the basins, including most dry land in the northern THM. Except for farmland, averaged MGNDVI value in different land-use types and the entire basin show single-peak curve along elevation, with the largest value (0.628 for the entire basin) occurred on elevation of 1600-1800 m (Figure 3), which indicating the moisture-thermal condition within this elevation was better than other region for plant growth, though the absolute amount of water or energy was not the highest (Ru et al. 2005). Quadrat investigations also showed that species numbers, richness and diversities reached the peak within the similar elevation, reported by Zhang et al. (2013b) (1200-1600 m in the northern of THM) and Ru et al. (2006) (1500 m in the southern THM). However, MGNDVI did not show

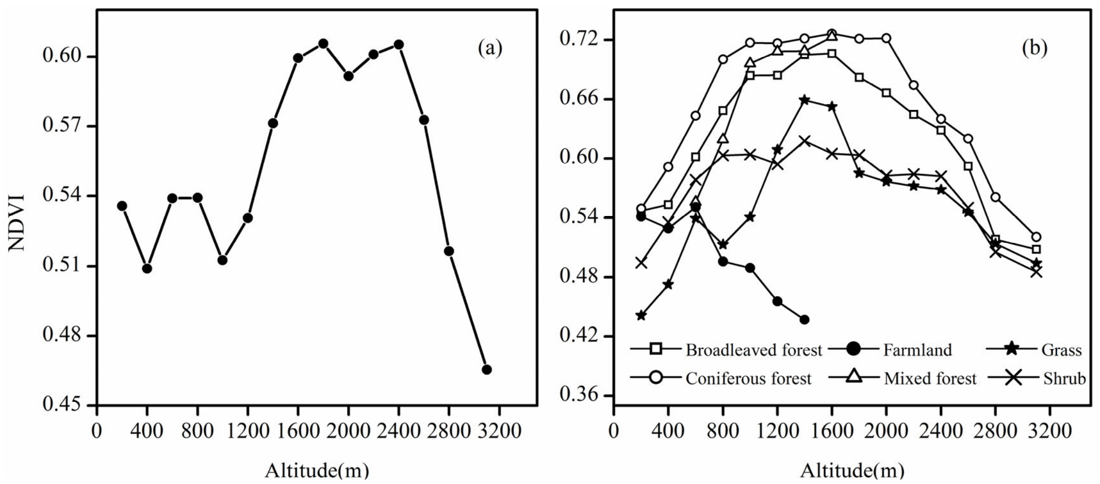

Figure 3 The distribution of growing season mean NDVI along elevation.

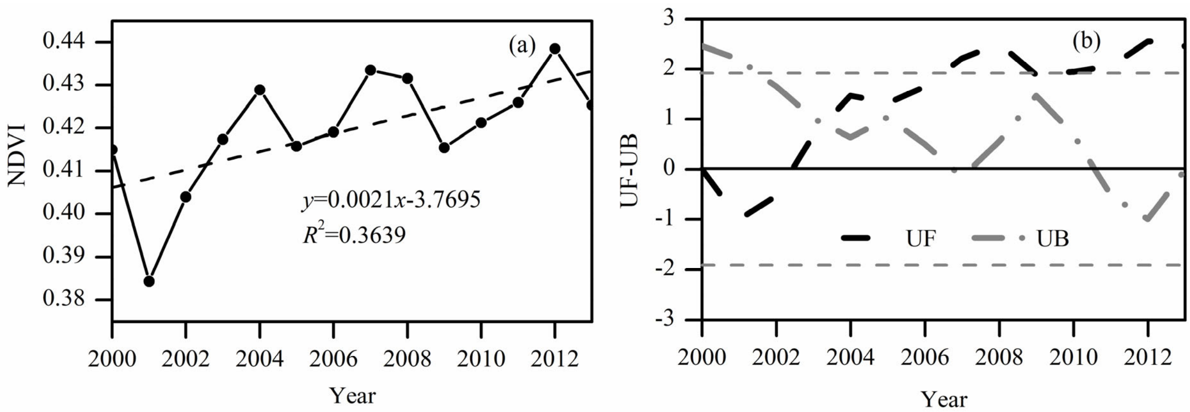

Figure 4 Temporal variation of mean NDVI during growing season in Taihang Mountain from 2000 to 2014. (a) is the temporal variation of mean NDVI during growing season; (b) is M-K test, Gray horizontal lines in (b) represent critical values corresponding to the 95% confidence interval.

significant difference in different slope gradients and aspects.

2.2 Spatial-temporal change of NDVI

Growing season mean NDVI showed an increasing trend from 2000 to 2014, with an average increasing rate of 0.002 yr^{-1} (P<0.05) (Figure 4a). The forward (UF) and backward (UB) trends of NDVI was tested by the sequential Mann-Kendall test (Figure 4b). The results showed that there was an abrupt increased trend of MGNDVI in 2003, which may attribute to exceptional precipitation. The precipitation in 2003 was extremely high and 150 mm above the average value from 2000 to 2014. Spatially, growing season mean NDVI showed a significantly increasing trend in more than 90% of area in THM (Figure 5). The highest increasing rate appeared in the southwestern part (0.0072 yr^{-1}), followed by that in the mid-western border (0.0014 yr^{-1}) (Figure 5a). A significant decreasing trend of MGNDVI was found in less than 5% of area, which mainly belonged to the southeastern part and eastern border of THM, with a decreasing rate ranged from 0.002 y^{-1} to 0.013 y^{-1} (P<0.01).

As the most important topographic factor, elevation influences hydrology, temperature, light availability, edaphic factors and wind exposure, thus finally have effect on plant growth (Moeslund et al. 2013). The average increasing rate of MGNDVI displayed a single-peak pattern along elevation, with the highest value (0.0078 yr^{-1}) among 1200-1600m (Figure 6a). More than 88% pixels among 1200-1600m showed significant increasing tendency, whereas above 3000m, only 20% pixel showed significant increasing tendency (P<0.05). Slope gradients also play important roles in vegetation growth through influencing the redistribution of solar radiation, light duration, water (Zhang et al. 2006), and soil characteristics (Sollins 1998; Seibert et al. 2007; Zhao et al. 2014). More than 85% pixels on the hillside with slope gradients among 3°~5° have significant increasing tendency (P<0.05), with an average increasing rate

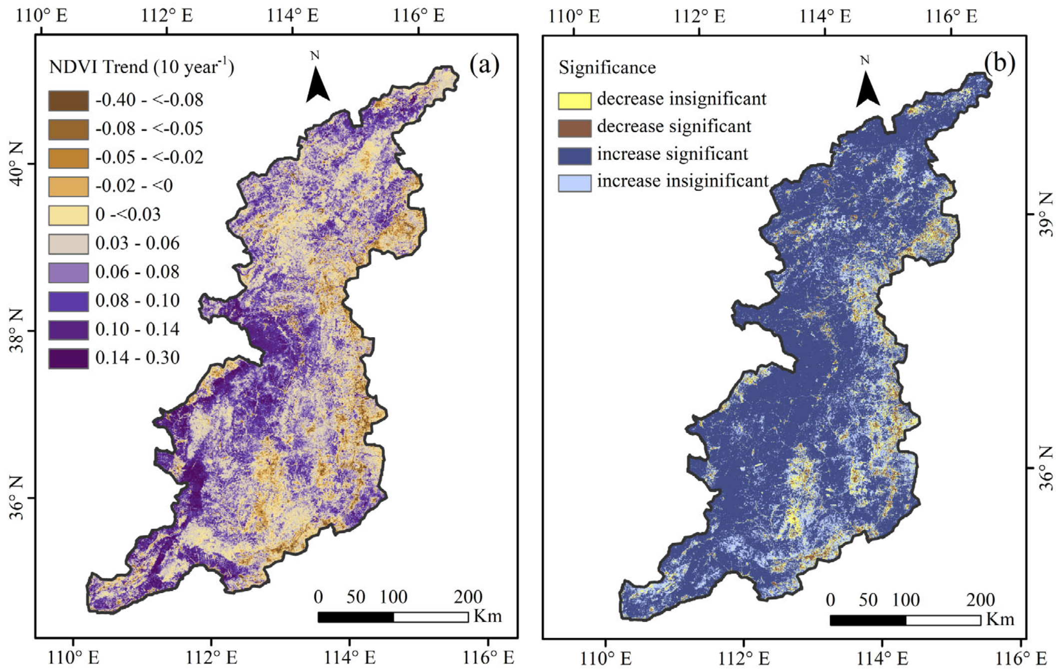

Figure 5 Spatial pattern of temporal change of mean NDVI during growing season in Taihang Mountain from 2000 to 2014 (a is pattern of NDVI trend; b is the significance of NDVI trend in P=0.05).

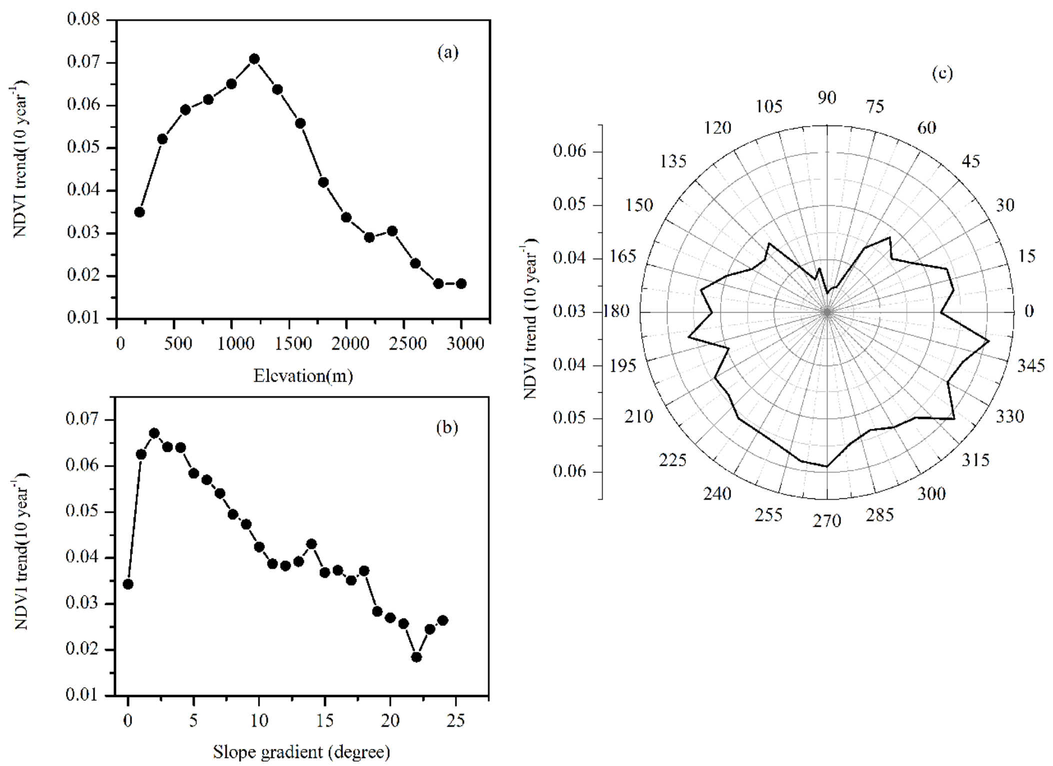

Figure 6 Temporal change of averaged mean NDVI during growing season in different elevations, slope gradients and aspects from 2000 to 2014.

of 0.0068 yr^{-1} (Figure 6b). In the hillside with slope gradients over 5°, the percentage of pixels with significant increasing tendency (P<0.05) and averaged increasing rate of MGNDVI decreased with slope gradients. Compared with the north-facing hillside, south-facing hillsides received more solar radiation which was benefit for vegetation growth. Thus, averaged increasing rate of NDVI was slightly higher on the south-facing hillside (0.005~0.006 yr^{-1}) than that on the north-facing (0.0035~0.005 yr^{-1}) (Figure 6c).

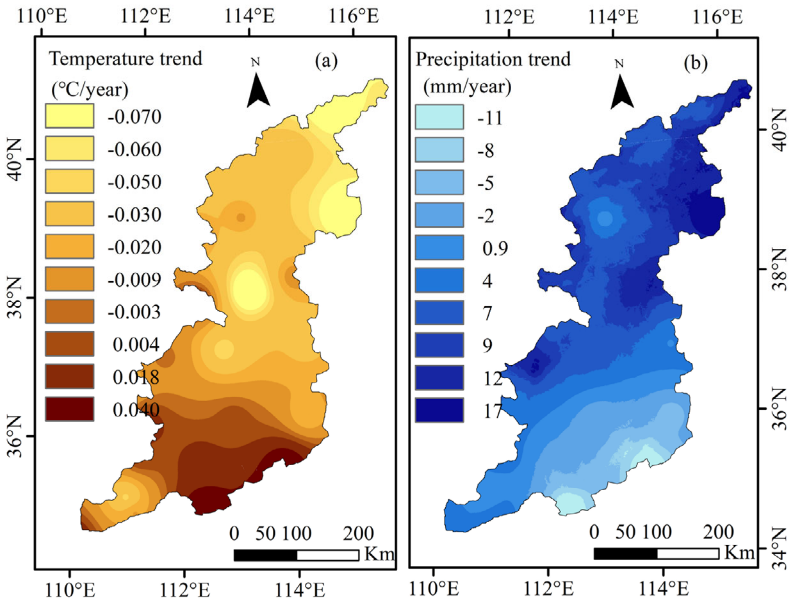

Figure 7 Spatial pattern of temporal change of mean temperature and precipitation during growing season in Taihang Mountain from 2000 to 2014.

2.3 Relationships between climate change and vegetation variation

THM went through a slightly wetter and colder process from 2000 to 2014. In the north part of THM, the average growing season temperature has a decreasing trend and accumulative precipitation presented an increasing trend, whereas in the southern THM , temperature and precipitation presented an opposite variation pattern, with an increasing trend in temperature and a decreasing trend in precipitation (Figure 7). In most arid and semi-arid regions over North China, water is the major factor limited vegetation growth. The increasing precipitation in the northern THM is benefit for vegetation growth. According to simple correlation analysis, about 74% pixels in the study area presented positive correlation with precipitation, with 23.4% has significant trend (P>0.05), most of which located in the northern THM, whereas in the south part of THM, precipitation showed negative correlation with NDVI, indicating decreasing precipitation limited vegetation growth (Figure 8a,b). Considering temperature in most part of THM has a decreasing trend, NDVI showed negative correlation with temperature in about 64.8% pixels (Figure 8c), most of these pixels located in the northern THM, whereas in the south part of THM, rising temperature has a positive correlation with NDVI, indicating the rising temperature is benefit for vegetation restoration in southern THM.

Based on the partial correlation and multiple correlation analyses (Chen et al. 2001), the pattern of climate factor drivers was shown in Figure 9. Vegetation variation in most part of the THM (81.8% pixels) was impact by non-climate factor, while the vegetation variation of 6.4% and 10.8% pixels were driven by precipitation and temperature, respectively, indicating the human activities are the major driver to the vegetation variation in THM. The pixels with vegetation variation mainly driven by precipitation change (refer to as P_driver) most located at the northern THM, where an increasing trend of precipitation was found, while pixels with vegetation variation mainly driven by temperature change (refer to as T_driver) located at the southern part, where an increasing trend of temperature was found in recent years. The pattern of climate factor driver also showed obvious difference with elevation. The percentage of P_driver (the ratio of P_driver to the Climate_driver (the sum of P_driver and T_driver)) decreased with elevation, in the low elevation zones (<1000 m), vegetation variation of more than 55% Climate_driver pixels were mainly impact by precipitation change, whereas in the high elevation zones (>2500 m), vegetation variation in more than 90% Climate_driver pixels is likely due to temperature change (Figure 10). However, in different slope gradients and aspects, the ratio between P_driver and T_driver did not show significant difference.

3 Discussion

3.1 NDVI pattern

The distribution of land use type and the response of each type to climate factors determined NDVI pattern along elevation. In THM, farmland and shrub located in the lower elevation than forest and grassland. For instance, *Betula platyphylla*, one of the dominant tree species in THM, distributes mai nly in higher elevation above 1000 m (Zhang and Chen 2004), whereas most shrub species, such as *Spiraea trilobata* and *Vitex negundo var. heterophylla*, distribute mainly in lower elevation below 1000m (Lü et al. 1991). In generally, farmland occupied more than 70% of the regional area below 400 m, shrub and grass mainly located among 400-1200 m, broad-leaved forest, which has higher NDVI value than other vegetation types, has highest proportion (more than 40%) among 1400-1800 m, and the proportion of alpine meadow is more than 70% above 2600 m. For each vegetation type (except for farmland), averaged growing season mean NDVI all showed a single-peak curve along elevation, with the largest values occurred on elevation of 1200-1800 m, which resulted in the regional averaged growing season mean NDVI has a largest value (0.628) on elevation of 1600-1800 m (Figure 3). In most arid and semi-arid regions over North China, water is the major factor limited vegetation growth. Precipitation usually displays an increasing trend along elevation till a maximum precipitation height (an elevation with the highest precipitation), and then conversely decrease with elevation increment in the mountainous area. The maximum precipitation height in THM is around 1800 m (Han et al. 2017), which provide a suitable condition for vegetation growth among the elevation of 1600-1800m.

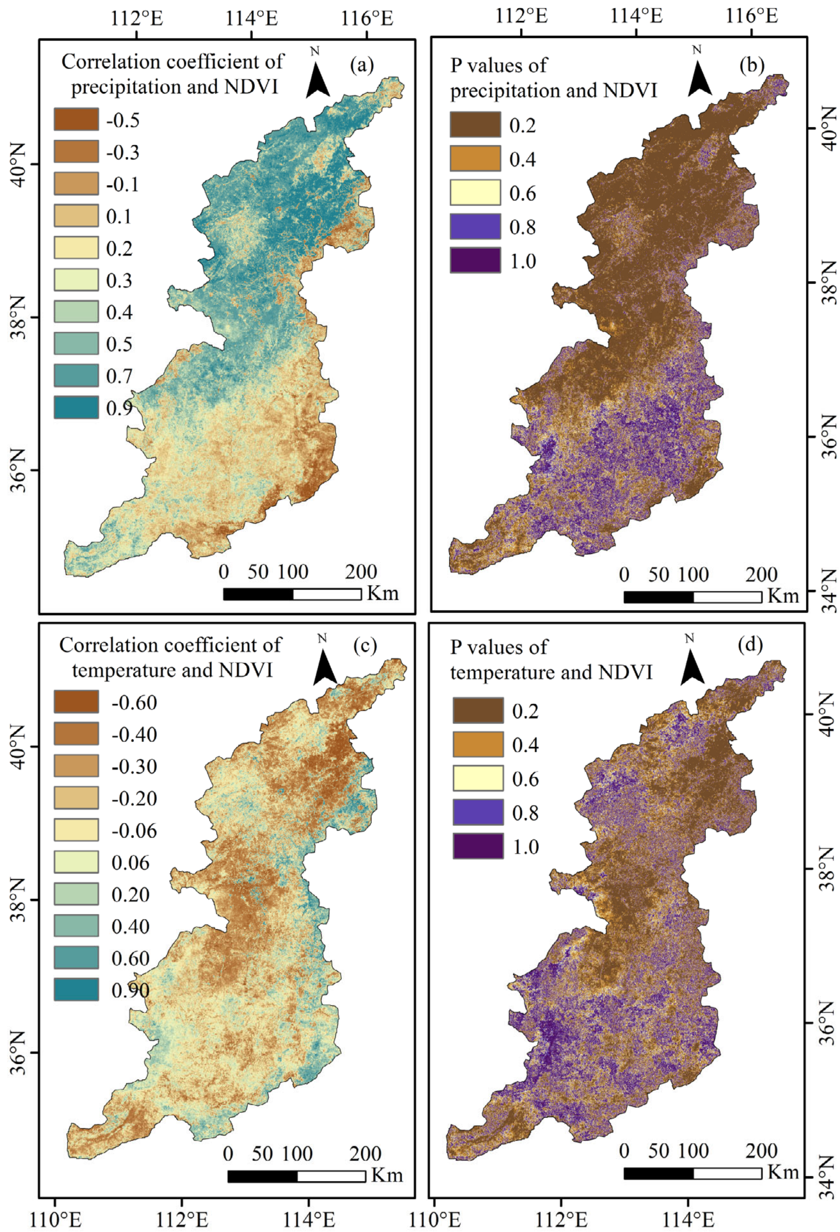

Figure 8 The pattern of correlation coefficients between growing season mean NDVI and precipitation, as well as temperature in THM. (a is the pattern of correlation coefficient between NDVI and precipitation; b is the confidence level (P value) of the correlation coefficient in map a; c is the pattern of correlation coefficient between NDVI and temperature; d is the confidence level (P value) of the correlation coefficient in map c).

3.2 NDVI variation

In recent decades, previous studies have found an increasing trend of averaged NDVI in and around THM for growing season (Zhang et al. 2008b; Piao et al. 2015; Duo et al. 2016). However, the increasing rate of growing season mean NDVI from 2000 to 2014 in our study was slightly higher than that reported by Piao et al. (2015) (0.0018 yr^{-1} from 1982 to 1999) and Duo et al. (2016) (0.002 yr^{-1} from 1981 to 2013), which can be attributed to a number of ecological restoration projects executed in the North China Plain since the first decade of the 21st century (Liu et al. 2012). The partial correlation and multiple correlation analysis also showed that vegetation variation in more than 81.8% pixels of the THM was impact by non-climate factor, which demonstrates that human activities, such as Greening Project in Taihang Mountain, may be the major driver for the vegetation variation in THM. With the land-use data at two periods, it is found that about 11.28% farmland and 16.9% bare soil have been replanted with trees from 2005 to 2010, the growing season mean NDVI in the transformed farmland showed significant increasing trend, with an averaged increasing rate of 0.025 $year^{-1}$. Considering the bare soil was eliminate in the analysis, the averaged NDVI of transformed bare soil was 0.15 in 2005 and 0.35 in 2010, indicating human activities has a noticeable impact on vegetation variation.

Simple correlation analysis showed that NDVI variation had positive correlation with precipitation increasing in the northern THM, which is consistent with the results of forest inventory data from 712 sample plots (Yang et al. 2006). Actually, the precipitation is less than 40 mm in April and May in THM, which always limited the vegetation growth in late spring and early summer. The negative terrestrial water storage anomaly (TWSA) from Gravity Recovery and Climate Experiment (GRACE) and Global

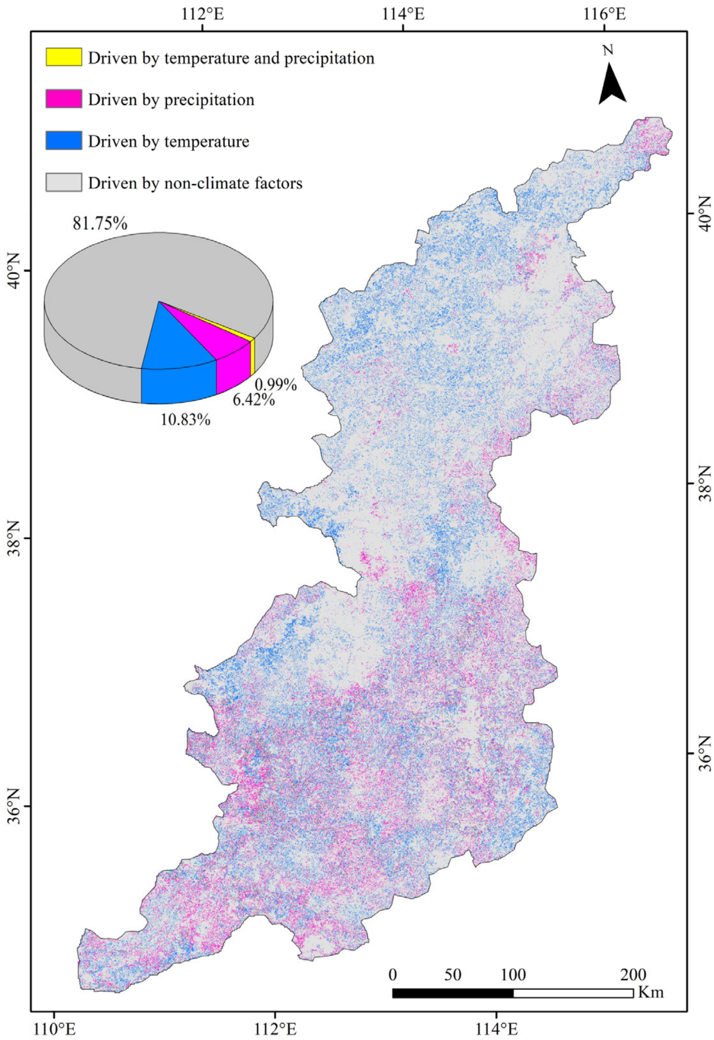

Figure 9 The pattern of climatic factor drivers for vegetation change in THM from 2000 to 2014.

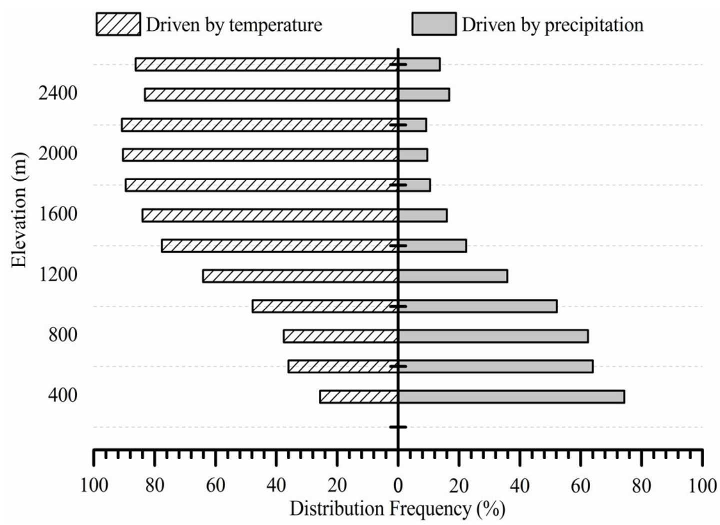

Figure 10 The distribution frequency of climatic factor drivers of vegetation change along elevation.

Land Data Assimilation System (GLDAS) was displayed over the whole Taihang Mountains in recent years (Yang et al. 2017), especially in the southern THM. The soil layer is shallow in THM, which is generally less than 50 cm. After a rainstorm, the infiltration may compose 70% of soil water (Song et al. 2010), vegetation productivity is therefore highly coincided with the variations of soil moisture and precipitation (Yang et al. 2003). Such phenomenon is very common in arid and semi-arid regions around word, such as in central Great Plains of the USA (Paruelo and Lauenroth 1995; Wang et al. 2001) and Inner Mongolia of China (Chuai et al. 2013), where grass growth related more closely to precipitation than temperature. Vegetation response to temperature rising in arid and semiarid region could be determined by water budget limitation (Yu et al. 2003). Rising temperature can facilitate vegetation establishment and recovery with plenty water, whereas climate warming can also cause evapotranspiration increasing and soil moisture reducing, which limited the plant growth (Yang et al. 2003), such as in the south of THM.

Generally, vegetation variation is closely related to the topography factors in the mountainous areas. With rising elevation, temperature decreases, precipitation and relative moisture content increase (Zeng and Yang 2008). As shown in Figure 10, vegetation variation in the low elevation zones under 1000m is likely due to precipitation change, while temperature is the major factors impact vegetation dynamic in the high elevation zones of THM. Sample investigations conducted in Dongling Mountain based on isotope ^{15}N also showed that vegetation growth was dominated by water below 1000m, while by temperature above the threshold (Liu et al. 2009). Additional, slope gradient and aspect are also important topography factors influence the vegetation growth in mountainous areas. In THM, the increasing rate of NDVI exhibited single-peak pattern along slope gradient, reaching the peak value of 0.0068 yr^{-1} at 4 degree and surrounding regions (Figure 6), where dominated by grass, shrub and forest. Considering grass and shrub had better adaptability to moisture-thermal condition on steeper slope than forest, they could grow on the land with large slope gradient till 15 degree or so, consistent with that found by Wang et al. (2015) in Taihang-Yan Mountain regions and Cheng (2009) in Beijing Mountain area. However, averaged increasing rate of NDVI was not significant in different slope aspect. Generally, south-facing slopes receive more solar radiation than north-facing slopes, which enhanced photosynthetic capability for vegetation growth. However, more radiation lead to more water loss from evapotranspiration and less soil water storage for plant growth (Zapata-Rios et al. 2015), especially in water-limited regions. The positive and negative effects counteracted with each other at regional scale, which resulted in the comprehensive effect of aspect on NDVI variation was not significant. In addition, large-scale analyses may inevitably overlook some detailed information because of limited spatial resolution of land use map and remote sensing data, which weakens the effect of aspect as well. Consequently, further research should be conducted at multi spatial scales in the future.

4 Conclusion

In this study, spatial-temporal variation of NDVI from 2000 to 2014 in Taihang Mountain was analyzed based on MODIS NDVI dataset, and the principal factor impacting vegetation variation was detected with the aid of partial correlation and multiple correlation analysis. Determined by the distribution of land use type and the response of each type to climate factors, the averaged mean NDVI during growing season showed a single-peak curve distribution with increasing elevation. More than 90% area in THM experienced a significant greening trend since 2000. Human activities, such as Grain for Green Program, play an important role in vegetation greening. Vegetation variation is closely related to the topography factors in the mountainous areas. With rising elevation, temperature decreases, precipitation and relative moisture content increase, temperature is the major factors impacting vegetation dynamic in the high elevation zones of THM, whereas in the low elevation zones under 1000 m, vegetation variation is likely due to precipitation change. Considering the dramatic climate change in the future, further studies should be conducted to explore more inherent mechanism of vegetation growing process on dynamic environment.

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