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Vegetation dynamics and ecosystem service values changes at national and provincial scales in Nepal from 2000 to 2017

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ABSTRACT

Identification of vegetation changes and economic valuation of natural resources are important to strengthen national economy and sustainable environment development. This study identified the changes in vegetation and ecosystem service values at the national and provincial scales in Nepal from 2000 to 2017. Mann Kendall test statistics and Sen's slope were computed for temporal and spatial normalized difference vegetation index (NDVI) values in each pixel having a spatial resolution of 250 m and at 16-days interval. Land cover types were defined based on the NDVI values and applied ecosystem service values (ESV) coefficient. Results show that NDVI has significantly increased in Nepal with an average trend of 0.0018 yr^{-1} during 2000–2017. Except for Province 6, the NDVI has increased significantly in all the provinces. Results additionally suggested a 27.88% greening in Nepal. At the provincial scale, the highest (56.41%) and lowest (12.52%) greening were observed in Provinces 2 and 6, respectively. In 2017, the total ESV in Nepal was 21.88 billion USD which showed a 1.15 billion USD higher than in year 2000. The ESV has increased in forests but decreased in the croplands, grasslands and barren lands between 2000 and 2017. The ESV of national forest are estimated at 19.17 billion USD in 2017. The highest value of 4.17 billion USD and the lowest of 1.09 billion USD were found in Provinces 1 and 2, respectively. Meanwhile, the available ESV per capita was relatively higher in Province 6 and lower in the Province 2. As the ESV is important lifeline for the society, this study provides crucial information about how this important environmental parameter has changed over time in Nepal.

1. Introduction

Global studies on vegetation dynamics have widely used normalized difference vegetation index (NDVI) (Chen et al., 2014; Gang et al., 2016; Kong et al., 2017; Panday and Ghimire, 2012; Piao et al., 2015; Wang et al., 2017; Zhong et al., 2010). Remote sensing of vegetation dynamics has shown increased vegetation mainly in the northern hemisphere (Eastman et al., 2013; Liu et al., 2015; Zhu et al., 2016). Further, global coverage of NDVI values have been used to predict the ecological effects from environmental changes (Pettorelli et al., 2005). As the NDVI has positive correlation with vegetation biomass (Myneni et al., 1995; Running, 1990) and productivity (Reed et al., 1994), NDVI has been used for wide ranging ecological applications. NDVI provides information on spatial

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and temporal distribution of vegetation (Reed et al., 1994), changes in CO_2 fluxes (Vourlitis et al., 2003; Wylie et al., 2003), land degradation (Bai et al., 2008; Holm et al., 2003; Thiam, 2003), variations of forest carbon dynamics (Dong et al., 2003; Myneni et al., 2001; Piao et al., 2005) and land use and land cover changes (He et al., 2017). NDVI has also been used for prediction of drought occurrence (Deng et al., 2013; Domenikiotis et al., 2004; Liang et al., 2017; Qian et al., 2016), studying forest fire (Maselli et al., 2003), flood forecasting (Wang et al., 2003) and mapping frost occurrence (Tait and Zheng, 2003). In addition, NDVI is the proxy of vegetation changes obtained from the ratio of near infrared and visible red reflectance. A higher absorption of visible light indicates the presence of healthy plants which can perform more photosynthesis and vice versa (Rouse et al., 1974; Tucker, 1979). NDVI values ranges from -1 to $+1$ with barren lands typically having value less than 0.1 (Fang et al., 2004; Zhou et al., 2001).

Satellite based vegetation study reunified many disciplines in ecological research (Davis et al., 2005). The different ecological applications of vegetation dynamics require large and broad spatial extents which are difficult to collect from field observations. Thus, satellite remote sensing has emerged and addressing these problems in studying ecological changes (Kerr and Ostrovsky, 2003; Turner et al., 2003). Ecosystem Service Values (ESV) were assessed using NDVI based land use types (He et al., 2017; Rouse et al., 1974; Tucker, 1979). Ecosystem services refers to goods and services delivered from ecosystems to humans benefits (Costanza et al., 1997, 2014; de Groot et al., 2010, 2012; Obeng and Aguilar, 2018; Ridding et al., 2018; Sannigrahi et al., 2018). Ecosystem services are categorized as provisioning services (food, firewood, fodder and timber), regulating services (climate, water, biodiversity and gas), supporting services (raw materials) and cultural services (tourism, recreation and aesthetic values) (Andrew et al., 2014; MEA, 2005). The economic values of these ecosystem services are generally quantified using direct benefit transfer approach (Costanza et al., 1997, 2014; Song and Deng, 2017; Song, 2018; Xie et al., 2003). Asia is one of the priority regions for ESV studies because of its higher transformation of land use in a relatively short period (Zhao et al., 2006). This is particularly true in Nepal where forests areas in the last decade have increased significantly. Nationally, forest including wooden lands occupy a total of 6.61 million hectare that account for 44.74% of the total area of the country (DFRS, 2015).

Since 2015, Nepal begun federal government system with 7 provinces, 77 districts and 753 local administrative units (MoFALD, 2017). The average annual per capita income is 1012 USD and 21.6% of the total population is still under the poverty line (NPC, 2019). The per capita Gross Domestic Product (GDP) and average Human Development Index (HDI) have been found to be disproportionate at the provincial scales (NPC/CBS, 2019; GoN, 2018). As a result, economic valuations of the natural resources are imperative for improve environmental planning and economic growth at national and provincial scales. Although, there were vegetation dynamic studies based on previous administrative, political and ecological foundations, this study is the first conducted after federal restructuring of Nepal. To our best knowledge, vegetation change has been studied in small spatial scales using points based tree rings observations (Chhetri and Cairns, 2016; Gaire et al., 2017; Shrestha et al., 2017; Sigdel et al., 2018; Thapa et al., 2017; Tiwari et al., 2017) and remote sensing in response to climate changes (Chhetri et al., 2017). Land use and land cover changes in Nepal has also been studied (MoFE, 2019; Paudel et al., 2016; Uddin et al., 2018; Uddin et al., 2015) based on Landsat and Google Earth imageries. ESV have also been computed for the Koshi (Zhao et al., 2017) and Gandaki (Rai et al., 2018) basins under site specific and limited temporal scales. Further, NDVI changes in response to climate have been derived in Koshi river basin (Zhang et al., 2013) and over entire Nepal (Baniya et al., 2018; Krakauer et al., 2017) using NOAA, GIMMS NDVI. The studies described above were carried out with previous administrative structures that existed before 2015 and did not coupled vegetation dynamics and ecosystem services. Therefore, there is critical need to provide an understanding of the changes in vegetation dynamics and ESV using the newly established administrative units. Rural livelihoods in Nepal are dependent on forest for food, fiber, timber and non-timber forest products (Adhikari et al., 2018; Bhatta et al., 2015). In particular, people in the Himalayan region have close nexus with ecosystem services in their daily life (Bhattacharjee et al., 2017), more so in the mountain regions of Nepal (Palomo, 2017). Thus, understanding of the benefits from ecosystem services is valuable to improve livelihood (Paudyal et al., 2015) at the national and provincial scales.

The primary objective of this study is to identify vegetation dynamics based on MODIS NDVI data in different provinces from 2000 to 2017. The use of MODIS data for vegetation analysis in newly established 7 provinces is first in its kind. The temporal and spatial average mean NDVI, trends and significant test for trends were computed at national and provincial scales. Further, we derived ecosystem service values using NDVI based land cover types. The land use classified based on NDVI for 2000, 2005, 2010 and 2017 could be a new example for land use land cover in Nepal. Finding vegetation dynamics and changes in ecosystem service values in large spatial scales are very important for livelihood. Identification of the potential service values of natural resources per capita in each province carry worth meaning to link environmental resources for poverty reduction and policy implications in Nepal. Numerous NDVI products such as NOAA NDVI from 1981 to 2015 (8 km and 15 days temporal resolution), MOD13 TERRA NDVI from 2000 to present (250 m and 16 days temporal resolution), VGT SPOT NDVI from 1998 to present (1 km and 10 days spatial resolution) and TM/ETM Landsat from 1984 to 2003 are available. We used MODIS NDVI because of good ecological implications (Pettorelli et al., 2005) and continuously recorded from higher quality sensors (Tucker et al., 2005).

2. Materials and methods

2.1. Study area

Nepal is a landlocked country located between 26° 22′ and 30° 27′ north and 80° 04′ and 88° 12′ east in the Himalayas and bordered to the North by China and to the South, East and West with India (Fig. 1). Nepal is composed of 7 provinces, 77 districts and 753 local bodies (MoFALD, 2017). The physical environmental conditions for each province are different (Table 1). The altitude varies between 57 and 220 m above sea level (m a.s.l.) in the South and reaches a maximum of 8848 m a.s.l. in the North. It covers an area of 1, 47,181 km^2 with a length of about 800 km parallel to the Himalayan ranges and a width of 160 km. The total population in Nepal is 26,494,504 while the average and maximum population density is 260 and 15,355 people/km^2, respectively (CBS, 2011).

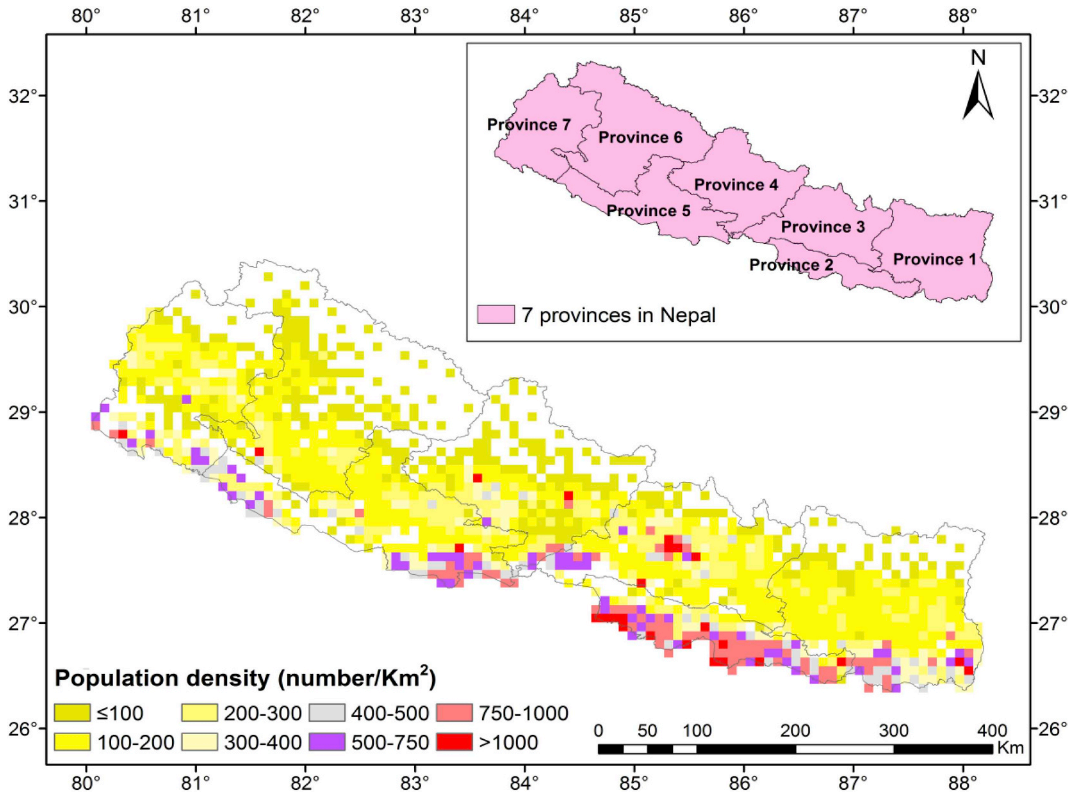


Fig. 1. Location map of the study area (top right inset map) and spatial distribution of population based on Central Bureau of Statistics 2011 in seven provinces in Nepal.

Table 1
Total area, population and physical environmental descriptions of 7 provinces in Nepal.

Provinces	Area (%)	Population (%)	No. of districts	Elevation (m a.s.l.)	Topography
Province 1	17.60	17.12	14	58–8848	Plains to Mountain
Province 2	6.56	20.40	8	57–908	Plains
Province 3	13.79	20.87	13	113–7203	Hill and Mountain
Province 4	14.61	9.07	11	102–8147	Hill and Mountain
Province 5	15.14	16.98	12	79–7053	Plains to Mountain
Province 6	19.01	5.93	10	196–7703	Hill and Mountain
Province 7	13.28	9.63	9	132–6553	Plains to Mountain

Lands within the study areas are occupied by 39.1% forest which are followed by 29.83% cultivated lands and 7.90% grasslands. Altogether, 10.65% lands are barren. The rest of other lands are shrub lands (3.40%), lakes (0.03%), rivers (0.57%), snow/glaciers (8.20%) and built-up area (0.32%) (Uddin et al., 2015). The topography of Nepal is characterized by Plains areas in the south, Hills in the middle zone and Mountains in the north. The national average annual precipitation is 1800 mm and average temperature reaches −10 °C in the north to 30 °C in the south (DHM, 2015). Based on plant species types and climate, the forest are further categorized in to needle-leaved closed forest (9.47%), needle-leaved open forest (5.62%), broad-leaved closed forest (14.40%) and broad-leaved open forest (9.61%) (Fig. 2) (Uddin et al., 2015).

The mountain region of Nepal is dominated by needle-leaved open and closed forests which are of mostly alpine and coniferous nature such as Pine forest (Blue Pine, Chir Pine), Birch-Rhododendron, Fir-Hemlock-Maple, Oak-Laurel, Mountain Oak-Rhododendron, Juniper and Larch forest. On the contrary, there is a dominance of broad-leaved forests in the hills and lower mountain regions of Nepal. The broad-leaved vegetation types include Sal, Chilaune, Katus, Lower tropical Sal, Mixed broad-leaved, Riverine broad-leaved, Khair and Sisoo (MENRIS/ICIMOD, 2008).

2.2. Data and data processing

In this study, the MODIS NDVI of MOD13Q1 Terra product was used (Didan, 2015). The data has 16 days temporal resolution and 250 m spatial resolution and is available for 2000–2017. The four horizontal and vertical tiles of h24 v06, h25 v06, h24 v05 and h25

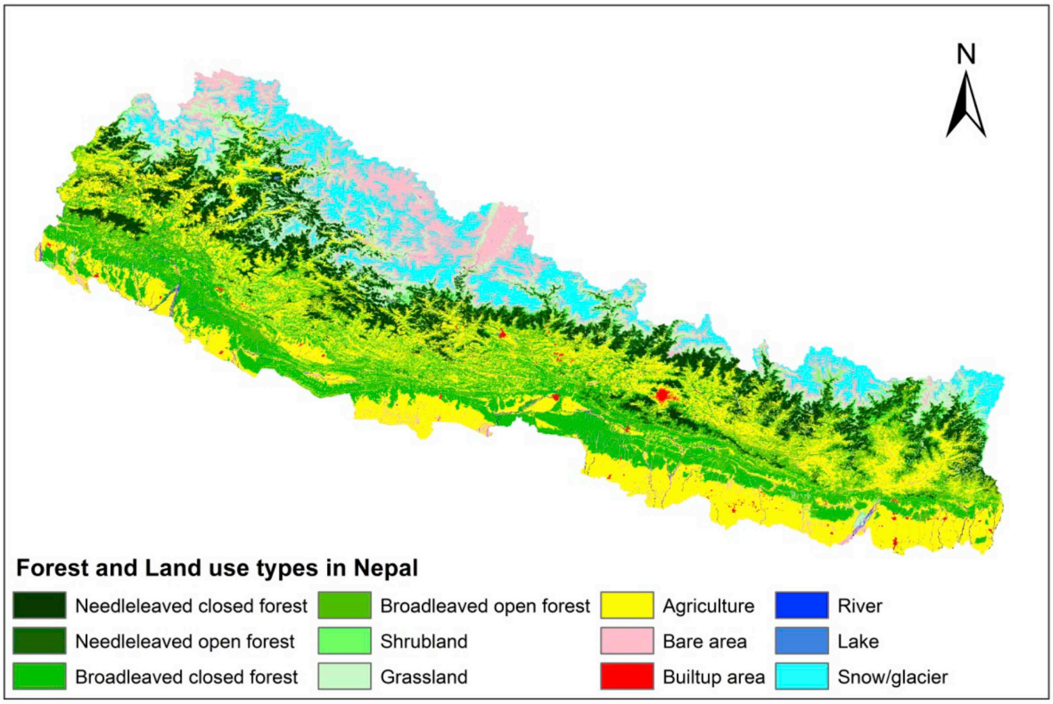


Fig. 2. National forest types and land use land cover standard during 2010 in Nepal.

v05 of Terra product MOD13Q1 0.006 version was used to cover the entire study area. The tiles were mosaicked and re-projected to Albers equal-area projection (STDPR1:25, STDPR2:47, CenMer:105) and nearest neighbor re-sampling method was applied with the WGS84 datum using MODIS Re-projection Tool (MRT) acquired from NASA website. The noise in NDVI time series datasets was removed using Savitzky-Golay filter which provides a simplified least-squares-fit convolution for smoothing and computing derivatives of a set of consecutive values (Savitzky and Golay, 1964). Altogether, 411 images were used. The auxiliary data i.e. land use land cover (Uddin et al., 2015) and population (CBS, 2011) were also employed.

2.3. Data analysis

2.3.1. Mann-Kendall test and Sen's slope

The Mann-Kendall (MK) test was applied to detect time series NDVI trends (Kendall, 1975; Mann, 1945) from 2000 to 2017. The null hypothesis H_o (no trend) was tested at 95% confidence level. The presence of a statistically significant trend was evaluated based on the *p* value. The null hypothesis is rejected if the *p* value is less than a predefined significance level of 0.05. Sen's slope (Sen, 1968) was used to estimate the NDVI change per unit time.

2.3.2. Area of significant NDVI changes

The significant NDVI trends in each pixel were computed using Z statistics in the Mann Kendall test at the national and provincial scales during 2000–2017. Then, areas of significant NDVI changes were computed as following (Equation (1))

$$\text{Significant NDVI changes} = \sum_{i=1}^{n} N_i A_i \tag{1}$$

where i represents a pixel with a statistically significant trend, n is the total number of such pixels, N_i is the number of pixel in which NDVI is significantly change and A_i is the area of the pixel.

2.3.3. Identification of land use and ecosystem service values

Land cover was defined based on the corresponding average MODIS and global standard average NDVI (Rouse et al., 1974; Tucker, 1979). The spatially average NDVI for different corresponding land cover was computed using national land use land cover (LULC) standard (Uddin et al., 2015). The following four corresponding land cover types were defined based on average NDVI in which annual average NDVI of forest including shrublands is more than 0.5. Agricultural lands have average NDVI of 0.3–0.5. During growing season from April–October, the average NDVI in agricultural lands do not exceed 0.5 and the grasslands have average NDVI of 0.1–0.3 in Nepal (Table 2) (Insert Table 2 here).

In this study, vegetated areas are considered as lands with average NDVI of > 0.1 but barren lands i.e. non vegetated lands as those with average NDVI of < 0.1 (Fang et al., 2004; Zhou et al., 2001). The barren lands of less than 0.1 NDVI includes the lakes, rivers,

Table 2
Average NDVI and corresponding land cover types in Nepal.

NDVI classes	Corresponding land covers
> 0.5	Forest lands
0.3–0.5	Croplands
0.1–0.3	Grasslands
< 0.1	Barren lands

snow/glaciers and built up areas. Similarly, the spatially average NDVI for shrublands was higher than grasslands in Nepal therefore it was kept under the forest category. The ESV on corresponding land categories at national and provincial level was analyzed based on global ecosystem service values (Costanza et al., 1997) and ESV used in Tibetan Plateau (Xie et al., 2003) (Table 3).

The ESV in each corresponding land covers types for national and provincial level in Nepal was computed based on simple benefit transfer approach (Costanza et al., 1997) using the equivalent value coefficient of each ecosystem services and functions (Equation (2))

$$ESV = \sum (A_k \times VC_k) \tag{2}$$

where ESV is the Ecosystem Service Values, A_k = area (ha) of each corresponding land cover category "k" and VC_k = Ecosystem service value coefficient (USD/ha/year). The ESV available per individual population was also calculated using the reciprocal relationship between ESV and population in national and provincial scales (Equation (3))

$$ESV\ (USD/head) = \frac{ESV_{total}}{N} \tag{3}$$

where, ESV_{total} is the total ecosystem service values (USD yr^{-1}) and N is the population based on Central Bureau of Statistics of Nepal, 2011.

3. Results

3.1. NDVI distribution and trends

The spatially averaged NDVI was estimated to be 0.44 in Nepal during 2000–2017. The NDVI distributions are higher in the lower hills and lower in the plains and the mountains. The maximum NDVI in Nepal was 0.8 which is mainly found in the foothills. The lowest mean NDVI was found in Province 6 with an average NDVI of 0.33. In Province 4, spatially average NDVI was 0.37 with a maximum NDVI of 0.78. The spatially average NDVI was 0.49 with a maximum NDVI of 0.73 in Province 2. In addition, the spatially averaged NDVI was 0.49 in Province 7 with 0.8 maximum NDVI. The spatial distribution of the mean NDVI during 2000–2017 at the national and provincial scales is depicted in Fig. 3. The NDVI distribution was higher in lower and upper hills but lower in the plains and mountains in Province 1. In Province 2, the NDVI was less than 0.4 in the lower plains and a higher in the Siwalik. Some parts of the mountains show less than 0.1 NDVI in Province 3. In Province 4, lower regions contain more NDVI and higher regions contain lower NDVI. The eastern, western plains and few parts of the mountain have low NDVI but central parts of the Province 5 have good NDVI distribution. In Province 6, the mountain parts have low NDVI but the NDVI was slightly more in the hills. The spatially averaged NDVI was lower in Province 4 and 6 as compared to others as the large fraction of the mountains of these provinces are located in the Trans-Himalayan regions (Insert Fig. 3 here).

Temporally, The NDVI has changed positively at both the national and provincial levels during 2000–2017. The NDVI has significantly increased with an average trend of 0.0018 yr^{-1} (p = 0.0002) across the country. All the provinces showed significant NDVI increase except Province 6 where the NDVI showed non-significant (p = 0.069) increased by 0.0012 yr^{-1} (Fig. 4).

Province 4 and 6 have almost similar spatially averaged NDVI but the NDVI trend of Province 4 was positive and highly significant (0.0018 yr^{-1}, $p < 0.0001$). The average Kendall tau was 0.63 which was more than 0.5 in all the provinces except in Province 6 and 7 where tau values were 0.32 and 0.42, respectively. Generally, the positive Kendall's tau values for overall Nepal and each province showed that the spatially averaged NDVI has increased over time.

Table 3
Average ecosystem service values of different ecosystem types in the Tibetan Plateau.

Land cover types	Ecosystem Service Values (USD ha^{-1}, yr^{-1})
Swamp/wetland	8939.26
Forest	2168.84
Shrub lands	1089.19
Grasslands	565.88
Croplands	699.37
Barren lands	59.83
River/lakes	6552.97
Snow/glaciers	59.83

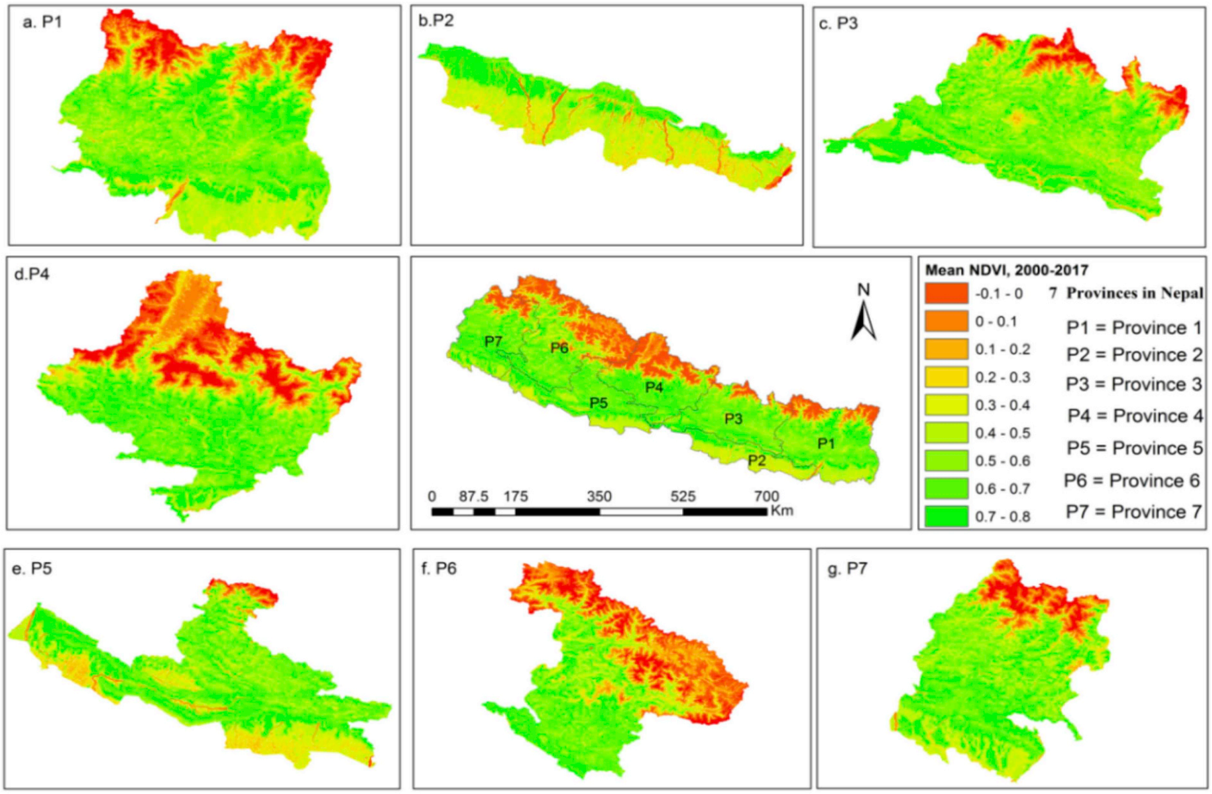


Fig. 3. Spatial distribution of mean NDVI at national and provincial scales during 2000–2017.

3.2. Area with significant NDVI changes

The NDVI increased in more than 80% areas in Nepal. The significant vegetation changes at national and provincial scales are presented using Z statistics as shown in Fig. 5. Overall, the significant positive NDVI trends were found in eastern, central and inner Terai. The south-eastern Terai experienced high positive trends. Similarly, the central hills near the capital city Kathmandu and some parts of the Churia (i.e. above Terai) showed significant negative. In Province 1, the mid hills and the south east regions showed highly significant NDVI trends. In Province 2, the lower regions were observed with more significant NDVI trends. In Province 3, the central parts which are occupied by the dense settlements showed negative NDVI trends but some parts of the surrounding hills were found to have significant positive NDVI trends. The lower hills of Province 4 showed significant positive trends. In Province 5, large areas have significant positive change mainly in the higher lands and the west and eastern Terai. In Province 6, majority of the vegetation has no significant changes. In the south, central and far western parts of Province 7 have shown significant positive NDVI changes (Insert Fig. 5 here).

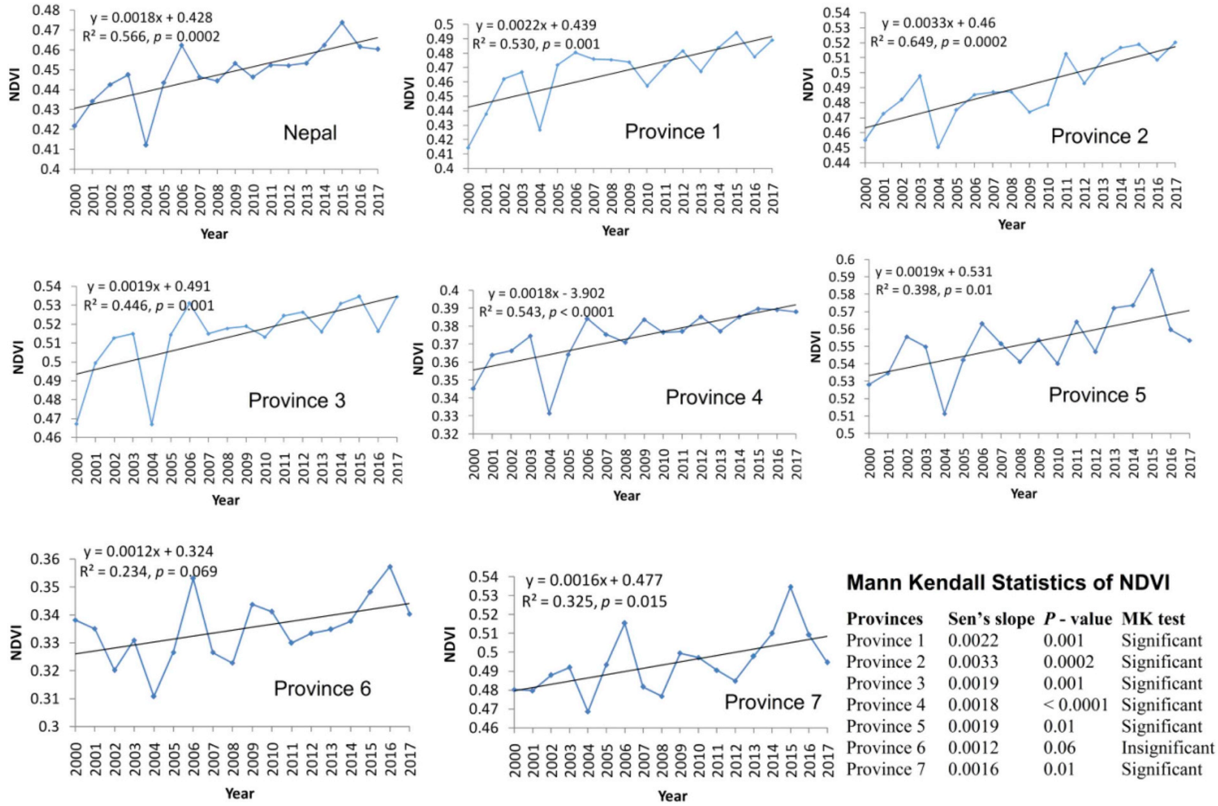
Overall, the majority of Province 1, 2 and 5 showed significant positive changes but far western site of Province 6, central parts of Province 3 and upper regions of Province 2 showed significant negative trends. The total areas of the NDVI and significant NDVI changes at national and provincial scales are summarized in Table 4 (Insert Table 4 here).

In Nepal, 27.88% (41,034.06 km^2) greening and 1.18% (1736.73 km^2) browning is observed during last 17 years. The highest (56.41%) and lowest (12.52%) greening is found in Province 2 and 6, respectively. The Province 1 experienced 40.05% greening indicated significant positive NDVI trends. Provinces 3, 4 and 5 also experienced significant greening. Province 7 was the second lowest greening province in Nepal. Browning (i.e. significant negative NDVI trends) is nominal in all provinces.

3.3. Ecosystem service values (ESV) in Nepal

The total ESV in Nepal was 21.88×10^9 USD yr^{-1} in 2017. The ESV has increased by 3.10×10^9 USD yr^{-1} in last 17 years. In 2010, The ESV was lower compared to that in 2000, 2005 and 2017. The highest ESV was found in the forest which increased by 4.56×10^9 USD in between 2000 and 2017. Currently, ESV has increased in forest but decreased in croplands, grasslands and the barren lands (Table 5). The ESV in forest lands was 19.17×10^9 USD in 2017 which was higher as compared to that in 2000, 2005 and 2010. The total ESV in the croplands was higher than in that the grasslands and barren lands in 2017 (Insert Table 5 here).

The ESV was also derived in all types of ecosystem based on national land use land cover standard of Nepal (Table 6). As forest and agriculture occupied more lands, it provides more ESV. The rivers and lakes are very important ecosystem to the communities



Mann Kendall Statistics of NDVI

Provinces	Sen's slope	*P* - value	MK test
Province 1	0.0022	0.001	Significant
Province 2	0.0033	0.0002	Significant
Province 3	0.0019	0.001	Significant
Province 4	0.0018	< 0.0001	Significant
Province 5	0.0019	0.01	Significant
Province 6	0.0012	0.06	Insignificant
Province 7	0.0016	0.01	Significant

Fig. 4. Average annual NDVI trends (yr^{-1}) at national and provincial scales during 2000–2017.

which contribute ESV of 0.5 billion USD in 2010. Similarly, shrublands and snow/glaciers in the mountain contribute ESV of 0.54 and 0.072 billion USD, respectively (Insert Table 6 here) .

Although, the high lands have less ESV in Nepal, the distribution of spatial averages ESV in different periods showed high ESV in the midlands followed by low lands. In 2000, the mid lands especially in mid and far western regions have higher ESV. The eastern parts have found lower ESV in 2000. The spatially average ESV in midlands during 2005 has increased but ESV has decreased in the low lands and the grasslands. The spatial variations of the ESV per hectare of land in Nepal are given in Fig. 6. In 2017, areas with NDVI higher than 0.5 covered 8.83×10^6 ha where the ESV was 2.16×10^3 USD ha^{-1} but the areas with NDVI of more than 0.5 were 6.73×10^6, 8.16×10^6 and 5.14×10^6 ha in 2000, 2005 and 2010, respectively (Insert Fig. 6 here).

The spatial distribution of the ESV per hectare with NDVI less than 0.1, 0.1–0.3 and 0.3–0.5 decreased in 2017. The ESV also showed variation among different provinces in Nepal. Compared to other provinces, Province 1 and 2 showed the highest and lowest ESV, respectively (Table 7). The total ESV in Province 2 has increased by 0.35×10^9 USD from 2000 to 2017. Except Province 7, the ESV has increased in all provinces. In Province 7, ESV decreased by 0.44×10^9 USD from 2000 to 2017. The higher ESV changes were observed in Province 1. In comparison based on total population recorded in 2011 census and obtained ESV in 2017, the per capita ESV in 2017 was also varied in different provinces in Nepal (Table 7). Similarly, GDP and HDI based on national account and economic survey are presented in which the highest and lowest per capita GDP and HDI was found in Province 3 and 6, respectively (Insert Table 7 here).

The higher per capita ESV was found in Province 6 which was followed by Province 7 and 4. The ESV of these three provinces was more than average annual per capita income of Nepal. The least per capita ESV was found in Province 2 and followed by Provinces 3, 5 and 1, respectively. The average per capita ESV has become 825.83 USD which accounts for 81.60% per capita income of Nepal. Beside it, The NDVI and LULC based ESV was compared and determined accuracy difference. The accuracy of NDVI based total ESV in Nepal was 99.6%. While, the higher accuracy was found in forest i.e. 95.40% and lower was 75.52% in barren lands (Insert Table 8 here).

4. Discussions

4.1. Temporal and spatial NDVI variation and net NDVI changes

MODIS NDVI showed higher greening (slope = positive, $p < 0.05$) than browning (slope = negative, $p > 0.05$) during last 17 years. The greening refers to statistically positive and browning refers to statistically negative NDVI trends. The MODIS NDVI in Nepal increased significantly with a significant increased in all provinces except Province 6 during 2000–2017. The NOAA GIMMS NDVI3g data also suggested that NDVI in Nepal increased at an average trend of 0.0008 yr^{-1} (Baniya et al., 2018) and 0.0004 yr^{-1}

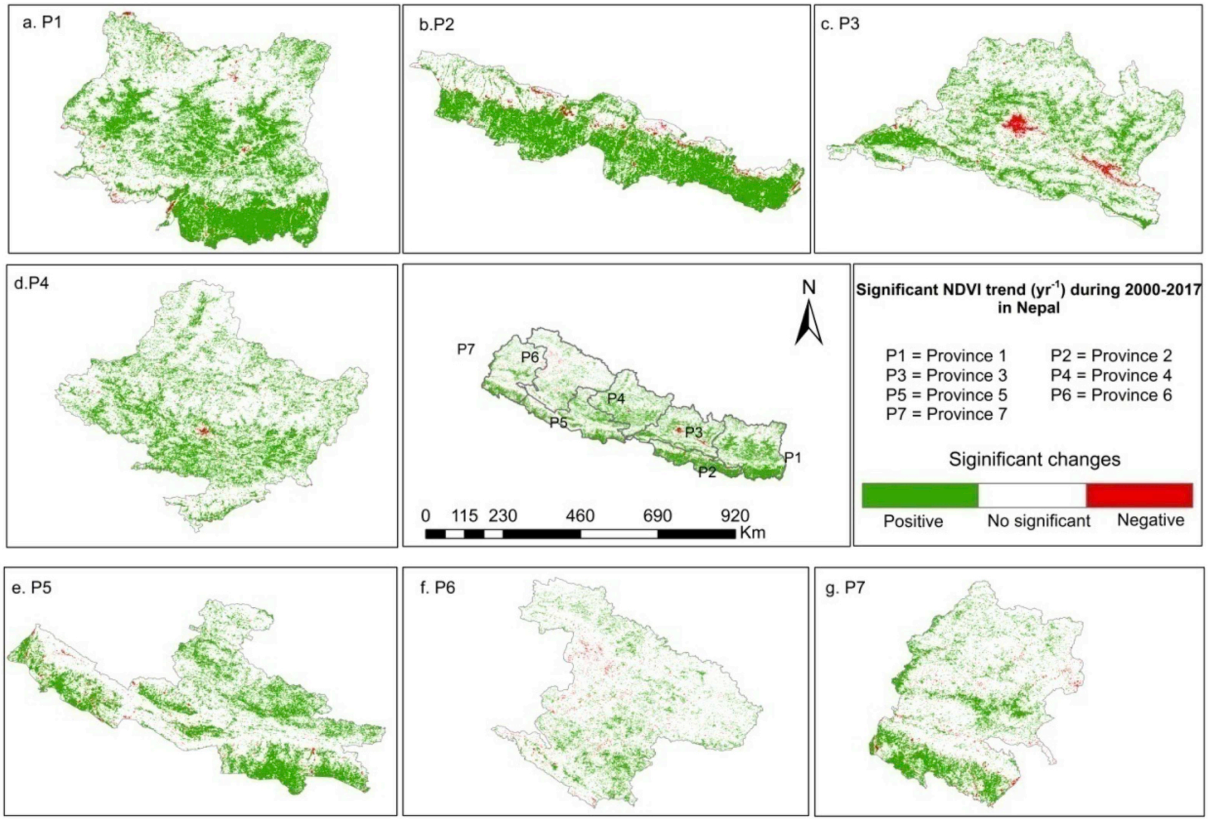


Fig. 5. Area with significant NDVI trends at national and provincial scales in Nepal during 2000–2017.

Table 4
Total area of significant NDVI changes at national and provincial scales during 2000–2017 in Nepal.

Nepal/Provinces	Significant NDVI changes during 2000–2017					
	Positive changes ($10^3 km^2$)	Significant positive ($10^3 km^2$)	Significant positive (%)	Negative changes ($10^3 km^2$)	Significant negative ($10^3 km^2$)	Significant negative (%)
Nepal	123.985	41.034	27.88	23.195	1.736	1.18
Province 1	23.062	10.374	40.05	2.841	0.194	0.75
Province 2	8.273	5.446	56.41	1.381	0.222	2.30
Province 3	17.475	5.589	27.54	2.821	0.430	2.12
Province 4	19.456	5.438	25.29	2.047	0.079	0.37
Province 5	19.290	6.112	27.43	2.992	0.205	0.92
Province 6	20.732	3.502	12.52	7.246	0.335	1.20
Province 7	15.704	4.051	20.73	3.840	0.267	1.37

Table 5
Ecosystem Service Values (USD yr^{-1}) in different land cover types based on corresponding NDVI values in Nepal during 2000–2017.

Land covers	Total ESV (10^9 USD yr^{-1})				ESV Changes (10^9 USD)
	2000	2005	2010	2017	2000–2017
Forests	14.61	17.70	13.07	19.17	4.56
Croplands	3.208	2.23	3.60	1.84	−1.36
Grasslands	0.854	0.78	0.76	0.762	−0.092
Barren lands	0.112	0.117	0.119	0.111	−0.001
Total ESV (10^9 USD yr^{-1})	18.78	20.82	17.54	21.88	3.10

Table 6
Ecosystem Service Values (USD yr^{-1}) in different land cover types based on national standard land use land cover types in Nepal, 2010.

Land use types	Land Cover, 2010		Total ESV (10^9 USD yr^{-1})
	Area (Km2)	Area (%)	
Forest	57,538	39.1	12.47
Shrubland	5008	3.40	0.54
Grassland	11,634	7.90	0.65
Agricultural area	43,910	29.83	3.07
Barren area	15,678	10.65	0.09
River/Lakes	882	0.6	0.5
Snow/Glaciers	12,062	8.20	0.072
Built up area	469	0.32	0
Total	1,47,181	100	17.47

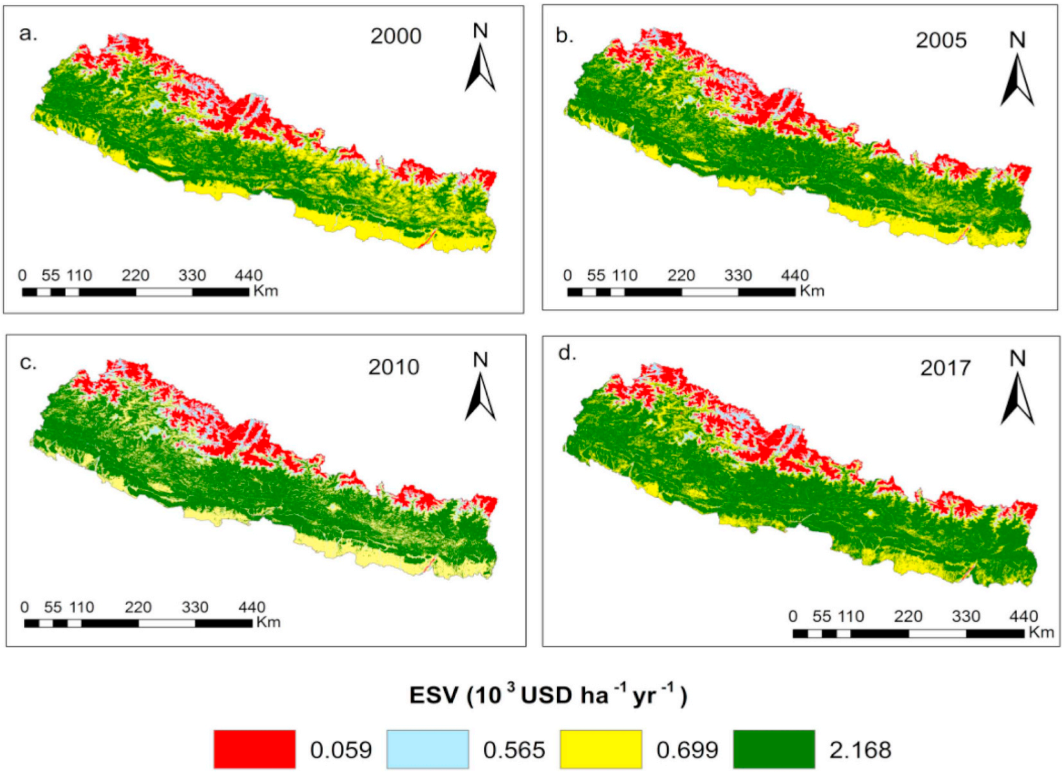


Fig. 6. Spatial variation of the Ecosystem Services Values (ESV) in different time periods in Nepal.

Table 7
Variation of total and per capita ESV, GDP and HDI at national and provincial scales in Nepal.

Provinces	Total ESV (10^9 USD yr^{-1})				ESV Changes (10^9 USD)	Population (in, 000)	ESV/Head (USD yr^{-1})	GDP/Head (USD yr^{-1})	HDI
	2000	2005	2010	2017	2000–2017				
Province 1	3.015	3.70	2.89	4.17	1.15	4535.85	919.34	976.86	0.504
Province 2	1.07	1.09	1.09	1.42	0.35	5404.87	262.72	720.32	0.421
Province 3	2.85	3.73	3.40	3.56	0.71	5529.40	643.83	2269.55	0.543
Province 4	2.23	2.55	2.01	2.73	0.4	2403.05	1136.05	1050.43	0.512
Province 5	3.11	3.44	2.89	3.42	0.31	4498.76	760.20	881.51	0.468
Province 6	2.83	3.18	2.20	3.25	0.42	1571.12	2068.58	664.73	0.427
Province 7	3.67	3.13	3.06	3.23	−0.44	2551.42	1265.96	788.32	0.431
Nepal	18.78	20.82	17.54	21.88	3.10	26,494.50	825.83	1144.83	0.490

Table 8
Comparing NDVI and national LULC based ESV during 2010 in Nepal.

Land use types	NDVI based ESV (10^9USD)	National LULC based ESV (10^9USD)	Accuracy different (10^9USD)	Accuracy (%)
Forests	13.07	12.47	0.6	95.40
Croplands	3.60	3.07	0.53	85.27
Grasslands	0.76	0.65	0.11	85.52
Barren lands	0.119	0.09	0.029	75.63
Total	17.54	17.47	0.07	99.6

Note: National LULC based total ESV (USD) includes the ESV values of River and lakes (0.5×10^9) and Snow and glaciers (0.072×10^9).

(Krakauer et al., 2017) during 1982–2015. The NDVI increased rapidly after 2000. The Koshi River basin also experiences a significant increased NDVI in summer during 1982–2006 (Zhang et al., 2013). Similar greening trends were observed globally (Chen et al., 2019), South Asia (Sarmah et al., 2018) and in the Himalayas (Misra and Mainali, 2017). In Nepal, forest cover has fluctuated in last few decades. In 1960, forest occupied 43.5% of the total land while it was reduced to 29% in 1990. After the initiation of community forest programs (Acharaya, 2002), forest cover increased to 39.1% in 2010 (Uddin et al., 2015), 40.36% in 2015 (DFRS, 2015) and 44.47% in 2018 (MoFE, 2019). The increased greenery through the community forestry program is achieved by reducing forest or tree cover loss and increasing their gain (Shrestha et al., 2018; Oldekop et al., 2019). Currently, only a small fraction of the country showed decreasing forest (only 1.18% browning) in which socio-economic factors such as deforestation, extension of farm lands, urbanization, overgrazing, forest fire and high consumption of fodder and firewood are primary driver of negative changes. Meanwhile, topography, CO_2 level (Krakauer et al., 2017), temperature (Baniya et al., 2018), international out migration (Oldekop et al., 2018) are also driving vegetation changes in Nepal. The dry mountains mainly in the Trans-Himalayan region have shown positive correlation between vegetation and precipitation (Ale et al., 2018; Tiwari et al., 2017). Similarly, Moisture availability has shown important for vegetation productivity in South Asia (Wang et al., 2017). At the Provincial scales, the greening was higher in Province 2 followed by Province 1 due to good agricultural practices and forest management in the foot hills because the majority of Province 2 and lower regions of Province 1 have large agricultural lands. Relatively, the greening is lower in Province 6 because the majority of the lands in northern parts are located in dry parts of the Trans- Himalayan regions. The Trans-Himalayan regions experienced severe drought (Baniya et al., 2019; Gaire et al., 2018) where the average rainfall is low and moisture is the main limiting factor for plant growth (Tiwari et al., 2017). A recent tree ring research also showed that the Trans-Himalayan region has experienced increased drought by decreasing scPDSI, since 1980s (Panthi et al., 2019) and SPEI since 2000s (Bhandari et al., 2019). Those studies are related to different metrics/indices of meteorological drought. In Province 6, spatially average annual NDVI is lower and few areas are experienced significant increased NDVI (Table 4). The presence of these low average NDVI and large areas of decreased NDVI is related to increasing drought. Spatially, the Inner Terai, Eastern and Central hills are more greening.

4.2. Identification of ESV changes in Nepal during 2000–2017

The total ESV of Nepal was higher in 2017 than that in 2000. The forest claims 87.61% of the total ESV of Nepal which is the paramount sources of national and provincial economy. The forest ESV has increased with response to increased forest areas in Nepal (MoFE, 2019). The broad-leaved forests have high contribution for ESV than needle-leaved forest in which ESV equivalent to 7.65 billion USD from broad-leaved forest and 4.82 billion USD from needle-leaved forest was contributed in 2010. Broad-leaved forests in hilly communities have high provisioning (food, firewood, fodder and timber) and supporting (raw materials) services in Nepal. The needle-leaved and broad-leaved forest are categorized to open and closed forest (Fig. 2) in which needle-leaved closed forests contributed to 3.02 billion USD and needle-leaved open forests contributed to 1.79 billion USD in 2010. Similarly, broad-leaved closed and open forests contributed to 4.59 billion and 3.06 billion USD, respectively. The ESV in croplands have decreased even though, the croplands areas have increased from 1978/1979 (27.19%; 40,019 km^2) (LRMP, 1986) to 2010 (29.83%; 43,910 km^2) in Nepal (Uddin et al., 2015). On the contrary, the ESV of croplands was decreased. The grasslands also have decreased ESV due to an increase human population and livestock grazing (Paudel et al., 2016). Barren lands (with an NDVI of < 0.1) also showed a decrease in ESV.

A previous study showed that total ESV in Gandaki river basin was 5.184 billion USD in 2015 (Rai et al., 2018). Similarly, total ESV in Koshi river basin was 8.95 billion USD in 2010 whereas forests have 3.68 billion USD (Zhao et al., 2017). Approximately, Gandaki river basin covers 25% and Koshi river basin covers 33% of ESV of Nepal. The highest greenings but lowest ESV was found in Province 2, which is the smallest but highly populous province with 20.40% of the total population and only 6.56% of lands were occupied (Table 1). The presence of small lands areas and high population in Province 2 are causing only 262.72 USD per capita ESV in 2017. Except in Province 7, ESV was found to have changed positively in all provinces. The presence of low agricultural areas, frequent occurrence of natural disasters and over consumption of natural resources are causing a decreased ESV in Province 7. The per capita ESV was high in Province 6 and 7 but poverty are prevalent in these provinces. The per capita ESV was also compared with GDP and HDI at national and provincial scales (Table 7). In Province 3 where the capital city is located, per capita GDP and HDI are found to be the highest but lower ESV indicates that maximum ESV were used for economic growth. In contrary, Province 6 and 7 have highest ESV but lowest HDI and per capita GDP which means that HDI should be increased to utilize ESV for higher GDP. Province 2 is found to have lower per capita ESV, GDP and HDI which suggests urgent needs for ecosystem restoration and balancing HDI. Overall, HDI is lower but ESV was higher in Nepal. Thus, HDI should be increased for optimal utilization of natural resources under the provision of sustainable development to enhance GDP at national and provincial scales.

In this study, the ecosystem service values coefficient of Tibetan Plateau (Xie et al., 2003) was replicated in Nepal, because, the biomes types and topography are almost similar, and both Nepal and the Tibetan Plateau are located within the same Himalayan region. The ESV coefficient in Tibetan Plateau was provided based on nine categories of ecosystem service function with response to global ecosystem service values obtained from 17 ecosystems and 16 biomes (Costanza et al., 1997). The ESV slightly differ due to inflation in the general price of goods and services of ecosystem over time. This study is a new attempt in sense that the four land use types were defined based on corresponding NDVI values and ESV for 2000, 2005, 2010 and 2017 were estimated. These land use types were compared and validated with national land use and land cover standard of Nepal (Table 8).

4.3. Limitation in using NDVI based ESV and accuracy in results

There are some limitations in satellite data such as the resolution of the sensors (Vermote and Kaufman, 1995), digitization (Viovy et al., 1992), atmospheric attenuation (Tanre et al., 1992) and sensor quality degradation (Kaufmann et al., 2000). The NDVI is a quality controlled product which have been pre-processed to correct for many of these associated drawbacks (Tucker et al., 2005). However, some noises such as cloud cover, water, snow and shadow are still present in the data sets. To avoid these problems, Savitzky-Golay filter (Savitzky and Golay, 1964) was used and smoothing was applied. Further, we used only four types of land cover categorized based on NDVI values i.e. vegetated (forest, croplands, grasslands) and non-vegetated (barrenlands including all lands having NDVI less than 0.1). In Nepal, shrublands occupied 3.40% of the total area, because of high annual spatially average NDVI and similar provisioning, supporting and regulating services as provided by forest, shrublands are considered under forest category. As NDVI increases in croplands, the forest NDVI is also increased during growing season because most of the forest in hills and Terai are deciduous and found climax of growth during growing season. Lacking own ESV coefficients in Nepal is another limitation while estimating ESV. Thus, subjective values coefficient of ecosystem services in four categories of land use types were used to find ESV. In this limited context, the accuracy of this results was tested with ESV obtained based on national land cover standard (Table 8). The accuracy in barren areas was relatively lower (i.e. 75.63%) because barren areas were considered for all the lands less than 0.1 NDVI values. The accuracy in all types of land covers is high. Thus, NDVI base land use classification and estimation of ESV is highly precise and relevant. However, identification of ecosystem service values coefficient objectively based on field observation in different types of ecosystem is important for further research in Nepal.

5. Conclusions

The changes in vegetation dynamics and ecosystem services based on NDVI at national and provincial scales in Nepal were investigated from 2000 to 2017. This study is first to use NDVI for identification of ecosystem service values in Nepal. We found that NDVI has increased significantly over time. The greening was found in 27.88% areas of Nepal during last 17 years. At the provincial scale, the highest and lowest greenings were observed in Provinces 2 and 6, respectively. The ecosystem service values (ESV) of Nepal was 21.88 billion USD in 2017 of which 87.61% ESV was contributed by forest only. The highest and lowest ESV was observed in Provinces 1 and 2, respectively. The ESV changes were positive at the national level and in all provinces except in Province 7. Meanwhile, forest ESV increased but ESV of croplands, grasslands and barren lands decreased from 2000 to 2017. The per capita ESV was higher in Provinces 6 and 7 but lower HDI and GDP. Thus, HDI can be improved for utilization of ecosystem services to increase per capita GDP in these provinces. Similarly, the lower per capita ESV was found in Province 2 that indicates necessities for improved natural resource management. Despite some limitations on the use of NDVI, the key results presented are found to have high accuracy. The results have significant policy implications at the national and provincial scales which is helpful to address the expected national economic growth target i.e. to increase 10.1% annual economic growth during the 15th five year (2019/2020–2023/2024) periodic plan and national level implementation for the agenda of sustainable development goals. Overall, this study could be useful to increase economic growth and prosperity through optimal utilization of ecosystem services based on sustainable approach at national and provincial levels in Nepal.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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