DEVELOPMENT OF METHODOLOGY FOR MONITORING AND ASSESSING THE NATIONAL GREENING PROGRAM USING OPTICAL AND SAR DATA

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ABSTRACT:

Launched primarily to address the growing concern of environmental sustainability and to combat climate change, the National Greening Program (NGP) is the most ambitious reforestation program undertaken in the Philippines. Given the enormous number of resources invested in the program, it is crucial to monitor and assess the effectiveness of this initiative. To do this, the success of the selected NGP site in Zambales Province was evaluated using land cover maps, Normalized Difference Vegetation Index (NDVI) from Sentinel-2 and MODIS, and Radar Vegetation Index (RVI) and Radar Forestation Degradation Index (RFDI) from Sentinel-1 Synthetic Aperture Radar (SAR) images. The index time series were processed in Google Earth Engine cloud computing platform. The findings indicate that the rise in vegetation density shown by the generally increasing trend in the NDVI and RVI was consistent with the increase in vegetation cover indicated by the land cover maps. This work contributes towards the field of environmental monitoring and resource management, with potential applications that extend beyond monitoring and assessment of the NGP and towards dealing with global issues regarding land use and environmental protection.

1. INTRODUCTION

Over the past few decades, ambitious reforestation efforts have been undertaken by governments around the world in response to growing global concern for environmental sustainability. The discovery that roughly 10 to 20 % of emissions causing climate change are attributable to deforestation made it more pertinent (Asner, 2009; United Nations, n.d.; Watson et al., 2013). Scientists' claim in 2019 that reforestation can potentially delay climate change sparked international initiatives to plant 1 trillion trees in 900 million hectares (ha) of degraded land by 2030, with the ability to capture about 25 % of the world's atmospheric CO_2 (Little, 2021). Notable reforestation efforts include the Green Wall of China project (Veste et al., 2006) that aims to stop the expansion of the Gobi Desert and the Great Green Wall in Sub-Saharan Africa, also intended to stop the southward expansion of the Sahara Desert (Mirzabaev et al., 2022).

In the Philippines, the government spearheaded the country's most ambitious reforestation program through the National Greening Program (NGP). President Benigno S. Aquino III signed Executive Order No. 26 on February 24, 2011, which served as the legal basis for the implementation of the NGP. It planned to plant 1.5 billion trees in 1.5 million ha of land for a period of 6 years, from 2011 to 2016. Launched mainly in response to the escalating rate of deforestation and environmental challenges, the objectives of the NGP also include poverty reduction, food security, environmental stability, enhancement of biodiversity, and mitigation of the effects of climate change. Among the areas for development by the NGP include open, degraded, and denuded forestlands, protected areas and mangroves, ancestral domains, civil and military reservations, urban areas, and inactive and abandoned mine sites. Before the end of his term, then President Aquino signed Executive Order No. 193 on November 12, 2015, to sustain and expand the gains of the NGP. The remaining 7.1 million ha of unproductive, denuded, and degraded forestlands will be restored between 2016 and 2028 as part of the Expanded National Greening Program (ENGP) (DENR, 2018).

In a 2020 report, the Department of Environment and Natural Resources (DENR), the agency responsible for the implementation of the NGP, stated that since 2011, the government has consistently provided funding for the execution of the program. In the year 2020, the initiative will have received about PhP 49 billion in funding. Since the program began in 2011, it has produced almost 5.6 million jobs. Since 2010, 23 % of the area of denuded forestlands has been planted as a result of the ENGP. The DENR further asserts that between 2010 and 2020, the amount of forest cover increased, rising from roughly 6.8 million ha to roughly 7.7 million ha. Given the enormous financial and resource investments made in these reforestation efforts, monitoring the development and results of these extensive programs is crucial to ensuring their success and for guiding future conservation efforts. An accurate and timely assessment of the success of thousands of NGP sites is a very challenging task where remote sensing is the principal methodological preference.

Numerous large-scale reforestation efforts have been evaluated using remote sensing technology (Gerlein-Safdi et al., 2020; Lin et al., 2020; Wu et al., 2022). Remote sensing, using satellite imagery such as optical and synthetic aperture radar (SAR), can provide a powerful tool for monitoring large-scale environmental changes over time. The vegetation indices obtained from these imaging sources provide valuable information on vegetation status, enabling a comprehensive assessment of the effectiveness of reforestation programs such as the NGP (Nesperos et al.,

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2021). These vegetation indices quantify specific spectral properties of vegetation and can help reveal subtle changes in vegetation cover, density, and health that may not be easily noticeable by conventional ground monitoring methods. Furthermore, unlike direct ground monitoring, remote sensing offers quick, economical, and recurrent coverage of vast areas. It also makes it possible to gather environmental data from hazardous or inaccessible locations.

Several prior works utilized remote sensing to study the NGP and ENGP. Tandoc et al. (2019) used PlanetScope and WorldView images to estimate canopy cover in an NGP site in Basay, Negros Oriental. Arellano et al. (2019) differentiated the dense and sparse forests of several NGP sites in Ipil (Zamboanga Sibugay), Basay (Negros Oriental), and Ubay (Bohol) by identifying the range of backscatter values using multi-temporal Sentinel-1 images. To date, the most comprehensive study that evaluated the NGP was accomplished by Perez et al. (2020) by utilizing NDVI calculated from Landsat and MODIS images. Their work suggests an overall insignificant gain from the NGP as shown by an overall balance between reforestation and deforestation.

Utilizing remote sensing data, this paper delves into the impact of NGP on the forest areas of the Philippines. Development of a methodology for monitoring the vegetation status in NGP sites is attempted by exploring various vegetation indices sourced from optical and SAR images. First, change in extent of vegetation cover of the pilot site was assessed using land cover maps. Second, to determine the quality of change in vegetation cover, temporal Normalized Difference Vegetation Index (NDVI) of the pilot site was calculated using Sentinel-2 and Moderate Resolution Imaging Spectroradiometer (MODIS) images. And lastly, to complement the results of the NDVI, temporal Radar Vegetation Index (RVI) and Radar Forest Degradation Index (RFDI) were used to detect changes in vegetation density and degradation/disturbance, respectively. By merging optical data, which collects data from the visible to the near-infrared spectrum, and SAR data, which permits imaging in all weather conditions, a more refined understanding of ecological restoration activities can be obtained. This work promises an informed approach to creation of policies surrounding sustainable environmental management techniques.

2. MATERIALS AND METHODS

2.1 Location of Study Area

There are more than 13,500 NGP sites throughout the Philippines, mainly categorized into agroforestry, mangrove reforestation, reforestation, urban, and watershed. One NGP site located in Sta. Cruz, Zambales, western part of Luzon Island of the Philippines (**Figure 1**) was used as the pilot site for this study. This site was adopted by Eastern Sta. Cruz Community Management Center Inc. (ESCMCI) and Eramen Minerals Inc. (EMI). It has an area of 98 hectares categorized as "reforestation" under the NGP. The site is dominated by tree species endemic to the Philippines such as *Acacia auriculiformis*, *Acacia mangium*, *Casuarina equisetifolia* (Agoho), and *Eucalyptus obliqua* (Eucalyptus).

2.2 Land Cover Data

The land cover classified images of the pilot site were generated using the harmonized data of Landsat 8 OLI and Sentinel 2 Level-2A Imageries using freely available datasets in Google Earth Engine. Images of Landsat 8 and Sentinel 2 with less than 30.0% cloud cover were queried from the image collection, compiled into one year composite, and harmonized. In addition, the compiled image collection was used to extract phenological features and different band indices of the 12 land cover types (water, trees, grass, flooded vegetation, crops, shrubs and scrubs, built-up, bare, mangroves, etc.). The pre-processing and extraction of features were done in the Google Colaboratory Environment using different Python packages including Earth Engine API and Geemap. A supervised classification using Random Forest was then performed on the dataset to produce the classified image of the area.

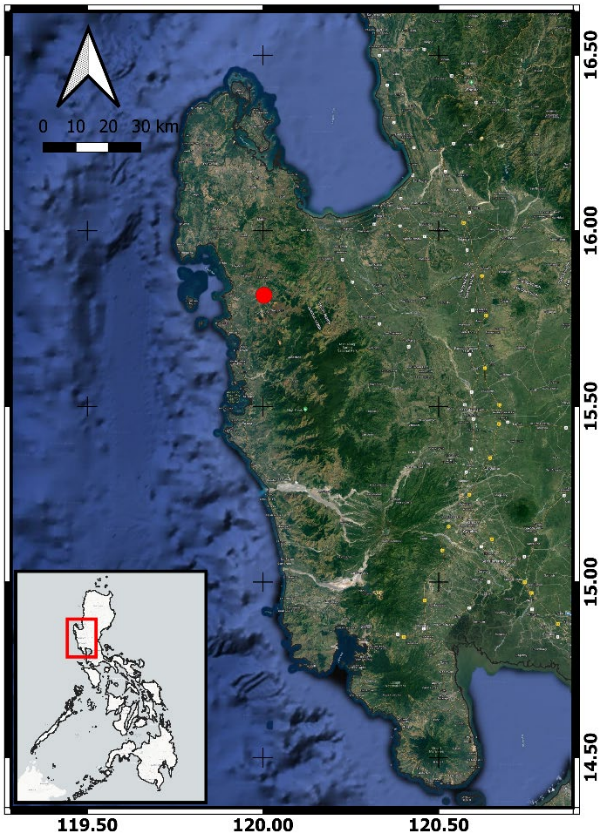

Figure 1. Location map of the pilot site (red dot) assessed in this study.

2.3 Satellite Images

To show a qualitative change of vegetative cover, high resolution images of the site for 2016 and 2022 were downloaded from PlanetScope (3 m resolution), as shown in **Figure 2**. Based on the images, it can be observed that the middle and right sides of the NGP site become noticeably greener.

Moreover, several optical and Synthetic Aperture Radar (SAR) images were used to assess the temporal changes in vegetation cover in the NGP site. Sentinel-2 that includes S2A and S2B is an optical satellite of the Copernicus Program of the European Space Agency (ESA) with a revisit time of 5 days. It has 13 bands in the visible/near infrared (VNIR) and short wave infrared spectral range (SWIR) spectrum. The red and near-infrared (NIR) bands with spatial resolution of 10 m were used from surface reflectance (SR) data of Sentinel-2 images. Sentinel-2 SR images corresponding to "COPERNICUS/S2_SR" are available from 2015 to present in the Google Earth Engine (GEE) cloud platform.

To complement the low temporal resolution of the Sentinel-2, another optical satellite-based sensor with higher temporal resolution called the Moderate Resolution Imaging Spectroradiometer (MODIS) was used. But unlike Sentinel-2, MODIS has lower spatial resolution of 250 m and more frequent revisit time of 1 to 2 days. There are two MODIS sensors aboard two satellites, Terra and Aqua. The Terra and Aqua images of the pilot site from 2003 to 2023 corresponding to "MODIS/006/MOD09A1" and "MODIS/006/MYD09A1", respectively, were collected and merged in the GEE cloud platform. These images are SR 8-day composite with 500 m resolution and 7 bands in the VNIR and short SWIR spectrum.

Lastly, C-band SAR images from Sentinel-1 were also used to study the changes in vegetation cover of the pilot NGP site. Sentinel-1 consists of twin satellites, S1A and S1B, which share the same orbital plane with a revisit time of 6 days, although the recent decommissioning of S1B reduced the revisit time to 12 days. The interferometric wide swath (IW) mode was chosen with vertically transmitted and horizontally received (VH) and vertically transmitted and vertically received (VV) polarizations.

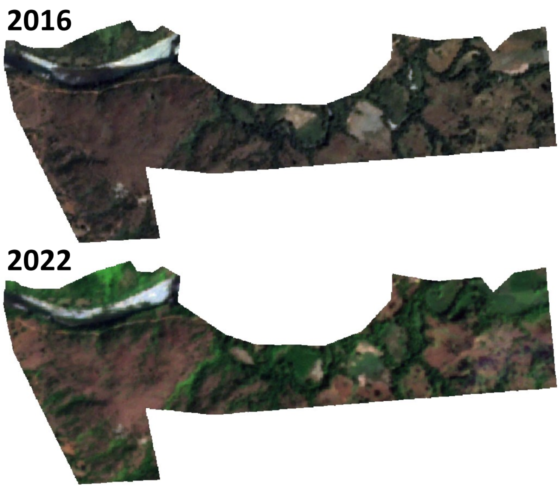

Figure 2. Satellite images (PlanetScope) for 2016 and 2022 of the pilot site assessed in this study.

2.4 Index Calculation

Normalized Difference Vegetation Index (NDVI) using Sentinel-2 and MODIS images were calculated in GEE. NDVI is used to quantify vegetation greenness by measuring the difference between near-infrared (NIR) which the vegetation strongly reflects and red light which the vegetation absorbs. It is useful in understanding vegetation density and assessing changes in plant health (Altieri et al., 2022). It ranges from 0 to 1 wherein a higher value denotes greener plants. To note, NDVI was also used to assess the NGP (Perez et al., 2020; Tandoc et al., 2019). Meanwhile, Radar Vegetation Index (RVI) and Radar Forest Degradation Index (RFDI) were calculated using SLC products of Sentinel-1. Like the NDVI, RVI is sensitive to vegetation cover. It also ranges from 0 to 1 where higher value suggests vegetation growth (Chang et al., 2018). RFDI is used to detect both loss of forest cover and its recovery after a disturbance. RFDI values range from <0.3 for dense forests, 0.4 to 0.6 for degraded forests, and >0.6 for deforested landscapes (Ningthoujam et al., 2016). NDVI, RVI and RFDI were calculated using **Equations 1-3**:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

$$RVI = \frac{4\,VH}{VV + VH} \quad (2)$$

$$RFDI = \frac{VV - VH}{VV + VH} \quad (3)$$

where NIR is the near-infrared band, RED is the red band, VH is the vertical transmit, horizontal receive band, and VV is the vertical transmit, vertical receive band.

2.5 Decomposition of Time Series

NDVI time series was calculated for the pilot site. The median values were calculated from MODIS and Sentinel-2 images. To remove the effect of seasonal variations in NDVI, the time series was decomposed. The decomposition was carried out in R using the *decompose* function. Decomposition breaks the time series into several components such as the level, trend, seasonality, and noise. The level is the average value in the series; trend is the increasing or decreasing of the value in the series; seasonality is the repeating short-term cycle in the series; and noise is the random variation in the series (West, 1997). Lastly, the Mann-Kendall Trend Test (McLeod, 2005) using XLSTAT was used to determine the significance of the observed NDVI trend.

3. RESULTS AND DISCUSSION

3.1 Land Cover Change

Land cover maps are crucial tools in reforestation efforts as they instantly identify areas that have experienced significant forest degradation (Mi et al., 2019). In this work, the land cover maps were used to determine changes in vegetation cover of the NGP site in terms of area coverage. Briefly, the land cover maps of the pilot site were assessed in GEE using harmonized Sentinel-2 and

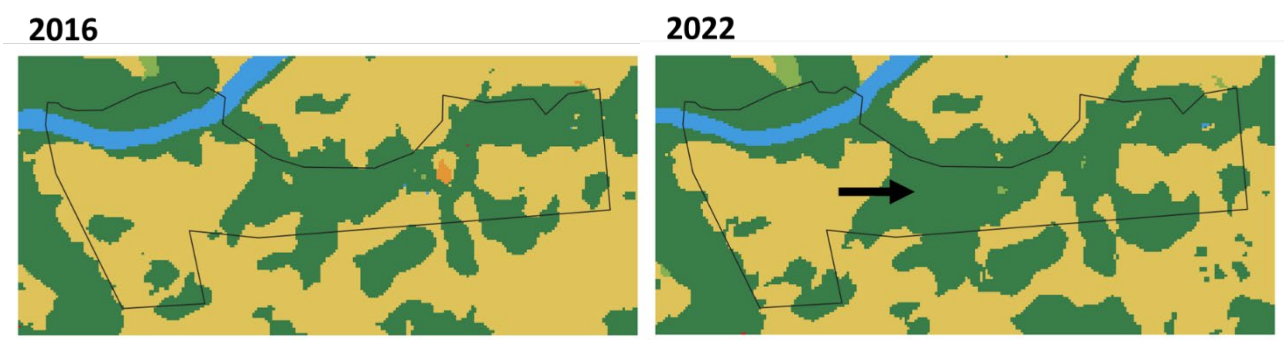

Figure 3. Land cover maps of the NGP site for 2016 and 2022. The black arrow indicates a noticeable change in land cover. Green is the trees, light green is grasslands, yellow is shrubs and scrubs, orange is crops, and blue is water.

Landsat-8 imageries. A supervised classification using Random Forest Algorithm was then performed to produce the classified image of the area. The land cover maps of the NGP site for the years 2016 and 2022 (**Figure 3**) were generated through the JuanMap project of the Philippine Space Agency.

The maps demonstrate that there was an increase in the area covered by trees (approximately 5.8 ha) and decrease in area covered by shrubs and scrubs (approximately 5.1 ha), particularly in the center of the site, where the black arrow is located. The increase in tree cover shown by land cover maps is consistent with the qualitative observations using PlanetScope images. Generally, the increase in tree coverage can be attributed to conversion of shrubs and scrubs to trees. Some of the croplands were also converted to trees.

Although the land cover maps show a change in vegetation cover in terms of extent, they are unable to show how green or dense the vegetation is. To address this, several vegetation-related indices including NDVI, RVI, and RFDI were computed.

3.2 NDVI

NDVI is a useful tool to quantify the health and density of vegetation cover across a landscape. It works through a very simple principle: healthier or greener vegetation reflects much of the near-infrared light and absorbs red light. Thus, NDVI offers information on vegetation status by measuring the difference between these two spectral bands (Pettorelli et al., 2005). A number of reforestation initiatives were evaluated for their effectiveness using the NDVI (Bondur et al., 2022; Gore et al., 2023; Lin et al., 2020).

The quarterly NDVI of the site from 2016 to 2022 calculated using Sentinel-2 is shown in **Figure 4**. It can be observed initially that the data series shows seasonal variation, making it difficult to draw significant insight. To extract more meaningful information, the time series was decomposed into several components such as the trend, seasonality, and noise. The plots show the seasonality of the NDVI as well as the increasing trend. The NDVI trend increased generally between 2016 and 2022, indicating that the vegetation increased in density and greenness

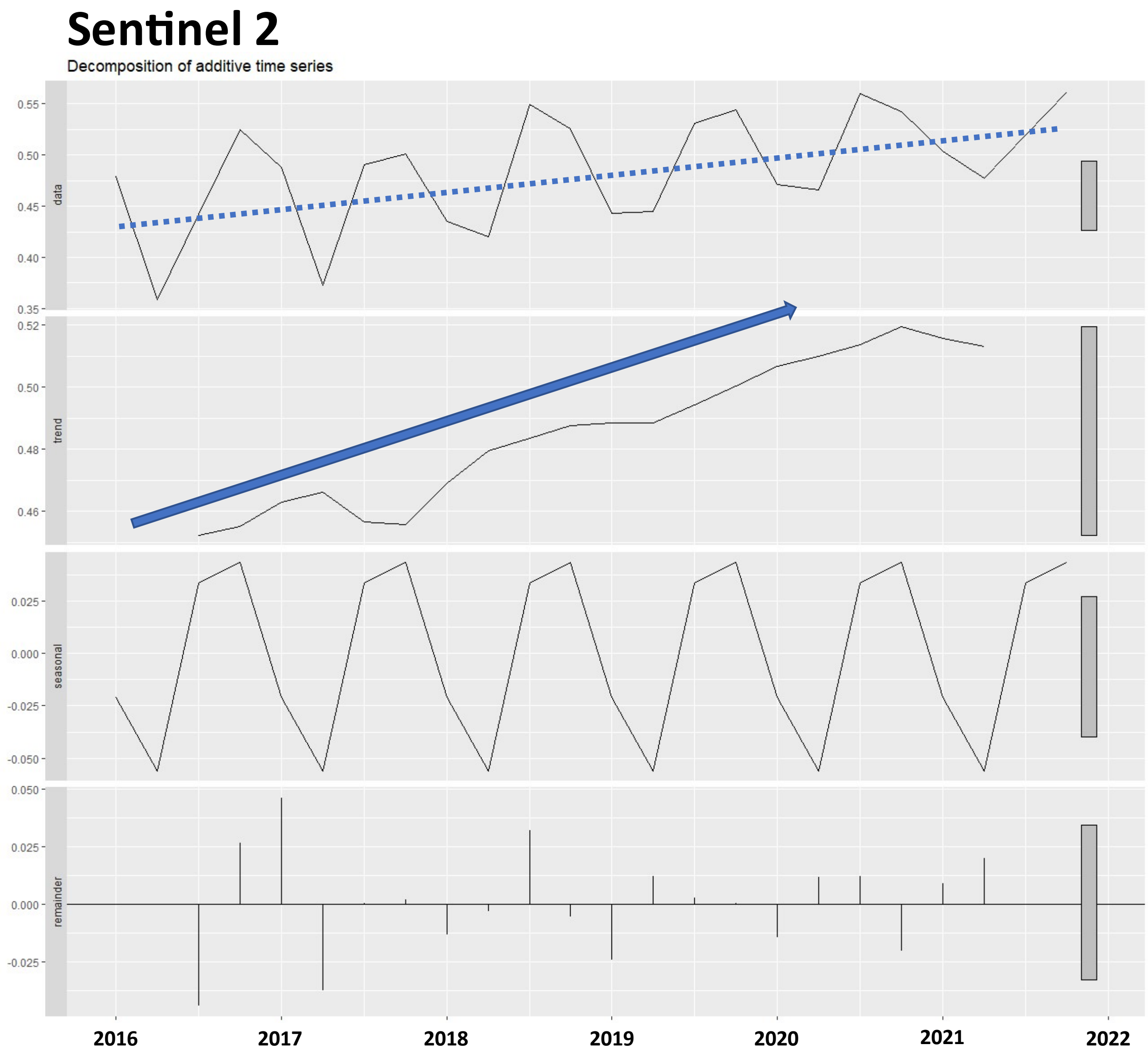

Figure 4. Decomposition of NDVI time series calculated using Sentinel-2 showing the increasing trend in NDVI during ENGP.

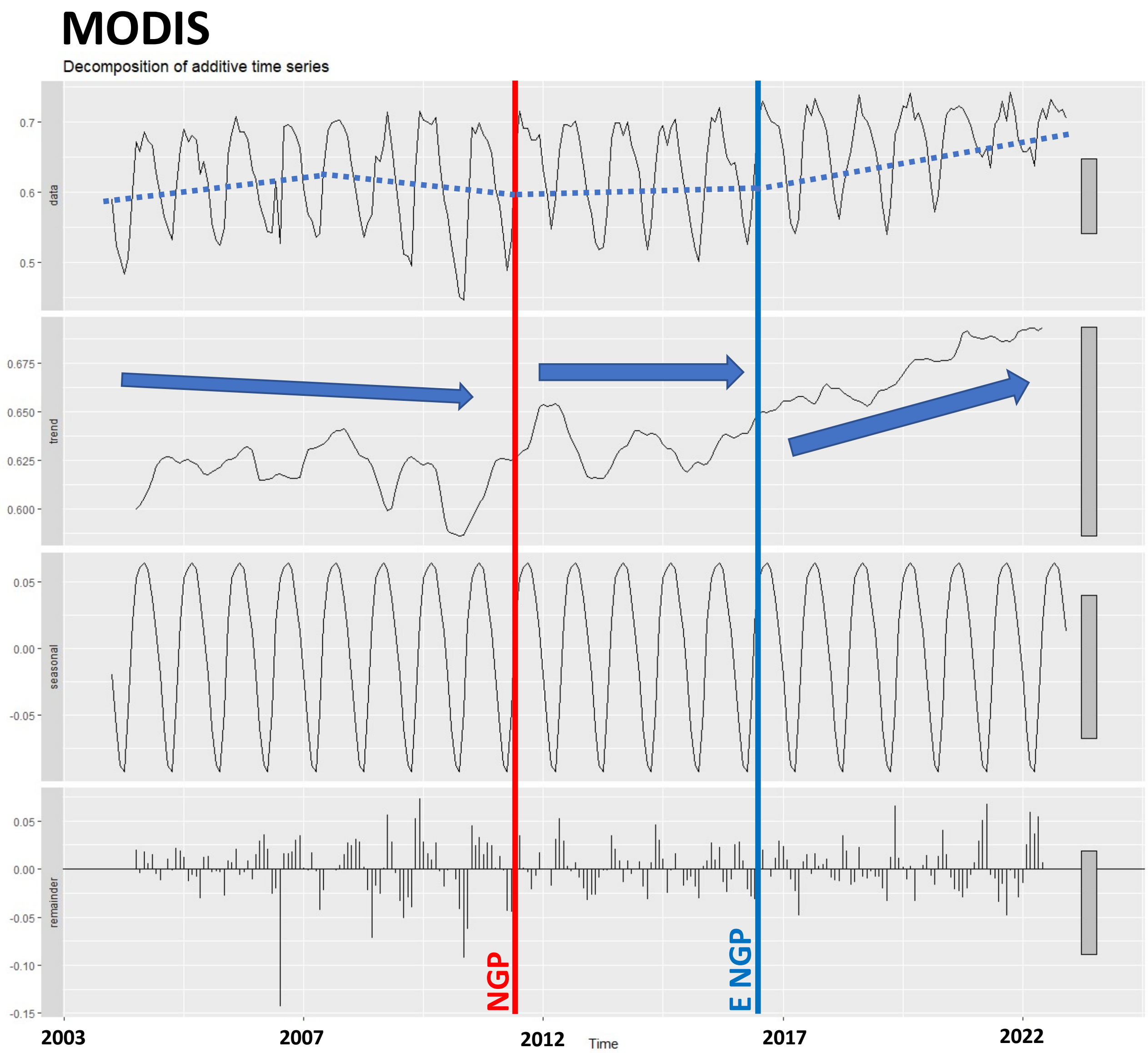

Figure 5. Decomposition of NDVI time series calculated using MODIS showing a generally unchanged NDVI trend during NGP (2011-2016) and an increasing trend during ENGP (2016 onwards).

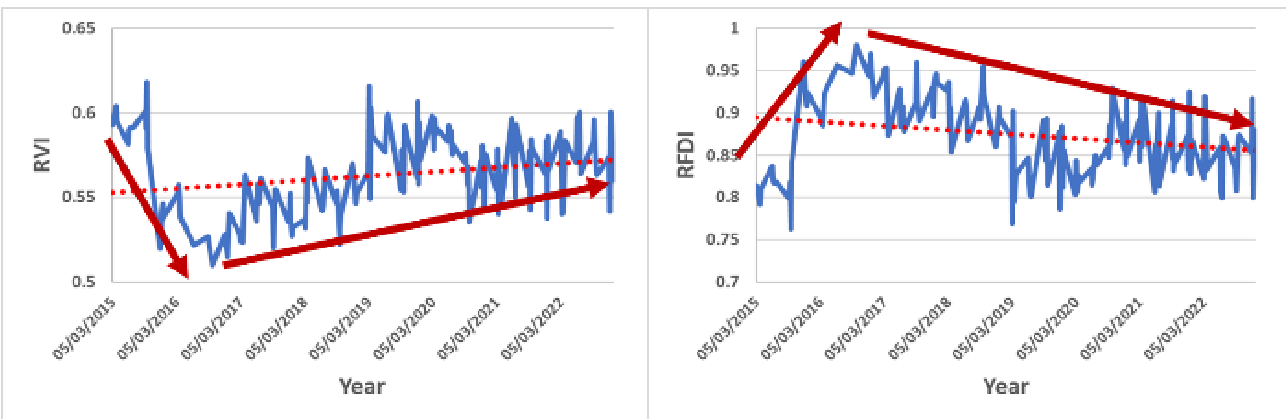

Figure 6. A decrease in RVI correspond to increase in RFDI. The overall trend in RVI and RFDI is shown by the broken red dots.

in addition to its extent as indicated by changes in the land cover maps. To check whether the trend observed is significant, the Mann-Kendall trend test was carried out. As the computed p-value (0.004) is lower than the significance level alpha of 0.05, the upward trend is significant.

To study long-term change, MODIS was used to calculate the monthly NDVI from 2003 to 2022 as shown in **Figure 5**. It can be observed that the trend generally decreased from 2003 to 2011 and generally remained unchanged from 2011 to 2016 during the time of the NGP. It then increased thereafter during the ENGP. The Mann-Kendall trend test shows that the upward trend in NDVI from 2003 to 2022 is significant since the p-value (<0.0001) is lower than the significance level alpha of 0.05.

All in all, the results of the NDVI suggest that there has been significant improvement in the vegetation cover of the pilot site since the start of the ENGP. Meanwhile, the impact of the initial program, the NGP, has been insignificant.

3.3 RVI and RFDI

In monitoring reforestation initiatives, vegetation indices using weather-independent SAR data can work as remarkably as the NDVI. The RVI and RFDI are indicators of vegetation density and degradation, respectively (Çolak et al., 2021). Several works used these indices to monitor changes in vegetation cover (Bondur et al., 2022; Çolak et al., 2021).

The RVI and RFDI of the pilot site from 2015 to 2022 were calculated in GEE using Sentinel-1 as shown in **Figure 6.** The inverse relationship of the indices can be deduced from the plots that show a vegetation disruption identified by the increased RFDI from 2015 to 2017 and a decline in RVI for the same period. RVI then continued to rise steadily while RFDI started to fall. The overall trend from 2015 to 2022 indicates a rise in RVI and a fall in RFDI, both of which point to vegetation growth. These findings corroborate the results of the NDVI although the NDVI could not identify the vegetation disruption that happened from 2015 to 2017.

3.4 Conclusion and Future Work

A methodology to monitor the effectiveness of the National Greening Program was assessed for a pilot site. The land cover maps were first used to see changes in the extent of tree cover. To check whether the quality and density of vegetation growth was significant, several vegetation indices that use both optical and SAR images such as NDVI, RVI, and RFDI were used. The initial analysis for the pilot site shows that the increased vegetation cover is related to increased vegetation density.

For future works, it is necessary to perform validation to ensure the accuracy and reliability of these remotely sensed results. The use of historical, very high-resolution satellite images of the pilot site serves as an appropriate validation approach for this work. Validation plays an essential role in identifying potential errors, optimizing algorithms, and improving the quality of remote sensing data.

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