Mapping of land degradation in Vietnam using NDVI MODIS time-series

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Abstract

This study aimed to identify the map of land degradation in Vietnam based on long-term trend of vegetation productivity. The Terra MODIS NDVI dataset in 16 years (2001 – 2016) at a resolution of 1 km x 1 km was used to determine the areas with significant decline or increase in productivity. Through examining the temporal relationship between NDVI time-series and rainfall data during the overlapping period, the areas that might have been affected by rainfall were separated from biomass productivity decline. The results showed that the area of significant decline of biomass productivity during 16 years in Vietnam were 15% of total national area. The degraded areas were found in the Northwest, the Central Coast, the Central Highland, the Southeast and Mekong River Delta. Results from this study may help researchers and policy makers identify the specific locations in Vietnam where more detailed actions may be required to mitigate vegetation productivity decline, thereby combating land degradation.

Keyword: *land degradation, MODIS, NDVI, time series, vegetation productivity, Vietnam*

1. Introduction

Land degradation has been considered as a major global environmental issue (Gibbs and Salmon, 2015; Safriel, 2007) that affecting nearly a quarter of the global land area (Lal et al., 2012). Land degradation is a serious problem for food security and development of society in the tropical countries (FAO, 2010; Vlek *et al*., 2010; Vu *et al*., 2014) where livelihoods are often agriculture-based. Land degradation is defined as "the temporary or permanent decline in the productive capacity of the land" (Stocking, 2001). It has been measured through a loss of biomass, a loss of actual productivity or in potential productivity, or a loss or change in vegetative cover and soil nutrients. Natural and anthropogenic factors are two major factors that caused land degradation (Vlek *et al*., 2010).

Satellite assessments of long-term trends of vegetation productivity have been carried out in many studies (Fensholt *et al*., 2012; Le *et al*., 2016; Vlek *et al*., 2010; Wessels *et al*., 2007). The vegetation-based approach has been recently used for global, continental, and national assessments of land degradation. With this approach, land degradation is measured by the persistent "change in net primary productivity (NPP) with deviation from the norm taken as indicators of land degradation or improvement" (Bai *et al*., 2008). The Normalized Difference Vegetation Index (NDVI), a remote sensing-derived product, is often used for assessment of the changes of vegetation productivity over a long period. Recently, the NDVI has been also used for approximately indicating the Net Primary Productivity (NPP) of the land to monitor temporal changes in vegetation (Fensholt et al., 2012; Holm et al., 2003; Le et al., 2016; Vu et al., 2014; Wessels et al., 2007), since NDVI has a strongly relationship with NPP (Fensholt et al., 2012; Zhao and Running, 2010). The correlation between inter-annual NDVI and climate factors (rainfall) can be used for distinguishing human-induced land degradation from climate-driven phenomena (Vlek et al., 2010).

Although remote sensing has been used by many research teams to detect land use and land cover change in Vietnam (De et al., 2008; Duong, 2004; Kham et al., 2007; Müller and Zeller, 2002), only one study by Vu *et al*. (2014) about spatio-temporal trend analysis has been made for assessing long-term biomass productivity decline in Vietnam using a long-term time-series (1982–2006) of the Global Inventory Monitoring and Modeling System (GIMMS) NDVI 8 km resolution. However, the limitation is GIMMS AVHRR NDVI data have very coarse spatial resolutions (e.g., 8 x 8 km^2) that may limit the accuracy of the assessment (Vu *et al*., 2014).

The NDVI (Tucker, 1986) derived from the The Moderate Resolution Imaging Spectroradiometer (MODIS) of the NASA's Earth Observing System has been used in several studies in assessing vegetation productivity and land degradation (Bédard et al., 2006; Chen et al., 2018; Dubovyk et al., 2012; Eckert et al., 2015; Nasanbat et al., 2018). However, recent reviews suggest that NDVI-based methods for detecting land degradation need to be continuously verified in different geographic regions (Vogt *et al.* 2011). Thus far, in Vietnam, spatio-temporal trend analysis using MODIS NDVI has not been used for assessing long-term changes in biomass productivity of the land on a national scale. The MODIS NDVI dataset is shorter time (started from 2000) than GIMMS AVHRR data, but it has finer reolution (250, 500 and 1000 m resolution) that is may yield more accuracy for assessment of land degradation at national level. Therefore, this study aimed to use the Terra MODIS NDVI at 1 km resolution (1) to identify the decline of the long-term trend of vegetation productivity in Vietnam, thereby representing past land degradation hotspots, and (2) to identify the areas of human-induced productivity decline by isolating the land degradation area from climate-driven impacts.

2. Materials and Methods

2.1. Datasets

2.1.1. MODIS NDVI product

The Terra MODIS Vegetation Indices Monthly L3 Global 1 km (MOD13A3) V006 (Didan, 2015) were used to analyze the long-term (2001–2016) vegetation variability and trends in Vietnam. The NDVI time-series data were downloaded from Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/data_access/data_pool). We aggregated the original NDVI time-series (1 km pixel size, monthly, period 2001–2016) to obtain the time-series of annual mean values as 12-month averages for inter-annual NDVI trend analysis.

2.1.2. CHIRPS rainfall dataset

Rainfall data were extracted from The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version 2 at 0.05° (approximately 5.5 km) spatial resolution over the period 2001- 2016 (Funk et al., 2015). To match the spatial resolution of MODIS NDVI data for later analysis, the grid cells of annual rainfall data were resampled to the same resolution of MODIS NDVI using bilinear technique, which works best for continuous data.

2.2. Methods

We used the MODIS NDVI time-series for the period of 2001–2016 for a pixel-based analysis of the temporal trend in biomass productivity. The trend was measured from the significant slope coefficient (A) in the linear equation $NDVI = A \times year + B$, where A and B are constants. The trend was considered significant at $p < 0.1$.

The significantly negative long-term trend of NDVI (slope coefficient A) can be attributed to either climate change (e.g., inter-annual variation in rainfall) or human activities (e.g., land cover/use conversion and/or change in land use intensity). To differentiate areas of human-induced biomass productivity decline from those in which the decline is driven by climate dynamics, we applied two methods: the trend-correlation stepwise analysis (Vlek et al., 2010) (Trend-Correlation) and residue trend analysis (Herrmann et al., 2005) (RESTREND). These methods examine the temporal relationship between rainfall and biomass productivity (NDVI). With the Trend-correlation method, the areas that have experienced a significant NDVI decline (negative Ai, $p < 0.1$) and show a significantly positive NDVI-rainfall correlation (i.e., ($R^2 > 0.5$; $R > 0$; $p < 0.05$) are considered as ranfall-driven degraded zones. Otherwise, the NDVI decline could have been caused by human activities. For the RESTREND method, the NDVI was regressed from annual precipitation and then the residuals – the difference between observed NDVI and NDVI as predicted from precipitation – were calculated. If there is a significant temporal trend of residual, then the declining biomass production may have been caused by factors other than a decline in precipitation. We compared the overlap between the degraded areas detected by both methods. A higher areal overlap indicates higher confidence of the used methods. The combined degradation areas derived by both methods were the biomass productivity-based map of land degradation.

3. Results and Discussion

3.1. Long-term trend of vegetation productivity over 16 years

Fig. 1a shows the mean NDVI in the period of 2001-2016 (16 years). The value of mean NDVI in Vietnama ranged from 0 (bareland, no vegetation cover) to 0.9 (very dense forest). The high mean NDVI value (> 0.8) in some areas of the Central Highland (CH), the Northwest (NW), along the boundary between Laos and Vietnam. The time-series of NDVI were then analyzed based on linear regression to identify the improvement or decline of NDVI over long time. The value of slope (A) of annual NDVI over 16 years was ranged from -0.04 to 0.03 (**Fig. 1b**). The significant test at $p < 0.1$ was carried out for slope A.

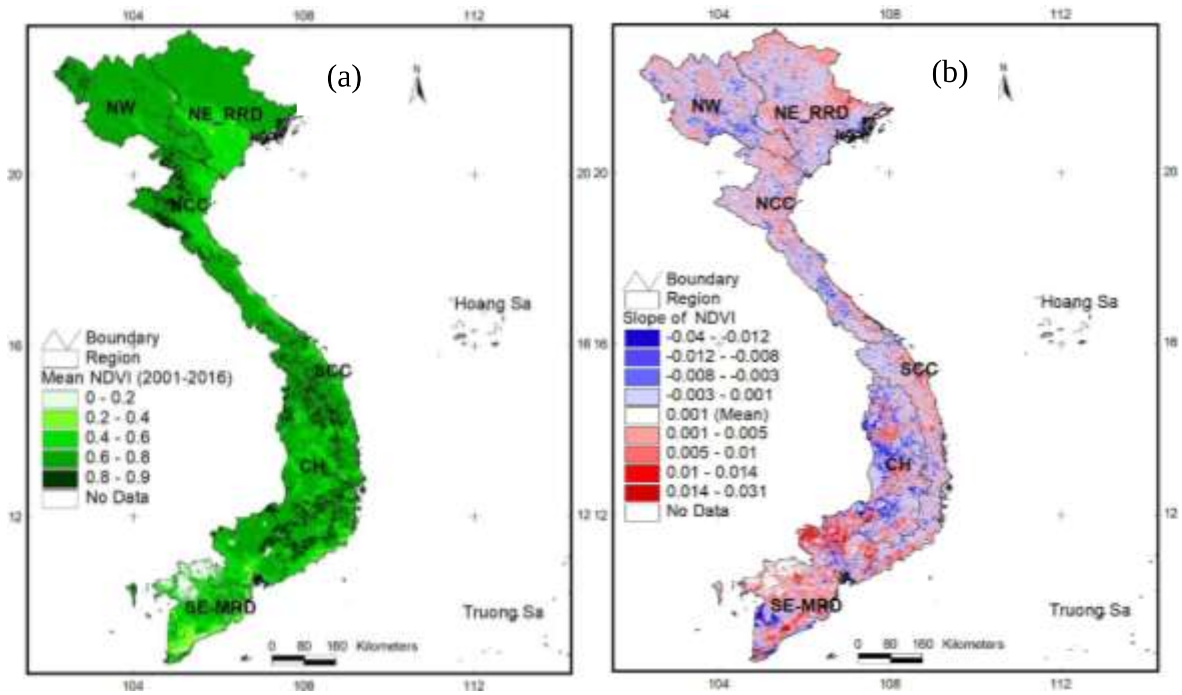

Fig. 1 (a) Mean annual NDVI during the period 2001-2016, and (b) Linear slope of annual NDVI (the slope *A* in the equation *NDVI = A×year + B*) for the period of 2001- 2016.

The trend in long-term vegetation productivity in Vietnam over 16 years ($p<0.1$) is shown in **Fig. 2**. The areas of significant improvements in biomass productivity comprise about 33% (109,063 km^2) of total national land, and they were mainly found in the Northeast (NE)-Red River Delta (RRD), North Central Coast (NCC), and Southest (SE)-Mekong River Delta (MRD). The findings agree with the fact that the intensification of rice-based agriculture in these areas have increased considerably since the beginning of the Era of Renovation (Doi Moi) in Vietnam (1986) (Linh, 2012; Thanh and Singh, 2006). Scattered pixels of improving NDVI in the Northern Mountains and hills are located mainly in protected areas or replanted forests (MoNRE, 2005).

About 15% (48,302 km^2) of national land has experienced persistent biomass decline over the last 16 years, mainly in the mangrove zones of the Mekong River Delta, the Central Highland and the Northwestern Mountains. The NDVI declines found in the Mekong River Delta are consistent with the rampant conversion of mangrove forest and swamp vegetation with rice paddies and/or aquaculture farms in the 1990s, while the NDVI declines in the Northwest and Central Highland regions could be attributed to deforestation caused by the expansion of agriculture on plateaus, hill slopes, and mountains (De Koninck, 1999; NAP, 2006). These findings were generally comparable to the four priority regions mentioned in the National Action Programme to Combat Desertification for the Period 2006–2010 and orientation to 2020 (NAP, 2006), and also consistent with the results found in previuos study (Vu *et al*., 2014).

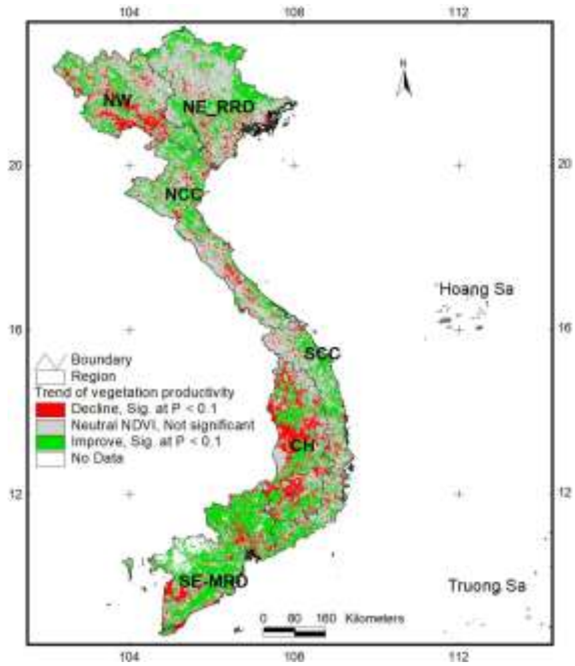

Figure 2. Long-term trend of vegetation productivity (2001-2016)

3.2. Isolating the land degradation area from climate-driven impacts

Fig. 3a shows the mean rainfall in Vietnam over 16 years. The total rainfall varied from 500-4500 mm per year. The high rainfall (more than 2500 mm per year) can be found in the middle of Vietnam, while almost other regions the rainfall ranged from 500-2000 mm. The relationship between NDVI and rainfall measured by Pearson correlation coefficient (R) for the period of 2001-2016 for each pixel is shown in **Fig. 3b**. The correlation coefficient varied from +0.87 to - 0.91, with the red colours (positive R) in **Fig. 3b** indicating the extensive zones where vegetation correlates positively with rainfall changes from year to year. The blue zones (negative R) indicate areas where the rainfall goes up the vegetation cover goes down nonetheless (possibly severe degradation), or rainfall goes down but vegetation goes up (possibly through irrigation or aforestation).

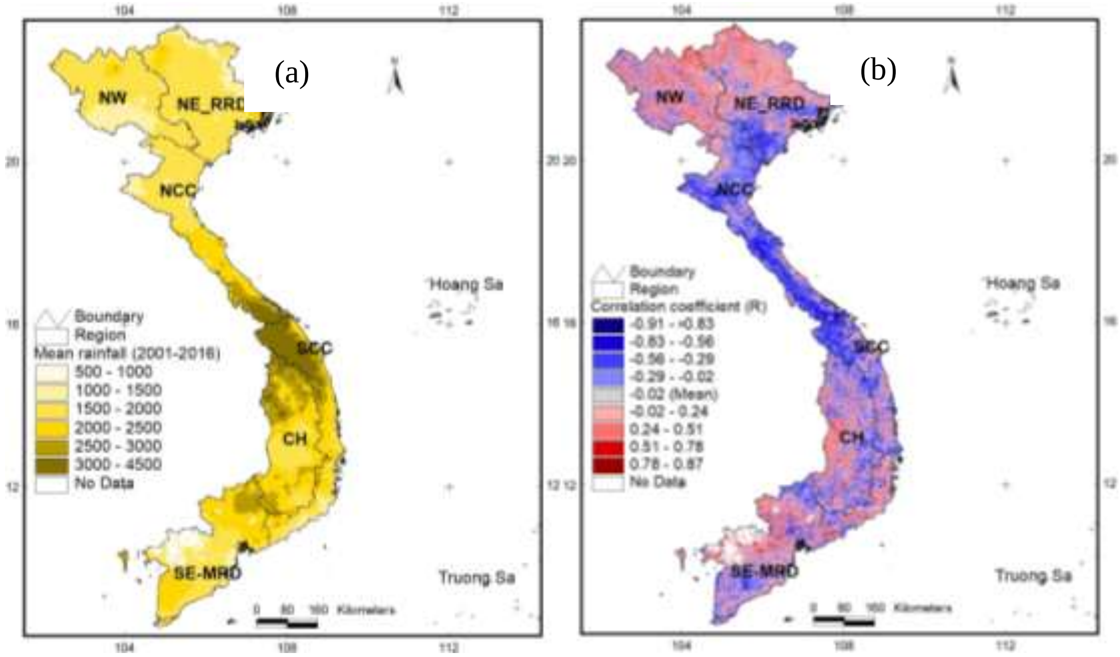

Fig. 3 (a) Mean annual rainfall during the period 2001-2016, and (b) Pearson's coefficient of correlation between annual NDVI and rainfall over the period 2001- 2016

The degraded areas where climate has had a dominant impact on vegetation productivity were seperated using the Trend-Correlation and RESTREND methods to yield human-induced land degradation map. A comparison of the results obtained using the two methods is shown in **Fig. 4**. Both methods yielded almost the same values for the spatial extent of human-induced biomass productivity decline, indicating a high confidence level for the used methodology. The Trend-Correlation and RESTREND methods result in 46,066 km^2 and 47,202 km^2 with human-induced vegetation productivity decline, respectively. The degraded area shared by both methods was 44,903 km^2, and the total merged area by two methods was 48,366 km^2 or about 15% of total national land. The result of this study was lower than the results reported by Vu *et al.* (2014) (i.e. about 19% of the national land mass). The difference in study period and spatial resolution of datasets could be the cause of the inconsistence between two studies. However, if comparing the spatial distribution of degraded areas, the results from both studies were relatively matched.

Table 1 Area of land degradation in different regions of Vietnam

Region		**Area (km^2)**	**% of total VN area**
Northwest	NW	9324	2.8
Northeast-Red River Delta	NE-RRD	4778	1.4
North Central Coast	NCC	5608	1.7
South Central Coast	SCC	4145	1.3
Central Highland	CH	16541	5.0
Southeast-Mekong River Delta	SE-MRD	7906	2.4

In the degraded area, the Central Highland was the largest region experienced the decline of vegetation productivity (5.0% of total national land). The Northwest region also faced with a large area of land degradation (2.8% of total national land) (Table 1). The possible reason for land degradation in these regions might be attributed to to deforestation and land conversion for agriculture on slopping areas (De Koninck, 1999; Rowcroft, 2008). The degradation in the MRD is generally due to the rampant conversion of mangrove forest and swamp vegetation to paddy rice and/or aquaculture farms in the 1990s and 2000s (Richards and Friess, 2016; Vo et al., 2013), and mangroves were overexploited as timber for construction and charcoal in the 1980s and early 1990s (Lebel et al., 2002)

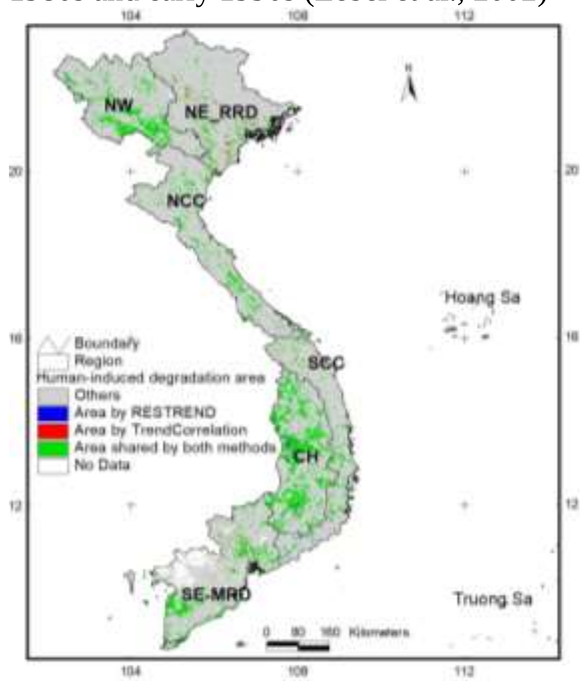

Fig. 4 Human-induced degradation areas identified by Trend-Correlation & RESTREND methods

4. Conclusions

This study examined the long-term trend of inter-annual MODIS NDVI over 16 years (2001-2016) as a proxy for measuring the decline or improvement in vegetation productivity on a national scale. The areas affected by human-induced productivity decline were isolated from those in which the decline is driven by climate dynamics by analyzing the temporal correlation between the rainfall and NDVI time-series over the period 2001-2016. We found that about 48,366 km2 or about 15% of total national land showed a persistent decline in vegetation productivity that was mainly caused by non-climate (i.e., anthropogenic) factors. The largest degraded areas were found in the Central Highland, the Northwest, the Southeast-Mekong River Delta and the Central Coast of Vietnam. The areas of land degradation found in this study could help policy makers in prioritizing limited budgets and planning strategic interventions and could provide the prioritizing areas for future field-based studies.

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