SPATIAL AND TEMPORAL CHANGES OF VEGETATION COVER IN CHINA BASED ON MODIS NDVI

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Abstract. Vegetation in China experienced serious threat from several driving forces such as population growth and anthropogenic activities. Real-time mapping and assessment of yearly vegetation cover is vital to understand environmental conditions. Here, we examined the trend of vegetation cover changes in China over a 15-year period using remote sensed data. To achieve this, we reclassified the Normalized Difference Vegetation Index (NDVI) values into four classes: No, Low, Medium, and High covers and proceeded to vegetation change detection. The results indicated a difference in values at each level. At the national level, there is an increase in vegetation cover as reflected by High cover class with 41.03% in 2015. At the regional level, the most significant changes were determined in the south where the rate of green cover was declining by -63622.3 km^2 from 2000 to 2015 in the High cover class. Vegetation cover changes varied from province to province. Some provinces showed a reduction in vegetation cover such as Guangdong; whereas Xinjiang experienced an increase (*Tables A1* and *A2*). The findings of this study provide further information on China's vegetation cover and will also serve as reference for future research.
Keywords: *remote sensing, satellites, monitoring, forest, environment*

Introduction

In the past decades, the Earth has experienced fast population growth which has led to a rise in demand and supply for consumer goods and products thereby leading to an overuse of natural resources from the ecosystem (Hutchinson, 1969; FAO, 1997; Li et al., 2013b; Obienusi et al., 2014). Consequently, this has exerted significant pressure on the ecosystem which in turn has led to a series of environmental issues such as soil erosion from water runoff (Arima et al., 2005), pollution through industrial emission of hazardous substances (Caldas et al., 2007) or soil degradation from intensive use of pesticides (Pacheco and Poccard-Chapuis, 2012) and fertilizers (Kaimowitz and Angelsen, 1998). Furthermore, issues of deforestation (resulting from excessive logging, bush fire, agricultural activities, urbanization) (Islam et al., 2018; Lambin, 1994), energy generation (Ratcliffe, 1984; Sasaki and Takahara, 2011) and tourism (Burden and Randerson, 1972; Kerbiriou et al., 2008; Lucas-Borja et al., 2011) are high. All these activities lead to a reduction in the quantity and quality of natural resources available in the ecosystem (Vitousek et al., 1997). Globally, research has proven that vegetation cover that has undergone pressure from anthropogenic activities is more significant than vegetation without pressure (Zubair, 2006; Jacinthe and Lal, 2006; Wang et al., 2014). In addition, changes in vegetation cover have a more important

effect on the ecosystem than changes in climatic factors (Jensen, 1996) and China is equally affected by these pressures on the ecosystem.

China is a leading country in technology, industrial development and has the largest population over the world (United Nations, 2017). From the 1970s, the country has undoubtedly undergone rapid economic expansions and urbanization (Wang, 2010) and has managed to take a great number of its population out of poverty. According to Yan et al. (2017), China's population explosion has led an alarming expansion of urban areas from 17.92% in 1978 to 57.35% in 2016 and was projected by the National Bureau of Statistics of the People's Republic of China to reach 60% in 2020. Despite the great benefit behind the development of China, the effect of the development on the ecosystem has caused an alarming degradation level. For instance, mining projects have negatively affected the vegetation and contributed to spatial changes in Pingshuo opencast coal mining located in Shanxi province (Zhang et al., 2019). In addition, some research have observed deficit in ecosystem resources and an important green land transformation in built up areas, agricultural land, opencast mining, and barren land which have largely influenced the decrease in vegetation cover (Zhang et al., 2007; Wang, 2010).

Owing to the complex situation of vegetation cover changes in China, the government implemented several laws and policies on ecosystem protection mainly for vegetation conservation. According to some studies, the country has financed several projects with the amount of 354 billion Yuan from 1999 to 2003 and with 1636 billion Yuan for environmental restoration and protection from the year 2003 to 2008 (Kauppi et al., 2006; Piao et al., 2009; Liang et al., 2018). The results of all these attempts have been positive in several provinces with a significant vegetation growth and reduction of degradation of the ecosystem. Nevertheless, permanent monitoring and mapping of vegetation cover dynamic at different scales is important in order to predict the future state, understand and assess the development and changes that occur as a consequence of human activities (Bozkaya et al., 2015; Gu et al., 2016; Weng, 2001; Mao et al., 2011; Mu et al., 2012; Mooney et al., 2013; Sterling et al., 2013).

Several methods were applied in some studies for analyzing the trend of vegetation cover and were mainly based on traditional surface measurement methods with a mandatory field observation (Liu et al., 2018). These methods have good precision, however, they showed limitations due to high cost and the results are often personal to the data collector (Wei et al., 2006) when the study is on a large scale (Lu, 2006; Bao et al., 2014; Zhou et al., 2015). Therefore, other methods have emerged such as remote sensing with the benefits of brief sampling time, dynamic data, wide scale cover, spectral resolution, and minimal costs (Gillespie et al., 2018; Zoungrana et al., 2018). Remote sensing becomes a method widely adopted and applied in land survey and vegetation cover analysis because of its ability to offer multi-spatial and temporal crop cover changes (Zhang and Wu, 2015). Furthermore, it has been given free access on earth data with a great amelioration on methods analysis (Gutman et al., 2013).

Recently, there has been growing interest in the use of Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI data for land cover analysis and monitoring especially vegetation cover (Beck et al., 2006; Lunetta et al., 2006; Jacquin et al., 2010; Louise et al., 2014; Usman et al., 2015; Zoungrana et al., 2018). MODIS NDVI products have been mostly used in studies over large surface areas compared to other NDVI products such as VEGETATION instrument on Satellite Pour l'Observation de la Terre (SPOT VGT) and National Oceanic Aeronautic Administration Advanced Very

High-Resolution Radiometer (NOAA-AVHRR) NDVI (Fensholt and Sandholt, 2005; Fensholt et al., 2006). They have high-sensitivity radiometric information in 36 spectral bands allowing in-depth perception of the changes that happened in the different components of land cover (Wang et al., 2013). In addition, they have three different spatial resolutions which are 250 m, 500 m and 1000 m making it possible to achieve studies at different scales (Skole et al., 1997; Janetos and Justice, 2000). Since MODIS NDVI products provide spatial resolution, surface anisotropy, calibration, atmosphere correction, grid protection, vegetation sensitivity and cloud detection, they are considered as one of the most sophisticated remote sensing data images and mostly used in land cover monitoring (Yan et al., 2013). Furthermore, the NDVI contained in the MODIS data is described as a quantitative index which explains the health of vegetation cover by using the near infrared and visible band (Carlson and Ripley, 1997) and it is among the most applied indices for monitoring changes in vegetation cover (Scanlon et al., 2002; Yang et al., 2012; Zhang et al., 2018).

Investigations carried out by several authors (Liping et al., 2018; Xu et al., 2018), applied remote sensing techniques to assess the global trend of vegetation cover changes, including China. Their findings showed how remote sensing is a reliable method to understand land cover changes by providing accurate information on vegetation changes. Going further, numerous studies have used vegetation indices to detect the vegetation cover changes which were limited to either provincial or regional levels in China (Mu et al., 2012; Li et al., 2013b; Zhang et al., 2017). However, few of them have assessed the spatial and temporal changes in vegetation at three levels in China using MODIS NDVI time series. Therefore, our study provides useful information on vegetation cover trend for provincial, regional, and national levels.

Thus, the current research attempts to assess spatial and temporal changes of vegetation cover throughout China using MODIS NDVI data products over a 15-year period from 2000 to 2015. As a move in this direction, we hope that this research could be used as a starting point for further studies which intense will help local policymakers in environmental sustainability.

Review of literature

Vegetation cover is considered as a key constituent of the ecosystem and covers almost 70% of the earth land cover (Arellano et al., 2015; Veraverbeke et al., 2012; Zhou et al., 2015; Peng et al., 2015). It plays a major role in biogeochemical and hydrological cycles. Additionally, it connects with others natural constituents of the environment such as soil, water, and the atmosphere (Piao et al., 2003). Several environmental services and functions such as carbon sequestration, water and soil sustentation, air purification, and preservation of biodiversity are provided by vegetation which is important for all living things on the earth (Sheram, 1993; Wang et al., 2012). Vegetation cover is also an indicator of any change that occurs in the ecosystem (Lambin and Strahler, 1994). Furthermore, vegetation is one of the key elements in climate change mitigation and the reduction of greenhouse gases (Caputo, 2009; Moroni, 2013) and portrays an important function in the conservation and regulation of environmental quality (Piao et al., 2011; Peng et al., 2012; Yan et al., 2017).

Materials and methods

Description of the study area

The study was conducted in the People's Republic of China (PRC) which is the third largest country in the world with 9.6 million km² with almost 21% of the global population. China is located in the east side of Asia, between 73°33'E-135°05'E and 3°51'N-53°33'N (*Fig. 1*).
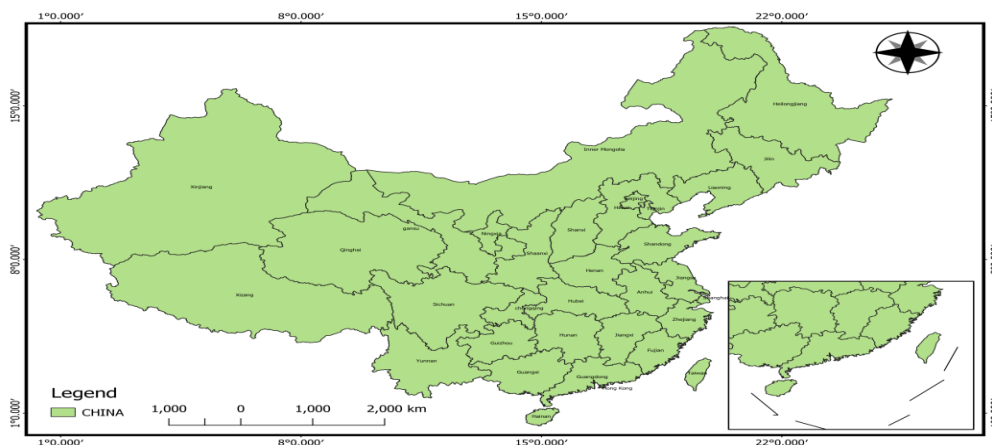

***Figure 1.** Overview of the study area*

China is covered by mountains, plateaus, valleys, plains and hills. The administrative subdivision of China is as follows: 4 municipalities, 5 autonomous regions and 23 provinces, as well as Macao and Hong Kong which are considered as special territories.

The study area has four main agro-climatic zones: the semi-humid zone and the humid zone in the southern and southwestern part of China, the arid zone in the western and northwestern, and the semi-arid zone in the central. Heavy rainy season extends in the northern part from June to September and in the southern part from April to August.

The average annual rainfall is estimated at 645 mm but may reach 1000 to 2000 mm in the southeast and southwest coastal regions. The research area has an abundant sunlight and radiation estimated between 3200 and 3300 h. China has a very diverse flora and is considered as one of the countries with the richest vegetation on the planet.

Our study was conducted on three scales: the national, regional, and provincial levels as described in *Table 1*. *Table 1* shows the description of different China's regions. The Special Territory of Macao was not analyzed as part of this research due to a lack of information and data.

Data source

In this research, the data used to assess the trends in vegetation in China over a fifteen-year period was MODIS NDVI data (MODND1M). The selected MODIS NDVI data was obtained from the web interface http://www.gscloud.cn./ and was presented by the satellite in a gridded appearance with a sinusoidal or periodic projection. The spatial resolution of the collected data was 500 m with a temporal resolution of 32 days.

The selected data of the years 2000, 2005, 2010, and 2015 were collected during summer in June because vegetation cover is usually varying accordingly to seasonal

factors which is favorable to generate a better reflectance in that period of the year, marked by the growing season in China.

Table 1. *Description of regions and provinces with their climate and terrain information*

Regions	Provinces	Climate	Topography
N	Inner Mongolia, Beijing, Tianjin, Shanxi, and Hebei	Semi-humid continental monsoon	Mountains, plains, and plateaus
E	Anhui, Fujian, Jiangxi, Jiangsu, Shandong, Shanghai, Taiwan, and Zhejiang	Subtropical monsoon humid	Plains, hills, and mountains
N-E	Jilin Heilongjiang, and Shenyang	Temperate continental monsoon	Mountains and hills
N-W	Xinjiang, Qinghai, Gansu, Shaanxi, and Ningxia	Semi-humid continental monsoon	Mountains and plateaus
S	Hong Kong, Hainan, Guangdong, and Guangxi	Subtropical and tropical monsoon	Hills, plains, mountains, and plateaus
S-W	Sichuan, Yunnan, Guizhou, Chongqing and Xizang	Subtropical wet monsoon	Hills, mountains, and plateaus
S-C	Hubei, Hunan, and Henan	Subtropical monsoon	Mountains and plains

N is north; E is east; N-E is northeast; N-W is northwest; S is south; S-W is southwest; S-C: south central

Data analysis

The selected MODIS NDVI data from the years 2000, 2005, 2010 and 2015 were clipped, extracted from all China (provinces and regions), projected with the Xian 1981 coordinate system using ArcGIS 10.5 software. Moreover, the reclassification of the images was performed based on the NDVI value of each pixel into four classes No, Low, Medium and High cover, respectively (Hashim et al., 2019; Sahebjalal and Dashtekian, 2013). The NDVI value is estimated between -1 and + 1, the highest value showed a greener cover and the lowest for a barren land, urbanized or water areas (Madonsela et al., 2018). The NDVI is often determined with the following formula (*Eq. 1*) by Tucker (1979):

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \tag{Eq.1}$$

where *RED* is the value of reflectance of red band and *NIR* is the near infrared band.

As described in *Table 2*, the NDVI values for the study area range from 0.1 to 0.9. Thus, after the reclassification of the NDVI images for the years 2000, 2005, 2010 and 2015, the new land cover maps for the different corresponding years were produced using ArcGIS 10.5 and QGIS 3.

Vegetation cover change analysis

Change detection images time series is a remote sensing method applied to estimate and locate changes occurred in a study area. This method is mainly established on the comparison of the spectral change of the image between two time periods (*Eqs. 3* and *4*).

It is widely used and is very useful for vegetation cover change studies (Lu et al., 2004; Coppin et al., 2004; Kashaigili et al., 2006).

Table 2. *NDVI density classes*

Vegetation classes	Description	Vegetation cover (NDVI)
No vegetation	Barren land, built up areas, road network and water	< 0.1
Low vegetation	Shrub land	0.1 -0.3
Medium vegetation	Grassland and agriculture land	0.3 - 0.6
High vegetation	Forest land	0.6- 0.9

In this research, change detection analysis was conducted to understand the trend of spatial variations in vegetation cover in fifteen years.

As a result, the trend of change of each class and year were calculated in km² and then converted to percentages (%) as shown in *Equation 2*. The results obtained helped to detect and identify changes occurred in China on three different scales. The percentage rate of each class was calculated by:

$$n = \frac{A*100}{S} \qquad (Eq.2)$$

where *n* was the percentage rate of each class, *A* was surface area of each class and *S* was the total surface area in km^2.

Percent area change between the two periods (2000 and 2015) was calculated according to the following equation:

$$PAC = \left(\Delta A/_T\right) * 100 \qquad (Eq.3)$$

where *PAC* corresponds to the Percent area change, ΔA was the value of the final and initial years ($a_2 - a_1$), and *T* was total area of the study area.

Percent annual rate (*PAR*) of change was estimated by the formula:

$$PAR = \left(\Delta A/_T * 100\right)/n \qquad (Eq.4)$$

where *n* denote the number of years between the initial and final years

Results

Spatial variation of vegetation coverage classes from 2000 to 2015 at national level

Following the NDVI density classes in *Table 2*, the spatial and temporal changes of vegetation cover were revealed from the year 2000 to 2015. As shown in *Table 3*, the results demonstrated that in 2000, 17.75% of the land cover in China was found to be in No cover class (barren land, water, road network, and built-up areas). Notwithstanding, in 2005, 2010 and 2015 of the same class, results showed a change of 17.43%, 15.50% and 15.15%, respectively. The Low class characterized by shrub land experienced a saw-tooth dynamic, increase, and decrease during the fifteen years of study with 21.21% in 2000 and 20.72% in 2015, respectively. However, the Medium and High

classes showed a significant rise in the area of vegetation with 22.60% in 2000 and 23.10% in 2015, and 38.44% in 2000 and 41.03% in 2015, respectively.

The results in *Table 3* indicate the change in vegetation cover area from 2000 to 2015. It showed that the No cover and Low cover classes lost 2.61% and 0.49% respectively, i.e., -248679.97 km² and -46629.71 km² of surface area. In contrast, the Medium and High classes gained a 0.61% and 2.36% respectively, i.e., 48259.71 km² and 246341.28 km². All these results may reveal that forests and grasslands have increased slightly while barren land or shrub lands areas have decreased. Further information is also demonstrated in *Figure 2*.

Table 3. *Evolution of vegetation cover from 2000 to 2015*

| Types of vegetation	Spatial area cover								Change area (2000-2015)		The annual rate of change (2000-2015)
	2000		2005		2010		2015				
	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	PAC	km²/year
No	1693988	17.75	1662832	17.43	1479306	15.5	1445309	15.15	-248679	2.61	0.17
Low	2023697	21.21	2024872	21.22	2063100	21.62	1977067	20.72	-46630	0.49	0.03
Medium	2156018	22.6	2241893	23.49	2296709	24.07	2204278	23.1	48259.7	0.61	0.04
High	3668111	38.44	3613107	37.86	3702681	38.8	3914452	41.03	246341	2.36	0.16
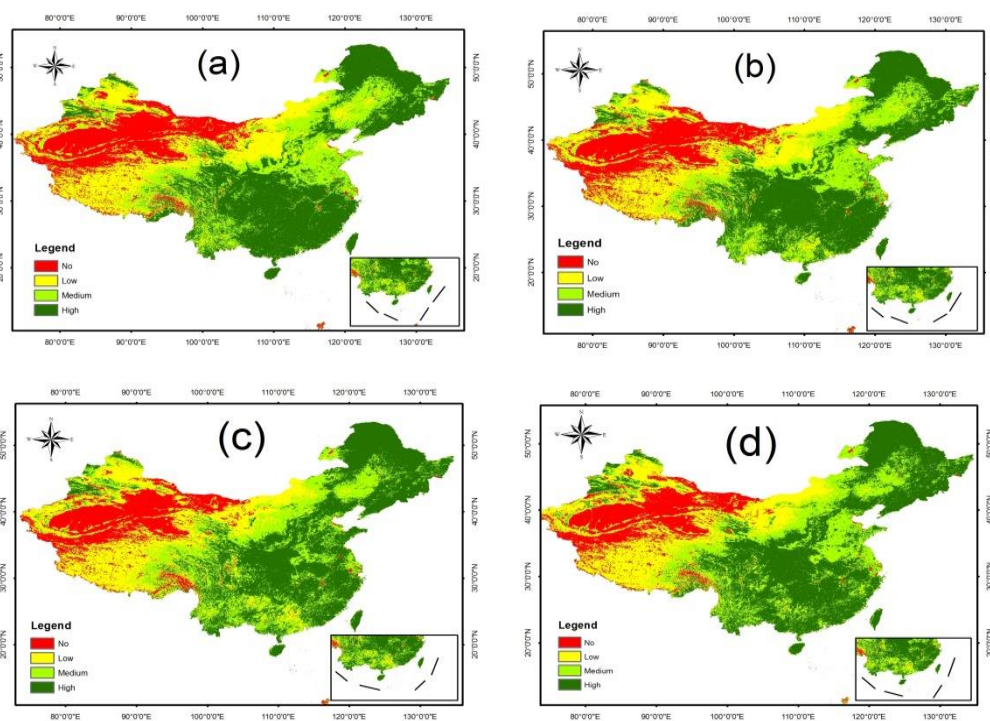
Figure 2. *The vegetation cover maps for the year (a) 2000, (b) 2005, (c)2010 and (d) 2015*

Spatial and temporal trend analysis (2000-2015)

Trend in changes of vegetation cover over the period of 2000 to 2015 at regional level

Table 4 shows variation of vegetation cover over 2000 through 2005 and 2005 through 2010. The findings for 2000 to 2005, showed that the southwestern and the

southern were highest in values in terms of No cover class with 44946.27 km^2 and 1080 km^2 respectively. However, in the northwestern and northern regions there were reduction of No cover class areas for the same period with -43528.9 km^2 and -34278 km^2. In addition, for the same period the results revealed a significant decrease in High cover class in the south-central region with -21475.5 km^2.

Similarly, the results of the 2005-2010 are presented in the same *Table 4*. It was observed that most regions such as the northern, northwestern and southwestern the amount of No cover areas were significantly reduced hence these could be converted to Low, Medium or High cover classes. Obviously, most of the regions revealed an increase in vegetation cover; with the exception of southern and southwestern regions which detected a decrease in High cover with -21391.9 km^2 and -226147 km^2, accordingly.

Comparing the results of both 2000-2005 and 2005-2010 in *Table 4,* the study reveals that from 2000 to 2010, there was positive improvement of vegetation cover areas in most of the regions, even though, there were few instances where reduction occurred.

Table 4. *Statistics of vegetation cover from 2000 to 2005 and from 2005 to 2010 at regional scale*

Regions	2000-2005				2005-2010			
	No	Low	Medium	High	No	Low	Medium	High
N	-34278	-14262	-11363	60002	-44479.5	-77161.9	-14455.6	136124
E	938	-5345	-12127	16466	-377.18	3111.15	-84532.8	81834.82
NE	-475.84	-8659.63	-8158.72	18307.48	-457.81	6193.9	-86495.7	92139.94
NW	-43528.9	18753.2	17384.88	7393.1	-94915.9	-38133.2	106460.2	26577.35
S	1080.18	40403.64	133853.6	-175378	760.43	7248.51	13367.62	-21391.9
SW	44946.27	-32154.7	-52470.7	39676.16	-44307.1	143808.6	126592.7	-226147
SC	162.92	2529.1	18776.07	-21475.5	250.42	5457.88	6139.24	437.12

The statistic of vegetation changes is estimated from 2010 to 2015 and from 2000 to 2015 at regional level in China (*Table 5*). Based on the results of 2010 to 2015, the northwestern, northern and southern regions experienced a reduction in No cover areas with -7846.14 km^2, -4070.48 km^2, -1686.47 km^2; whereas the southwestern and northeastern had an increase in No cover areas with 24165.9 km^2 and 2608.59 km^2. Our findings also showed that in High cover class, that is, southern and the southwestern regions there were significant increment in vegetation from 2010 to 2015.

Table 5. *Statistics of vegetation cover from 2010 to 2015 and from 2000 to 2015 at regional scale*

Regions	2010-2015				2000-2015			
	No	Low	Medium	High	No	Low	Medium	High
N	-4070.48	24106.01	34693.1	-54749.9	-82827.5	-67318	8874.36	141376.1
E	572.62	744.32	121306.7	-122686	1133.58	-1489.59	24647.34	-24384.9
NE	2608.59	-235.53	11289.59	-14179.7	1674.94	-15089.1	-83364.9	96267.69
NW	-7846.14	11572.6	-77238.5	73420	-146291	-7807.24	46606.58	107390.5
S	-1686.47	-40159.1	-91273.5	133147.3	154.14	7493.07	55947.63	-63622.3
SW	24165.9	-76033.4	-101014	201258.7	-23526.7	35620.57	-26891.6	14787.68
SC	590.23	-6027.38	9805.71	-4366.68	1003.57	1959.6	22442.54	-25405.1

From 2000 to 2015, the results of the study illustrated that there was a general decrease of No cover areas in the northern, southwestern and northwestern regions; while High cover areas showed a significant improvement over the fifteen years (*Table 5*). This may be as a result of the efforts made by the local and central governments to improve forest. On the contrary, the southern, eastern and south central regions recorded a reduction in vegetation cover with -63622.3 km^2, -24384.9 km^2 and -25405.1 km^2, respectively. The results can be concluded as having experienced a saw-tooth trend in each class of vegetation for the fifteen years study period.

Trend in changes of vegetation cover over the period of 2000 to 2015 at provincial level

Table A1 shows the changes in vegetation areas from 2000 to 2005 for each municipalities, autonomous cities and provinces of China. The results revealed that vegetation cover decreased, as shown in the High cover class, in some provinces such as Heilongjiang, Henan, Guangxi, and Qinghai with -16550.09 km^2, -12110.08 km^2, -131949.5 km^2, -12105.383 km^2, accordingly. However, other provincial levels demonstrated an increase of green vegetation during the same period. For instance, Inner Mongolia, Hebei, Sichuan, and Gansu with 17822.12 km^2, 26496 km^2, 29867.89 km^2, and 9522.64 km^2, respectively.

Similarly, changes in vegetation for the years 2005 to 2010 were produced and presented in *Table A1*. The data shows that numerous municipalities, autonomous cities and provinces which demonstrated a decrease in vegetation in previous years (2000-2005) had a significant increase in High cover class; for example Heilongjiang, Henan and Anhui. Furthermore, most provinces experienced significant reduction in No cover areas such as Xizang and Qinghai with -48234.65 km^2 and -21019.3 km^2. Nevertheless, most of provinces indicated an obvious change in both No and High cover classes.

For the years 2010-2015, our findings show that No cover class representing barren lands or built-up areas have escalated in Heilongjiang, Qinghai and Gansu with 212.41 km^2, 4932.93 km^2, and 3985 km^2; whereas most of the provinces reveal an increase in vegetation cover as referred to High cover class (*Table A2*).

In general, the results indicated an improvement in vegetation cover for many provinces; for instance Xinjiang, Heilongjiang, Jilin, Liaoning, Shaanxi and Gansu over the period of study. Even though there were huge reclamation of vegetation, provinces like Guangxi, Guangdong, Fujian, Jiangxi, Hunan, and Hubei showed degradation of forest zones mainly located in eastern and southern China as shown in *Table A2*.

Discussion

The continuous estimation and analysis of vegetation cover changes at different scales is a crucial tool for an in-depths understanding of the changes that happened in the ecosystem. This aims to establish a link with all ecosystem components and to acknowledge the driving factors that caused these changes. As aforementioned, remote sensing data has been demonstrated to be one of the best and widely applied methods used in several studies to assess changes in vegetation cover and the ecosystem (Guo et al., 2016; Lyon et al., 1998; Jia et al., 2014).

At the national level, the findings demonstrated that vegetation cover areas have risen throughout China. The analysis of vegetation trends revealed that in 2000, the vegetation cover was less dense than that observed in 2015 with 38.44% and 41.03%, respectively (*Table 3*). These changes are mainly reflected by the conversion in areas

from the No and Low cover classes to Medium or High cover classes in 2015 (*Table 3*). The slight evolution of forest land by 2.36% (*Table 3*) observed during the study period may be the results of greater efforts undertaken by the central government to conduct environmental restoration projects, particularly to increase green vegetation throughout the country. These results are consistent with studies (Xu et al., 2018) who indicated that 83.34% of China's territory are experiencing a general increase in vegetation due to environmental restoration projects. Recently, the 9th National Forest Inventories (NFI) revealed that there was an increase of forest lands (National Forestry and Grassland Administration, 2019). Similarly, Liang et al. (2018) indicated a rise in forest areas with 3.60 million ha over the 25 years of study (1982-2006) or 0.15 million ha/year. Besides these successes, the government has also promulgated a series of laws aimed at strengthening environmental restoration and management measures (Chunmei and Zhaolan, 2010; Sims, 1999; Zhang et al., 2007). For example, the Environmental Protection Law which has been formed to lead to ecological protection while industrial development will still be undertaken (Zwierzchowski and Rott-Pietrzyk, 2020; Mu et al., 2014).

Further, several other green building projects have been implemented such as "Pastureland to Grassland", "Shelterbelt", and "Grain to Green" with the same goal of improving vegetation conditions and to reduce human pressure on the ecosystem (Bennett and Smith, 2017; Xu et al., 2017). With the establishment of these projects, a significant change of forest areas has been recorded in the different zones where they have been carried out in China (Zhang et al., 2018; Li et al., 2018). Additionally, the growth in forest lands detected in these study areas may be as a result of climate change experienced in recent years around the globe including China. The contribution of climate change was explained by various authors that global warming has favored the lengthening of the vegetative season and also has increased the photosynthesis capacity of plants in non-arid areas. This has greatly influenced the growth in forests, grassland and the reduction of barren areas (Niemand et al., 2005; Piao et al., 2007, 2008; Arellano et al., 2015; Xu et al., 2014). Contradictorily, some authors declared a decrease in vegetation cover. According to Cao et al. (2011) vegetation lost in China has been intensified because of the unchecked reforestation projects. This lost is due to the fact that they do not take into account local conditions (pedology, hydrology or climate factors) and the use of unsuitable tree species in the regions which could not adapt to soil or weather conditions.

At regional level, the results (*Table 5*) indicated that the southern, south-central, and eastern regions have decreased in vegetation cover areas, over the fifteen years, with -63622.3 km^2, -25405.1 km^2, and -24384.9 km^2, respectively. Even though some studies indicated an increase in vegetation cover in these regions as a results of vegetation restoration projects (Wang et al., 2015). These three regions are among the most urbanized, populated, and developed regions in China. Therefore, the intense activities occurring may be due to changes in vegetation cover. For instance, a progressive reduction in green areas in the eastern were detected in *Tables 4* and *5*. These results are consistent with studies carried out by several authors in the eastern region. They noted that the excessive resource utilization, the conversion of forest to cropland and the increase in built-up areas have greatly impacted the urban and non-urban forest areas (Fan et al., 2015; Song et al., 2018; Zhang and Huang, 2019). Furthermore, studies showed that the high rate of population density increase of this region, with 503 persons

per km^2 in 2000 to 566 persons per km^2 in 2010, has also contributed the decrease in vegetation areas (Yu et al., 2018).

In addition, topography and climate may also act as driving forces for vegetation change. Topography influences vegetation distribution and density (Xin and Xu, 2007; Pan et al., 2003). As mentioned previously in *Table 1*, China has various terrain structure such as plains and plateaus which may be the cause of fast vegetation degradation. According to Zhao et al. (2014), forest lands are more dense in the upper terrain than in lower elevation. These low elevations facilitate access to human-being for resources extraction which might result to fast vegetation alteration in the east, south and south-central regions of our study area. Furthermore, several studies have stated that changes in climate conditions in China plays a crucial role in vegetation distribution. This is mainly due to the fact that temperature and precipitation changes with time and hence have great impact on vegetation cover growth in several regions, including the southern and eastern China's regions (Wang et al., 2019; Xu et al., 2014).

In contrast, the north, northeast, and northwest regions showed significant growth of vegetation cover over the fifteen years period, with 141376.1 km^2, 96267.69 km^2, and 107390.5 km^2, accordingly. Our findings agree with ShengPei et al. (2011) and Wei et al. (2018) who carried out studies on vegetation cover in the northwestern of China from 1982 to 2006 and 2000 to 2010, respectively. The increase in vegetation was illustrated with a rise in NDVI values over the study period due to barren lands reduction by 40,925 km^2 and forest improvement of 10% (ShengPei et al., 2011). Going further, both research indicated that grassland and forestland expansion in the northwestern China, was as a consequence of the Three-North Shelterbelt, Return Cultivated Land for Forest Land and Grass Land Projects.

At the provincial level, the results of 34 provinces, including autonomous cities and municipalities, were shown in *Tables A1* and *A2* with a constant five-year interval. The results depicted an obvious difference in each province. From the year 2000 to 2015, High cover areas evolved slightly in Xinjiang, Inner Mongolia, Gansu, Yunnan and Shandong provinces, with 40239.77 km^2, 60650.32 km^2, 33835.56 km^2, 39962.94 km^2, and 33020.3 km^2, respectively as indicated in *Table A2*. Additionally, some provinces such as Guangdong, Guangxi and Jiangxi showed irregular changes or a reduction in vegetation cover over the 15-year period. Our results are in conformity with a study carried out by Hu et al., (2019) and Zhang et al. (2020). Their results showed that Guangdong, Guangxi and Jiangxi had decreased in green cover; whereas in Inner Mongolia and Yunnan there was an increase. However, other studies indicated that Jiangxi has demonstrated a slight increase of vegetation due to reforestation projects, and a significant forest loss in Inner Mongolia due to rainfall and temperature change (Xu et al., 2014; Song et al., 2018).

Studies have explained the cause of vegetation cover change at provincial level in China as a consequence of various factors such as migration and population growth. Most of these studies are focused on human activities due to the rapid development that occurs in China since their economic reform. These factors influenced land use change in several ways. In China, the migration of population from rural to urban regions has brought about a significant increase in population density. This has also led to demand for land and raw materials causing a decrease in urban forests areas and grasslands (Walker et al., 2000; Barbieri and Carr, 2005; Carr, 2009; Zhou et al., 2014), and the degradation of ecosystems resources (Wang et al., 2014; Liu et al., 2014). For example, it was indicated that Guangdong province experienced a rapid growth of population

mainly attributed to fast economic expansion and geographical conditions which has impacted vegetation cover growth in suburban areas (Li et al., 2013a). In addition, an investigation conducted in Guangxi province also illustrated that population growth has influenced the transition of forestland and grassland to urban areas from 1990 to 2017 (Hu et al., 2019). Therefore, these examples show how human activities are the key to drastic vegetation cover loss in some provinces or municipalities in China.

It has also been shown that vegetation and weather conditions are interrelated (Xia et al., 2007). To be more precise, vegetation is sensitive to microclimate variations, thus this may have probably contributed to the vegetation cover changes of each province where there were changes depicted in High cover class.

Conclusion

Ecosystem health is determined by vegetation cover conditions. Therefore, providing information on the vegetation cover changes constitute an important and fundamental guideline for monitoring the environment. Implementation of effective laws with the purpose of protecting the vegetation from anthropogenic pressure as well as from natural pressure is vital. This research determined the spatial and temporal evolution trend of the vegetation cover in China by using MODIS NDVI data over a period of fifteen years. The study indicated a general trend of vegetation cover at national level in terms of increase in forestland and grasslands. Notwithstanding, the reduction of vegetation cover observed within the study area (regional and provincial levels) may be the results of several driving factors such as rapid population growth, climatic change, urbanization and fast development that occurred in China which need deeper investigations. The results of this study constitute a reference point for future research and a decision-making tool for ecosystems management and restoration. Future research should therefore focus on: (i) a more in-depth study of China's vegetation cover using other satellite products and classification methods which can provide the current and future vegetations conditions and in situ observations. (ii) More research of the driving factors that induce vegetation cover changes at three different levels. (iii) at the provincial level, local policymakers ought to strengthen environmental laws and measures in order to maintain vegetation recovery where there were rise in forest areas, for instance Xinjiang and Yunnan. (iv) However, Guangdong and Guangxi (with huge vegetation loss) need to implement more restoration projects which will essentially focus on forest growth.

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APPENDIX

Table A1. *Changes in area (km^2) from 2000 to 2005, 2005 to 2010*

Name	2000-2005				2005-2010			
	No	Low	Medium	High	No	Low	Medium	High
Heilongjiang	-442.40	-1747.15	18753.16	-16550.09	-95.97	-1144.1	-70506.3	71728.14
Xinjiang	-47162.31	31766.51	12741.53	2649.54	-47201.6	19249.5	16391.93	11568.58
Shanxi	-16.71	-15189.92	3569.34	11628.23	-4.04	-12958.4	-29346.8	42323.52
Ningxia	-631.85	-4478.22	4442.97	667.71	-136.76	-11225.6	8722.93	2633.98
Xizang/Tibet	46199.99	-28344.07	-23913.4	6048.23	-48234.7	100793.5	10842.93	-63409.4
Shandong	251.80	-4595.31	-6807	11144.23	-279.46	-1492.56	-83462.4	85234.22
Henan	16.07	452.16	11659.68	-12110.09	-29.92	-2323.64	-50309.3	52665.27
Jiangsu	363.00	-208.49	-11185.44	11031.65	34.8	-43.72	-21661	21670.19
Anhui	125.93	-226.86	5559.98	-5446.39	-182.77	-490.43	-22344.6	23011.32
Hubei	153.06	-304.57	-1777.19	1931.10	-62.26	792.71	16790.71	-17525.8
Zhejiang	46.60	-68.93	1516.89	-1494.33	-49.35	90.75	1757.22	-1805.17
Jiangxi	213.95	-322.11	-86.87	196.08	134.86	3587.46	27145.11	-30882.7
Hunan	-6.20	2291.51	8875.59	-11296.57	342.59	7078.8	27397.34	-34702.4
Yunnan	-1888.43	-4481.52	-506.52	6890.59	1754.63	1728.58	1226.77	-4726.41
Guizhou	6.85	2021.74	-1904.66	-130.28	150.72	19252.47	39936.64	-59346.4
Fujian	41.97	38.75	-0.74	-74.82	-70.16	1423.74	14081.94	-15447
Guangxi	888.00	32108.96	98851.28	-131949.50	-20.68	-5589.91	-1409.89	7096.68
Guangdong	136.54	8050.20	29427.39	-37621.76	852.67	12941.94	18220.42	-32027.1
Hainan	-18.70	186.76	5245.4	-5414.57	1.6	-158.35	-3484.54	3637.03
Jilin	-32.04	-5450.71	10057.7	-4573.86	-174.66	-4835.4	-19300.3	24316.98
Liaoning	-1.41	-1461.77	-36969.58	39431.44	-187.18	-214.41	3310.83	-3905.18
Tianjin	19.23	-778.30	-1388.13	2152.95	-158.83	-328.89	-1411.51	1899.26
Qinghai	11719.82	11268.25	-10881.05	-12105.38	-21019.3	-9917.38	49879.89	-18944.7
Gansu	-7407.15	-3054.56	951.13	9522.65	-26529.2	-2404.88	24418.53	4503.09
Shaanxi	-47.46	-16748.66	10130.3	6658.58	-29.13	-33834.8	7046.97	26816.39
Inner Mongolia	-34301.31	14762.72	1812.44	17822.12	-44058.3	-60784.6	50980.47	53875.95
Chongqing	2.89	327.47	2674.28	-3000.27	-13.22	340.47	4227.67	-4558.19
Hebei	18.62	-12998.94	-13510.15	26496.00	-255	-3069.34	-30688.9	34010.23
Shanghai	-5.98	-18.11	-1147.94	1168.62	9.67	-13.58	-465.92	470.65
Beijing	2.62	-57.70	-1846.63	1902.68	-3.29	-20.72	-3988.85	4015.03
Taiwan	-26.75	56.00	24.55	-58.72	-47.16	49.49	416.76	-416.67
Hongkong	1.351	57.712	329.48	-391.917	-0.16	54.83	41.63	-98.45
Sichuan	624.97	-1678.27	-28820.41	29867.89	2035.47	21693.52	70358.69	-94106.9

Table A2. *Changes in area (km²) from 2010 to 2015, 2000 to 2015*

Name	2010-2015				2000-2015			
	No	Low	Medium	High	No	Low	Medium	High
Heilongjiang	2172.41	167.39	12155.2	-14501.6	1634.04	-2723.86	-39598	40676.42
Xinjiang	-16776.2	13102.49	-22356.9	26021.66	-111140	64118.5	6776.54	40239.77
Shanxi	137.13	-352.69	1505.63	-1291.82	116.38	-28501	-24271.8	52659.93
Ningxia	-1.82	4703.63	-3871.3	-828.46	-770.42	-11000.2	9294.6	2473.23
Xizang/Tibet	-18018	-27100.6	999.95	44125.17	-20052.7	45348.91	-12070.5	-13236
Shandong	150.76	281.27	62873.39	-63298.1	123.1	-5806.61	-27396	33080.3
Henan	49.1	1860.06	42811.16	-44724.3	35.25	-11.42	4161.54	-4169.11
Jiangsu	-259.75	522.17	31182.57	-31451.5	138.05	269.96	-1663.83	1250.32
Anhui	517.91	395.41	19603.06	-20518.3	461.07	-321.87	2818.43	-2953.38
Hubei	597.98	642.68	-5794.74	4551.63	688.78	1130.83	9218.78	-11043
Zhejiang	56.96	2351.72	15420.1	-17827.2	54.21	2373.54	18694.2	-21126.7
Jiangxi	-248.68	-2687.82	-13028.8	15827.39	100.13	577.54	14029.43	-14859.2
Hunan	-56.85	-8530.12	-27210.7	35805.99	279.54	840.19	9062.22	-10193
Yunnan	-1570.17	-11133.4	-25082.1	37798.76	-1703.97	-13886.3	-24361.9	39962.94
Guizhou	-108.19	-16112.1	-27172.3	43409.79	49.38	5162.09	10859.71	-16066.9
Fujian	164.7	-178.55	3708.83	-3692.23	136.5	1283.94	17790.02	-19214.1
Guangxi	-724.41	-20401.4	-55497.6	76644.96	142.91	6117.66	41943.75	-48207.9
Guangdong	-973.57	-19628	-34425.4	55027.56	15.63	1364.16	13222.4	-14621.3
Hainan	12.69	-16.17	-981.69	989.09	-4.41	12.24	779.17	-788.45
Jilin	150.05	-217.4	7559.64	-8009.3	-56.65	-10503.5	-1682.91	11733.82
Liaoning	286.14	-185.51	-8425.25	8331.2	97.55	-1861.69	-42084	43857.46
Tianjin	44.23	162.45	2109.44	-2315.72	-95.36	-944.74	-690.2	1736.5
Qinghai	4932.93	-5473.31	-30939.1	31482.33	-4366.54	-4122.44	8059.72	432.26
Gansu	3985.31	-4839.22	-18947.8	19809.82	-29951	-10298.7	6421.88	33835.56
Shaanxi	13.67	4079	-1123.42	-3065.35	-62.92	-46504.4	16053.85	30409.63
Inner Mongolia	-4360.36	23823.58	-8432.35	-11047.8	-82720	-22198.3	44360.56	60650.32
Chongqing	159.43	-609.48	-3388.02	3831.53	149.1	58.46	3513.93	-3726.93
Hebei	108.07	439.03	34632.26	-35177.5	-128.3	-15629.3	-9566.81	25328.69
Shanghai	-14.26	24.16	1141.94	-1151.99	-10.57	-7.53	-471.92	487.28
Beijing	0.45	33.64	4878.13	-4917.05	-0.22	-44.78	-957.35	1000.66
Taiwan	204.99	35.96	405.67	-647.03	131.09	141.45	846.98	-1122.43
Hongkong	-1.19	-113.53	-368.81	485.68	0	-0.99	2.31	-4.69
Sichuan	-4628.94	-21077.8	-46371.1	72093.5	-1968.5	-1062.59	-4832.8	7854.5