Forest restoration assessment in selected critical watersheds in the Philippines using NDVI and Google Earth Engine

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ABSTRACT

Forest cover in the Philippines has reduced drastically over the past decades. To address the problem, the government embarked on a massive forest restoration program called the National Greening Program (NGP) that started in 2011 and recently extended until 2028. The performance of NGP was evaluated using a cloud-based technique called Google Earth Engine (GEE). Landsat imageries were used within the cloud library of GEE, and vegetation index data were computed annually covering the period 1996 until 2021.

Reforestation sites were considered in the monitoring of vegetation quality using Normalized Difference Vegetation Index (NDVI). The annual trends in the vegetation index were analyzed for these sites. Sen's slope and Mann-Kendall trend test were employed to assess the statistical significance of the trends. Results reveal that from 2011 onwards, areas implemented purely with NGP could not yield statistically significant trends in all the watersheds chosen for the study, with p-values of 0.0736 for Salug Daku and Padada watersheds and 0.1611 for Labangxan watershed. Ground truthing may reveal further insights into the effects of the program on the vegetation coverage. Further studies are recommended to observe the consistency of the results, as the duration of the time series used in this study is limited.

INTRODUCTION

Land use/cover (LULC) change is a dynamic and complicated process that can be influenced by a variety of causes, ranging from natural to socioeconomic dynamics. Most landscapes' structure, functions, and dynamics are all influenced by it

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KEYWORDS

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(Yesuph & Dagnew, 2019). Throughout history, humans have altered landscapes to increase the quantity, quality, and security of natural resources essential to their survival, such as food, freshwater, fiber, and medicinal products. Human populations have increased their ability to derive resources from the environment and expand their territory through increased use of innovation, initially slowly and then at an increasingly rapid pace.

According to the Food and Agriculture Organization of the United Nations (2020), deforestation and forest degradation persist at alarming rates, contributing significantly to the ongoing loss of biodiversity. It is estimated that 420 million hectares of forest have been lost since 1990 due to conversion to other land uses, though the rate of deforestation has decreased over the last three decades. Deforestation was expected to be 10 million hectares per year between 2015 and 2020, dropping from 16 million hectares per year in the 1990s. Since 1990, the global area of primary forest has shrunk by more than 80 million hectares.

The country's ongoing deforestation has been a major issue due to the numerous established negative effects, such as soil erosion, landslides, flooding, biodiversity loss, and watershed degradation. The consequences are more severe, taking into account the critical role of forests in the sequestration of atmospheric carbon dioxide, the preservation of current biodiversity, and the resilience of ecosystems to climate change (Perez et al., 2020). Meanwhile, over 90 percent of the total land area of the Philippines is covered by watersheds. There are cities or municipalities which are subdivided neatly into various watersheds, while some watersheds cover multiple towns, provinces, or even regions. These watersheds capture rainwater for storage underground, which stakeholders depend on for their everyday lives.

The decline of forests is the result of several actions of individuals, groups of people, or institutions that directly convert forested lands to other uses or intervene in forests without necessarily causing deforestation but significantly reducing their productive capacity are referred to as agents (Contreras-Hermosilla, 2000). Activities such as legal and illegal mining operations, agricultural fires, collection of fuelwood, and rural population, which have caused pollution and have been linked to violent conflicts, also add to the threats to the Philippine forests (Bouquet, 2017).

Several forest restoration initiatives have been implemented in the country, to reduce the rate and mitigate the effects of deforestation. Lush rainforest continued to blanket around 68 percent of the Philippines after the Spanish colonial era. During the time of Spanish colonial authority, deforestation rates differed among the islands. Rapid deforestation occurred in Cebu. The first reforestation project was started in 1916 because of the province's need for reforestation being realized as early as that year (Carandang, 2013).

This study focuses on the monitoring and evaluation of forest restoration of selected critical watersheds in the country. The findings of the study showed how the rate of restoration increases after implementation of certain reforestation strategies within the selected watersheds. The analyses were focused on a watershed level, comparing the rate of the increase (or decrease) of forests within the reforestation areas and outside their boundaries.

Restoring forested landscapes is acknowledged as an important measure for improving resilience and mitigating the effects of major global environmental problems, particularly climate change. Forest landscape restoration (FLR) has been used as an integrated approach for several decades to improve the resilience of landscapes and the livelihoods they support (Kumar et al., 2015).

Several restoration and reforestation initiatives were employed to increase forest cover. The National Integrated Protected Areas System (NIPAS) Act was passed into law in 1992 and expanded (ENIPAS) in 2018 to manage protected areas. Meanwhile, under the Indigenous Peoples Rights Act of 1997, the rights of Indigenous People (IPs) to their ancestral domain by Native Title shall be respected and formally given recognition, which is embodied in a Certificate of Ancestral Domain Title.

On the other hand, the government launched a country-wide reforestation program called the National Greening Program in 2011. Goals of the program include poverty reduction, sustainable management of natural resources, provision of food, goods, and services, promote public awareness on importance of forests and watershed, climate change alleviation. The program was expanded in 2016, targeting the rehabilitation of all the remaining unproductive, denuded, and degraded forest lands to be implemented until 2028. Meanwhile, the Community Based Forest Management Agreement was put into place as a 25-year production-sharing agreement between the Department of Environment and Natural Resources and the participating people's organizations (POs) that provides tenurial security and incentives to develop, utilize, and manage specific portions of forest lands.

With the use of Google Earth Engine (GEE), a cloud computing platform used to store and process massive data sets (on the petabyte scale) for analysis and decision making (Kumar and Mutanga, 2018), this study visualized the changes in vegetation cover within the critical watersheds. Following the release of the Landsat series for free in 2008, Google archived all data sets and linked them to its cloud computing engine for open-source use. Other satellite data, as well as vector data sets based on Geographic Information Systems (GIS), social, demographic, weather, digital elevation models, and climate data layers, are currently archived in the GEE Application Program Interface (API) (Mutanga and Kumar, 2019).

The main objective of this study is to recommend the use of computing platform such as Google Earth Engine to observe changes in the vegetation cover of critical watersheds in the country brought about by the implementation of policy interventions and reforestation programs. Specifically, the study aims for the following:

1. Observe changes in vegetation coverage from decades' worth of satellite imagery from a public cloud-based catalog
2. Evaluate temporal trends from the NDVI classification within the watersheds and NDVI sampling within different policy interventions and reforestation program areas in the watersheds
3. Verify statistical significance of temporal vegetation trends generated for the watersheds and the different sampling zones

MATERIALS AND METHODS

Study Site

The presence of reforestation zones was a major consideration in the selection of watersheds for the study. Since there were overlaps within their boundaries, further GIS processing was conducted to extract areas of the protected areas, CADT areas, and CBFMA sites, with no overlap with one another. Upon generation of these reforestation zones with no overlaps, they were intersected with the NGP areas to generate new polygons where these reforestation zones simultaneously are also NGP sites.

The new polygons generated were as follows: 1) purely NGP sites, 2) intersect of NGP and CADT areas (NGP x CADT), 3) intersect of NGP and CBFMA sites (NGP x CBFMA), 4) intersect of NGP and protected area (NGP x PA), and 5) Outside the NGP sites. These polygons were used as sampling locations for the study. The critical watersheds selected for the study were required to have these new unique areas present within their boundaries. Upon inspection, three (3) watersheds were found to have all these unique areas within their boundaries. These watersheds are: 1) Salug Daku watershed. 2) Labangan watershed, and 3) Padada watershed.

Salug Daku watershed is part of the Cluster 8 River Basin, which is composed of seven (7) principal river basins and 26 minor watersheds. The watershed spans the provinces of Zamboanga del Norte, Zamboanga del Sur, and Misamis Occidental. There are 6 municipalities and 67 barangays that are covered by the watershed boundary. Meanwhile, Labangan Watershed is located at the heart of Zamboanga del Sur, and is also at the western portion of the Zamboanga Peninsula.

The watershed covers seven (7) municipalities and 60 barangays within the province. On the other hand, Padada Watershed is located mostly in the southwestern portion of Davao del Sur. It covers two (2) regions (Davao region and SOCCSKSARGEN) and four (4) provinces (Davao del Sur, North Cotabato, Sultan Kudarat, and South Cotabato), and the area also covers 78 barangays. The Figure 1 shows the location map of the watersheds while Figures 2, 3, and 4 show the sampling zones for Salug Daku Watershed, Labangan Watershed, and Padada Watershed, respectively.

Image generation and NDVI computation
Landsat imageries within the Google Earth Engine (GEE) cloud catalog were used in the generation of yearly images for the selected watersheds, covering years between the 1990s to the present. The GEE catalog already contains Landsat imageries already corrected for surface reflectance, thus eliminating the need for pre-processing and ready for input for computation of vegetation indices. The median values of each pixel in the composite images were also used for each watershed to remove clouds and cloud shadows.

Google Earth Engine was used to generate NDVI rasters covering the defined watershed boundaries for each year from when the satellite imagery is available. Images from all throughout each year were considered for the generation of mosaics for the selected river system to generate the largest possible cloud-free mosaic.

Satellite images from Landsat 5 and Landsat 7 were used to generate the rasters for years 1996 up to 2013, while the rasters for years 2014 to 2021 were derived from Landsat 8 imagery. Surface reflectance images from these satellites were used to have a standardized analysis, with atmospheric corrections already incorporated. The generated annual NDVI rasters were exported from the GEE interface into the user Google Drive account. NDVI rasters were exported with 30-m spatial resolution from the drive into the local hardware for further GIS and statistical analyses. Figure 5 shows a workflow summary of the whole methodology.

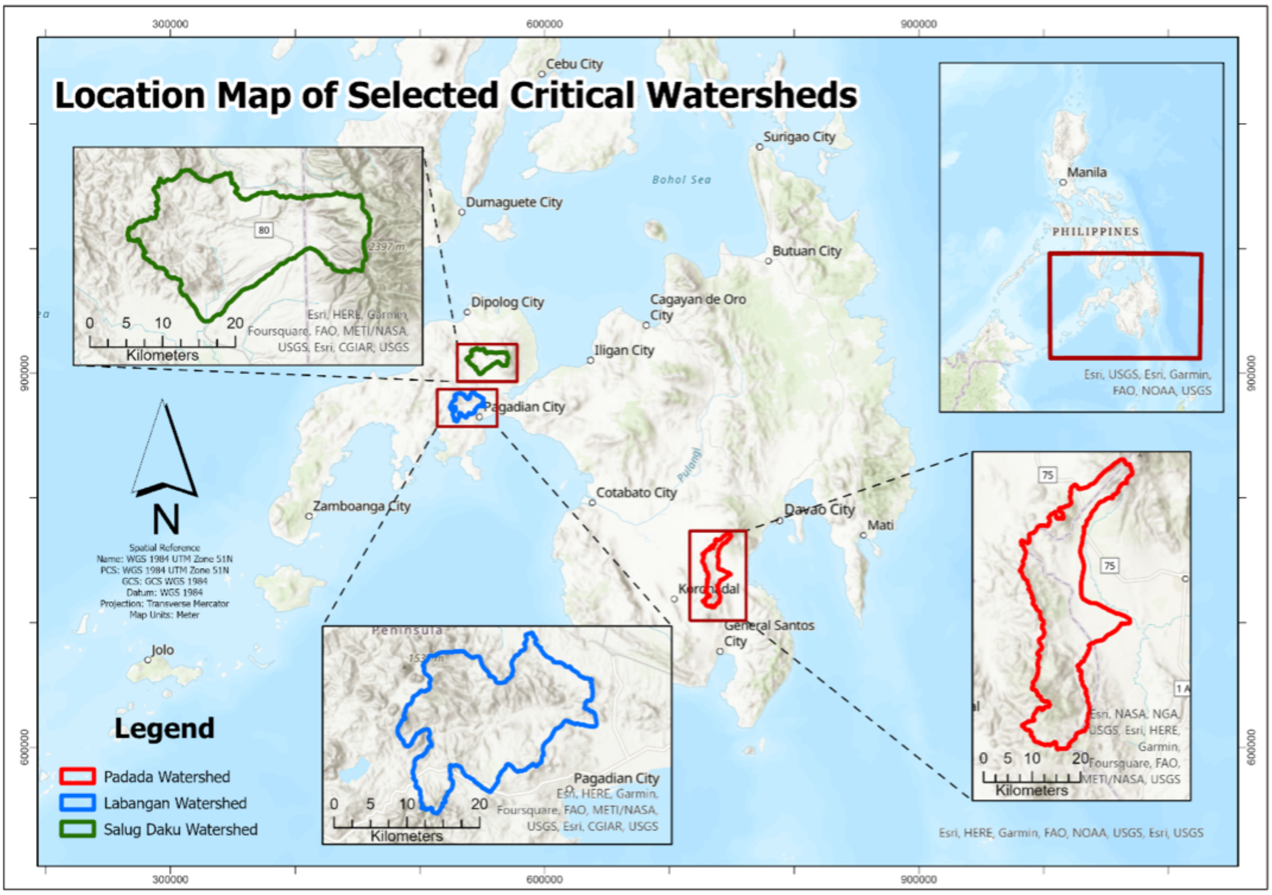

Figure 1: Location map of selected critical watersheds

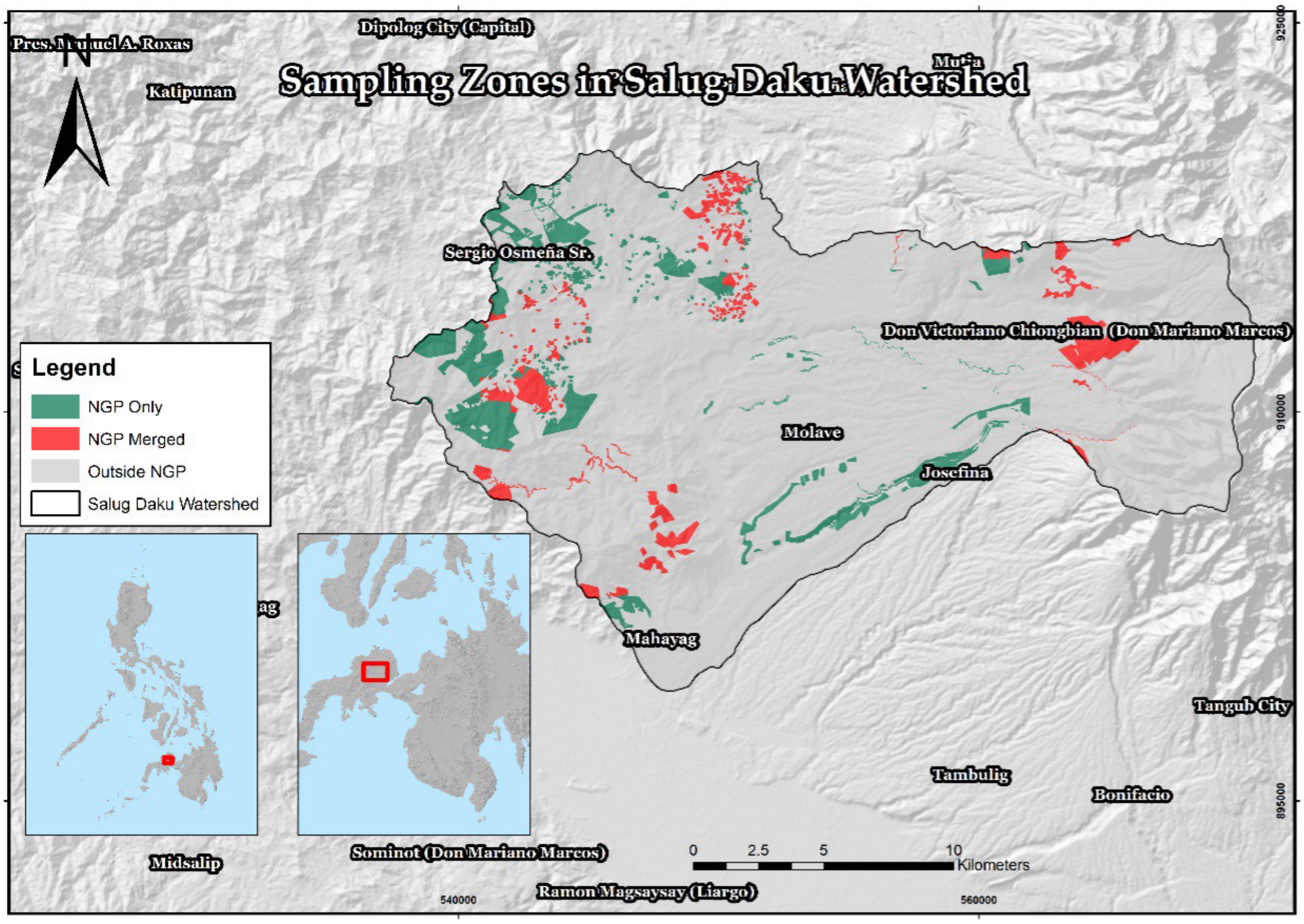

Figure 2: Sampling locations in Salug Daku Watershed

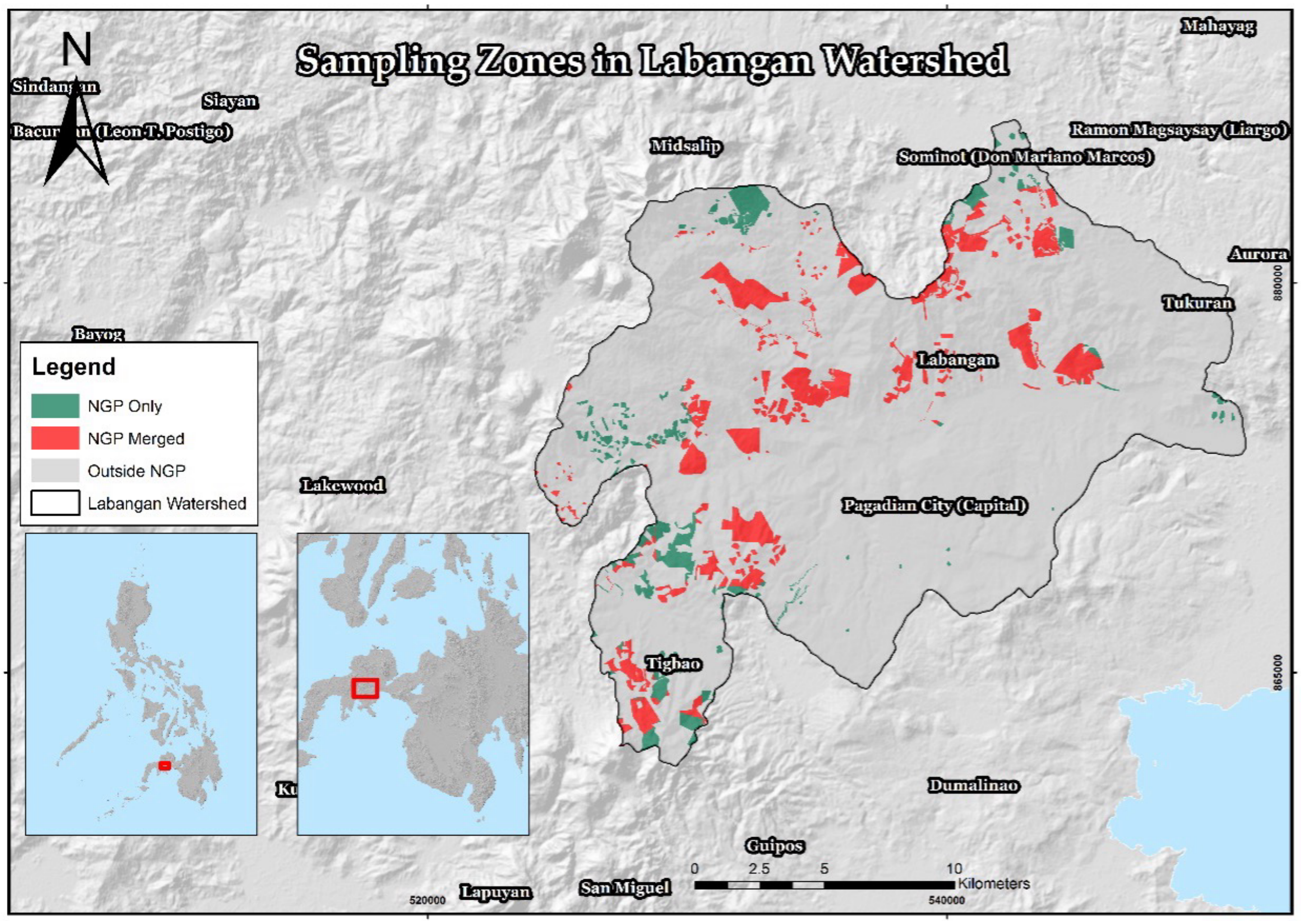

Figure 3: Sampling Zones in Labangan watershed

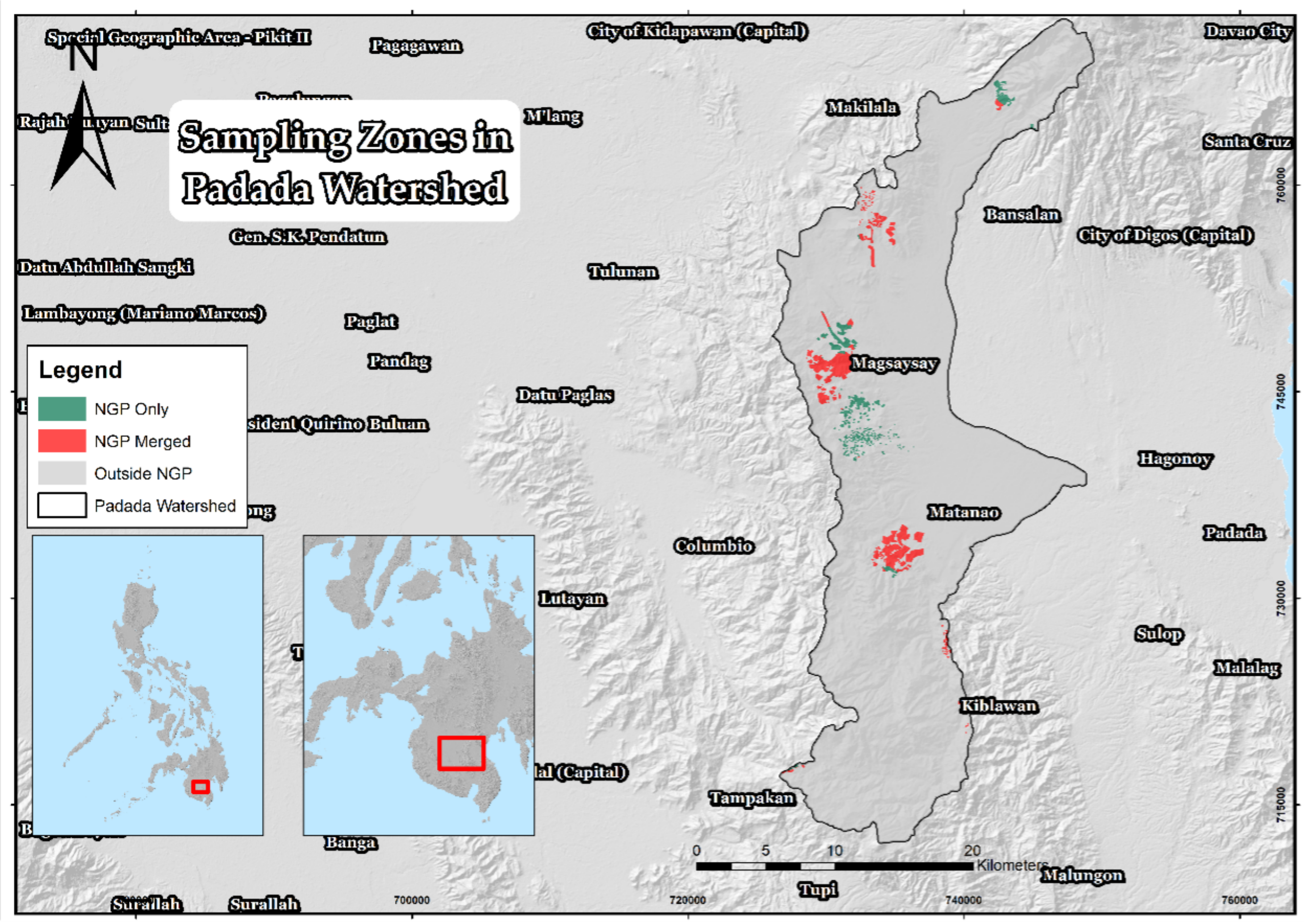

Figure 4: Sampling Zones in Padada watershed

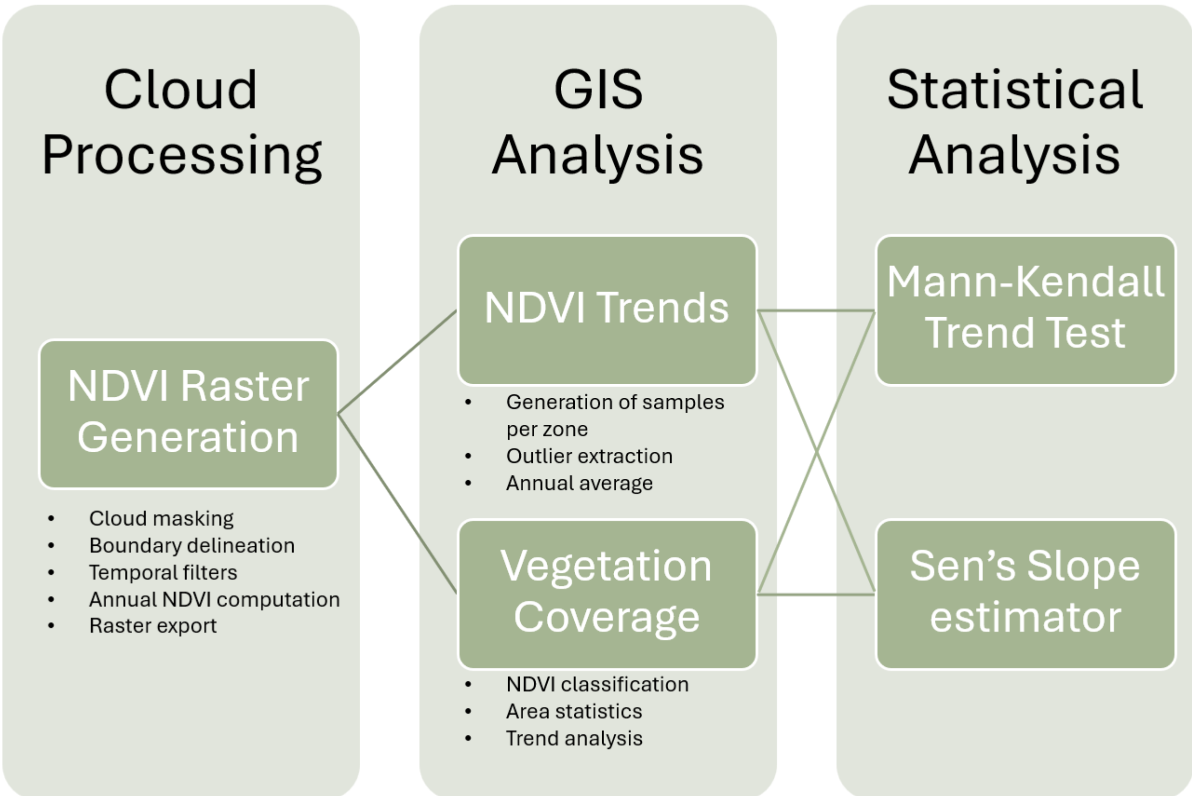

Figure 5: Workflow of the whole methodology

Generation of NDVI trends

Stratified random sampling was employed in the generation of annual NDVI trends for the selected watersheds. The different zones present in each of the watersheds serve as the basis for the sampling strata. Areas outside the reforestation programs were also merged to serve as another strata. Ten (10) sampling points were generated per square kilometer of the new polygons generated (also equal to 1 point per 10 hectares). The NDVI values for the rasters generated were then extracted into these sampling points. The extracted values in the points were tabulated and averaged annually, with all outliers removed from the computations of the averages. Graphical comparisons of the annual averages were generated to observe the performance of different programs.

NDVI Classification and Annual NDVI Statistics

NDVI values generated per year were classified according to the characteristics of global NDVI distributions used by Yang *et at* (2019). Reclassification is switching the values in a grid theme from one value to another. It simplifies the interpretation of the dataset by assigning new values to individual data or by combining ranges of values into simple values(ESRI, n.d.) It is occasionally necessary when a dataset must be reinterpreted or when classes must be combined in order to perform the desired analysis (Bantayan et al., 2015).

The table below shows the NDVI ranges for the classifications used. The classified rasters were reclassified for pixel count computation, and statistics of relative distribution of these NDVI classes were generated and graphed.

Table 1: NDVI ranges for characteristics of global NDVI distribution (from Yang et. al., 2019).

VEGETATION COVERAGE	NDVI RANGE
No vegetation	NDVI ≤ 0.2
Low vegetation	02 < NDVI ≤ 0.5
Medium vegetation	0.5 < NDVI ≤ 0.8
High vegetation	NDVI > 0.8

Random points were generated within the sampling polygons. The values for each annual NDVI raster were extracted to each of the random points generated. The NDVI values extracted from the mining areas were averaged and compared with the averages of those within the reforestation areas. The extracted values in the points were tabulated and averaged annually. Graphical comparisons of the annual averages were generated to observe the performance of different programs.

Statistical analysis of NDVI trends

Trend analyses were performed for two periods: pre-2010 and post 2010. The same periods were performed in all watersheds in the study. Graphs and summary statistics were also generated. For the pre-2010 period, the graphs of the trends of three (3) zones: 1) areas that are part of NGP post-2010 (to be denoted as "NGP Only"); 2) areas that are part of NGP and also within other reforestation zones and policy intervention implementations (to be denoted as "NGP Merged") and 3) areas not part of NGP (to be denoted as "Outside NGP") were highlighted to observe the performance of the areas where NGP was not implemented. This was essential in observing the status of the vegetation in the watershed prior to the implementation of the NGP in 2011.

The Mann-Kendall trend test and Sen's slope estimate were the statistical tools employed to prove (or disprove) the statistical significance of the NDVI trends generated for the different watersheds. The Mann-Kendall trend test makes no assumptions about the inherent distribution of the data and is a rank-based measure not influenced by extreme values. It evaluates whether the value of the variable tends to increase or decrease over time through a non-parametric form of monotonic trend regression analysis. The data need not follow any specific distribution and missing values are permitted. The test assumes the following: data are independent; the distribution of data is constant in either the original units or transformed units; and a value can always be declared less than, greater than, or equal to another value (Meals et al., 2011). The level of probability in which the null hypothesis will be rejected is set to 0.05.

Meanwhile, the simple non-parametric procedure developed by Sen was used to evaluate the magnitude of the time series trend. The formula for this is

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right), j > i$$

where β is the Sen's slope estimate. When β is greater than 0, it indicates that the time series experiences an upward trend. Otherwise, the data series shows a declining trend over the specified time. Computations for the trends generated were performed within the R and RStudio applications.

NDVI Trends within Different Zones

The polygons generated in the selected watersheds were sampled and compared to in terms of their NDVI. Representative NDVI values for each reforestation area were collected and examined for outliers, which were identified and omitted from the samples. These values were generated per year and plotted in a graph to observe the trend over time.

Trend analyses were performed for two periods: pre-2010 and post 2010. The same periods were performed in all watersheds in the study. Graphs and summary statistics were also generated. For the pre-2010 period, the graphs of the trends of two (2) zones: 1) areas that are part of NGP post-2010 (to be denoted as "NGP Only"); and 2) areas not part of NGP (to be denoted as "Outside NGP") are highlighted to observe the performance of the NGP. This was instrumental in observing the status of the vegetation in the watershed prior to the implementation of the NGP in 2011. The different forest zones were also tested individually to observe the existence of trends within their boundaries.

For the post-2010 period, the same areas as the ones in the pre-2010 period were sampled. Similar to the previous period, the different reforestation zones were also tested individually to observe the existence of trends within their boundaries, this time looking at the influence of the NGP. The "NGP Only", "NGP Merged", and "Outside NGP" zones were also consistent with the previous period.

RESULTS AND DISCUSSION

Salug Daku Watershed NDVI Classification

It was found that for Salug Daku watershed, medium vegetation cover dominated the total area. The high vegetation cover in the watershed started increasing after 2010, and in year 2021 had the most cover in the watershed, at around 53.49 percent. This is consistent with the forest cover changes in the whole watershed based on the NAMRIA land cover datasets, with was found to be increasing from 2010 (5,182.86 hectares) to 2020 (5,430.38 hectares).

In the same year, the medium vegetation cover was found to be around 45.72 percent of the watershed. Both the low and no vegetation cover areas were found to be less than one (1) percent of the watershed's total vegetation cover.

Annual measurements of the total area of high vegetation coverage areas (NDVI greater than 0.8) were recorded and underwent trend analyses to observe if there was a significant change in the area. Three periods were used in the analyses: 1) 1996 to 2021 (full); 2) 1996 to 2010 (pre-2010); and 3) 2010 to 2021 (post-2010). Analyses were conducted for all the watersheds in the study. Figure 6 shows the relative annual distribution of the vegetation cover for Saluk Daku watershed for the whole duration while Figure 7 shows the representative vegetation coverage maps for the watershed. Table 2 shows the summary of the test statistics and p-values.

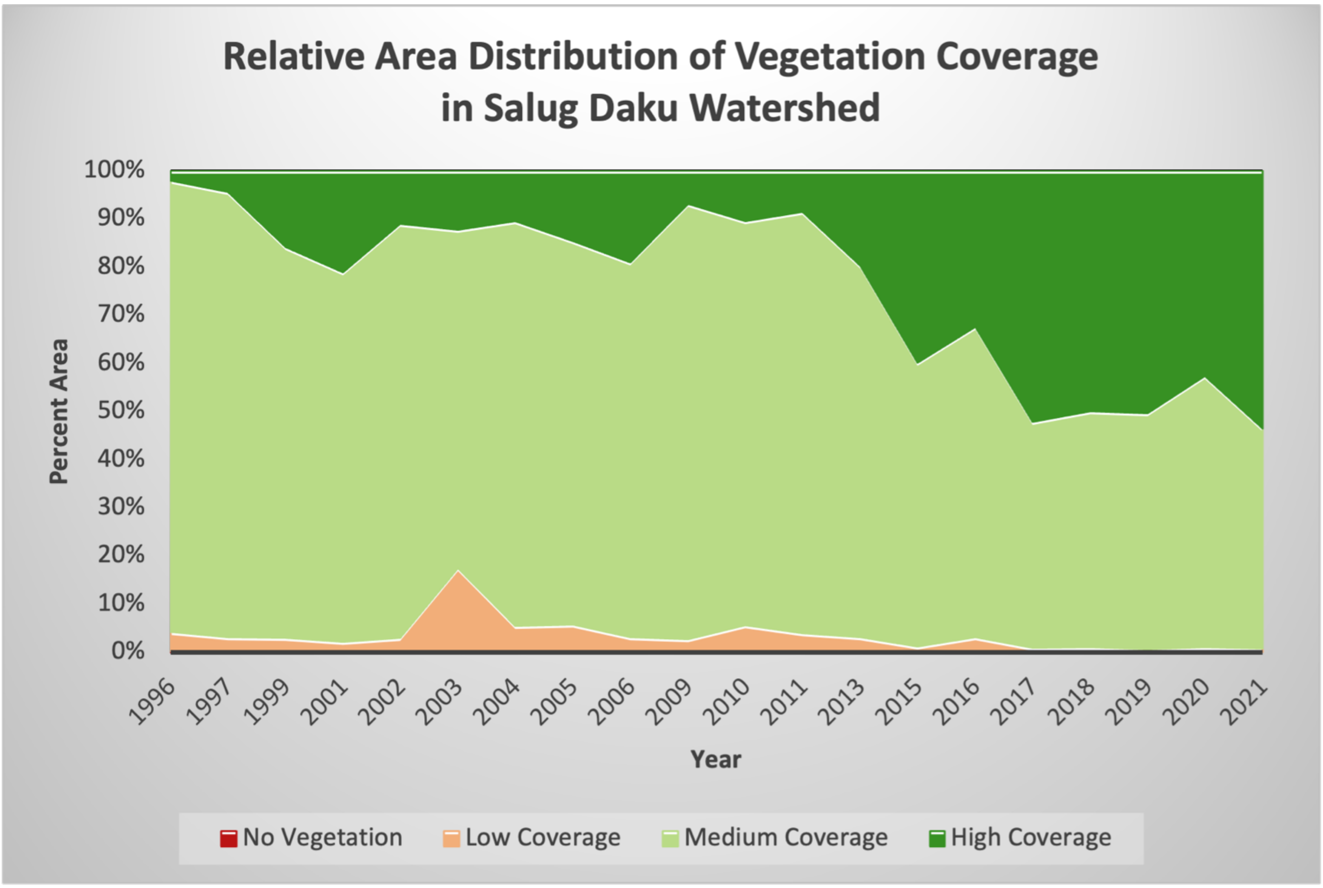

Figure 6: Relative annual distribution of the vegetation cover for Saluk Daku watershed

Table 2: Summary of statistics for trend analyses of high vegetation coverage area in Salug Daku watershed

PERIOD	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
Pre-2010	246.8	0.6404	0.127	0.6404	No trend
Post-2010	1627.8	0.0049	0.778	0.0049	Positive trend
Full	869.0	0.0002	0.611	0.0002	Positive trend

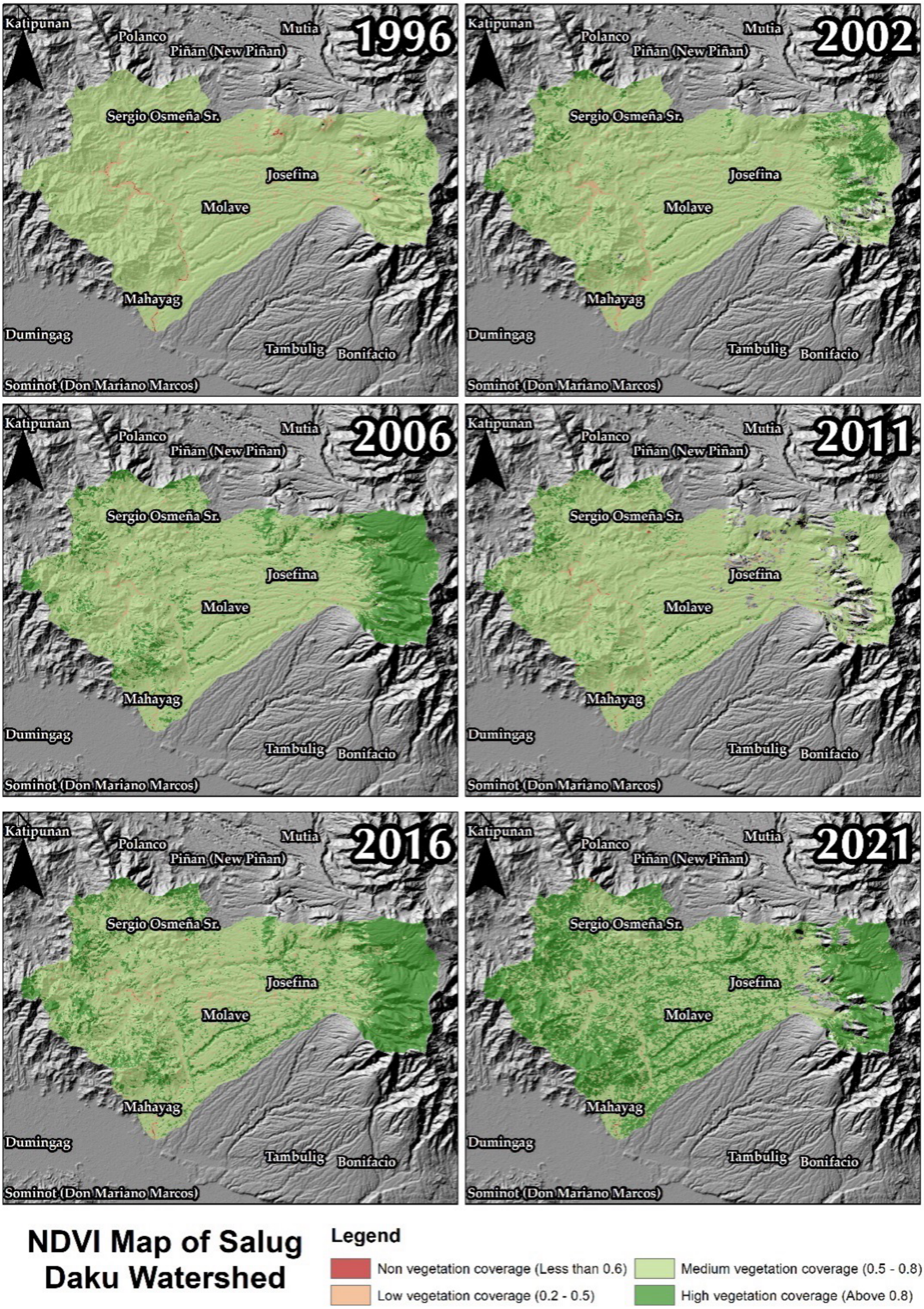

Figure 7: Representative vegetation coverage for Salug Daku Watershed

From the full period of the study, it was found that there is a significant increase in high vegetation coverage, consistent with the forest cover change from the NAMRIA land cover dataset. The same result was observed for the period between 2010 and 2021. Meanwhile, no trend was observed in the high vegetation coverage area of the watershed within the period of 1996 to 2010. This indicates that the increases in high vegetation coverage area occurred in the later part of the period. This is also supported by the changes in land cover from the NAMRIA datasets mentioned earlier.

Labangan Watershed NDVI Classification

For the most part, it was also found that medium vegetation coverage dominated the watershed. The high vegetation coverage areas were observed to start increasing at the onset of the 2010s, peaking in 2021 covering 66.75 percent of the watershed. During that time, the medium vegetation coverage got reduced to 31.84 percent of the watershed. The combined area of the no vegetation coverage and low vegetation coverage areas in 2021 was less than 2 percent of the watershed area.

Trend analyses were also conducted for the high vegetation coverage areas of the watershed. The periods of pre-2010 and post-2010 were also observed to have statistically significant trends. In terms of area, the high vegetation coverage was observed to have a consistent increase.

Table 3 shows the summary statistics for the trend analyses for the high vegetation area coverage, while Figure 8 displays the relative annual distribution of the vegetation cover for Labangan watershed for the whole duration. Figure 9 shows the map of representative vegetation coverage of the watershed.

Table 3: Summary of statistics for trend analyses of high vegetation coverage area in Labangan watershed

PERIOD	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
Pre-2010	706.6	0.0020300	0.697	0.00203030	Positive trend
Post-2010	1037.5	0.0292700	0.527	0.02927300	Positive trend
Full	806.9	0.0000002	0.779	0.00000024	Positive trend

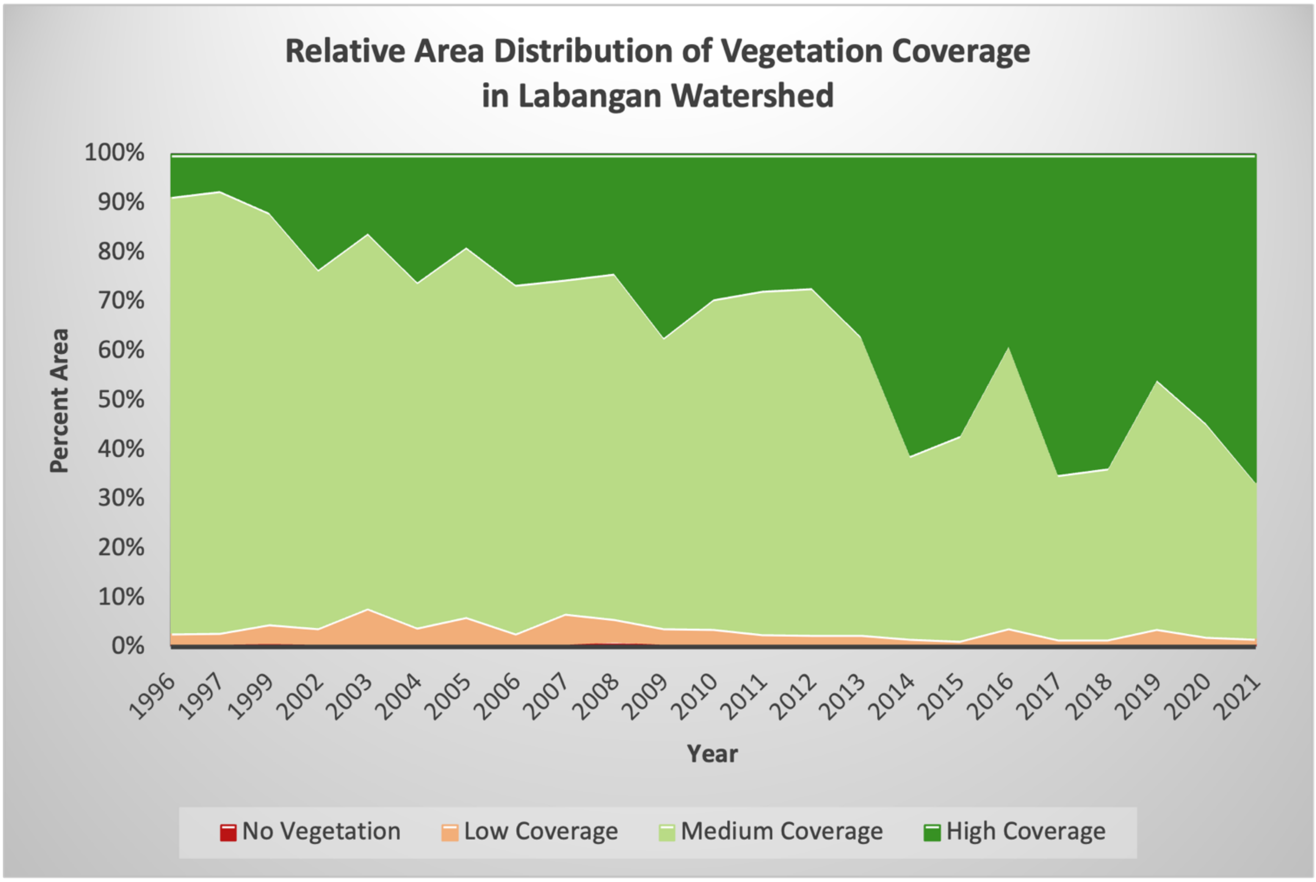

Figure 8: Relative annual distribution of the vegetation cover for Labangan watershed

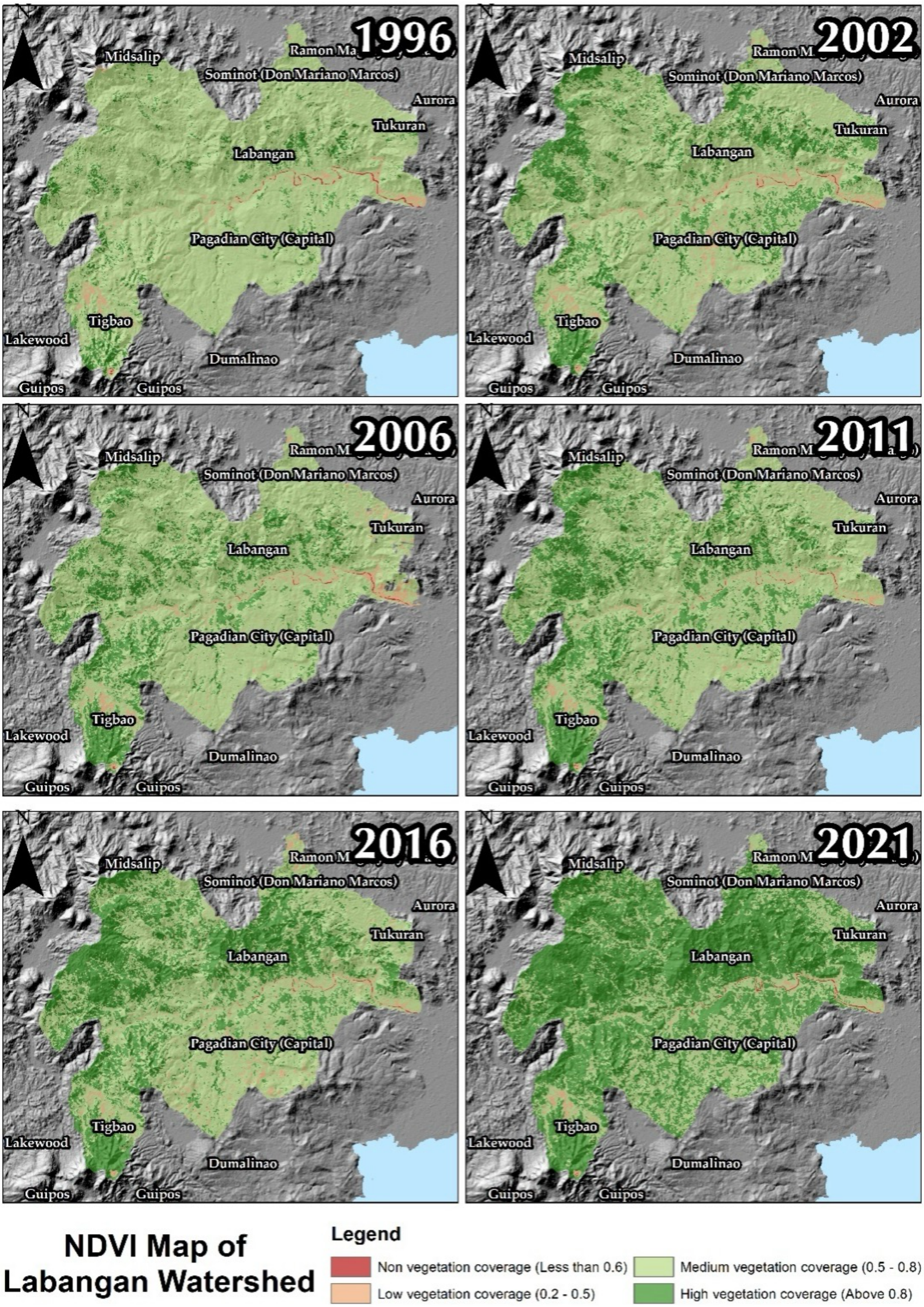

Figure 9: Representative vegetation coverage for Labangan Watershed

Padada Watershed

In the case of Padada watershed, the area of high vegetation coverage was observed to be consistently increasing with time. The increase was observed as early as the late 2000s. Further increase was noticed in the 2010s, with the highest recording observed in 2017, covering around 65.70 percent of the watershed. In 2021, the high vegetation coverage was recorded to be still above 60 percent of the total area, while the medium vegetation coverage was at around 37.23 percent.

Changes observed since 2020 may be attributed to the deforestation and forest degradation during the pandemic, where such phenomena were caused by several drivers in other parts of the country (Israel et al., 2023). Comparison with the NAMRIA land cover data revealed a similar behavior, with the forest cover observed to be increasing from 2010 (at 8,273.08 hectares) to 2020 (at 10,566.91 hectares).

Trend analyses were also conducted for the high vegetation coverage areas of the watershed. The high vegetation coverage area in the watershed was observed to have increased significantly for the whole duration of the study. Also, both periods of pre-2010 and post-2010 were also observed to have statistically significant trends.

Table 4 shows the summary statistics for the trend analyses, while Figure 10 shows the relative distribution of the area of vegetation coverage in the watershed. Figure 11 shows representative vegetation coverage maps for the watershed.

Table 4: Summary of statistics for trend analyses of high vegetation coverage area in Padada watershed

PERIOD	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
Pre-2010	1983.8	0.01649	0.667	0.016489	Positive trend
Post-2010	1416.3	0.02004	0.600	0.02004	Positive trend
Full	1687.9	0.000002	0.801	0.000002	Positive trend

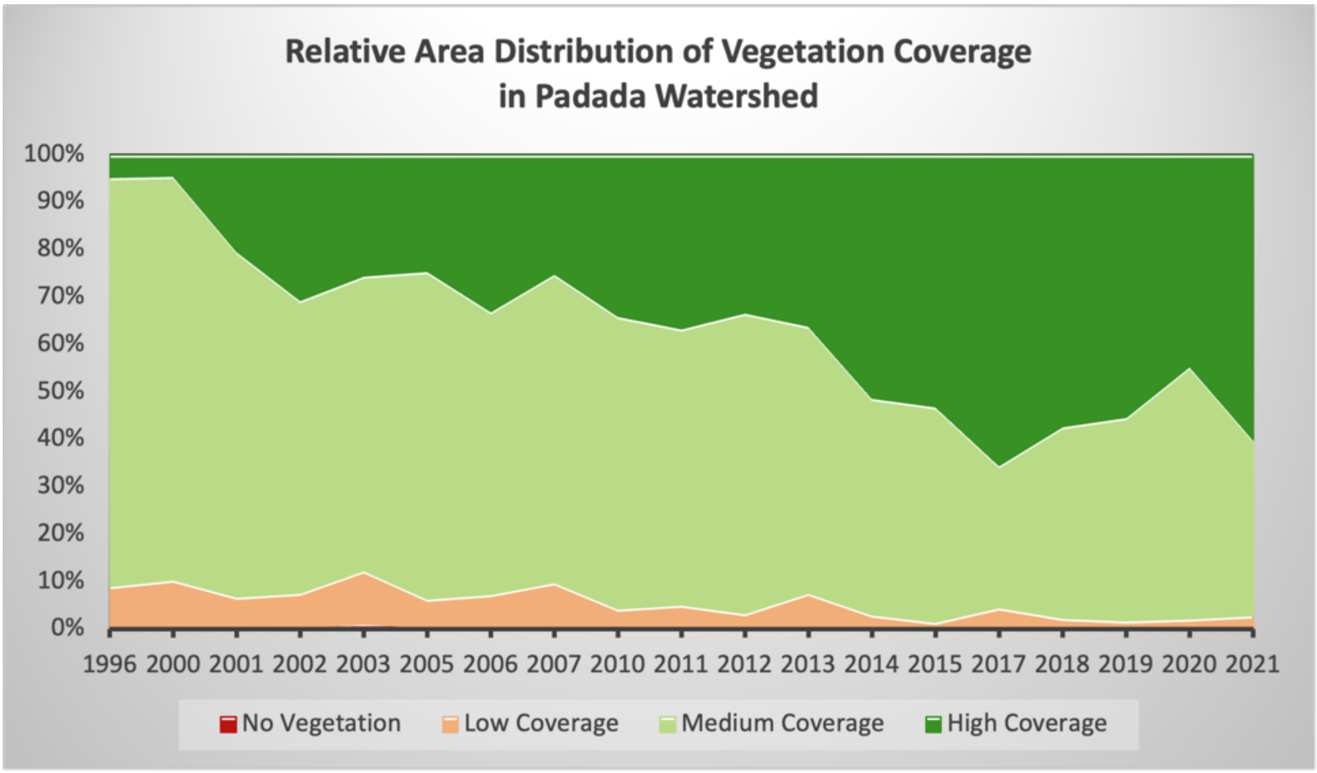

Figure 10: Relative annual distribution of the vegetation cover for Padada watershed

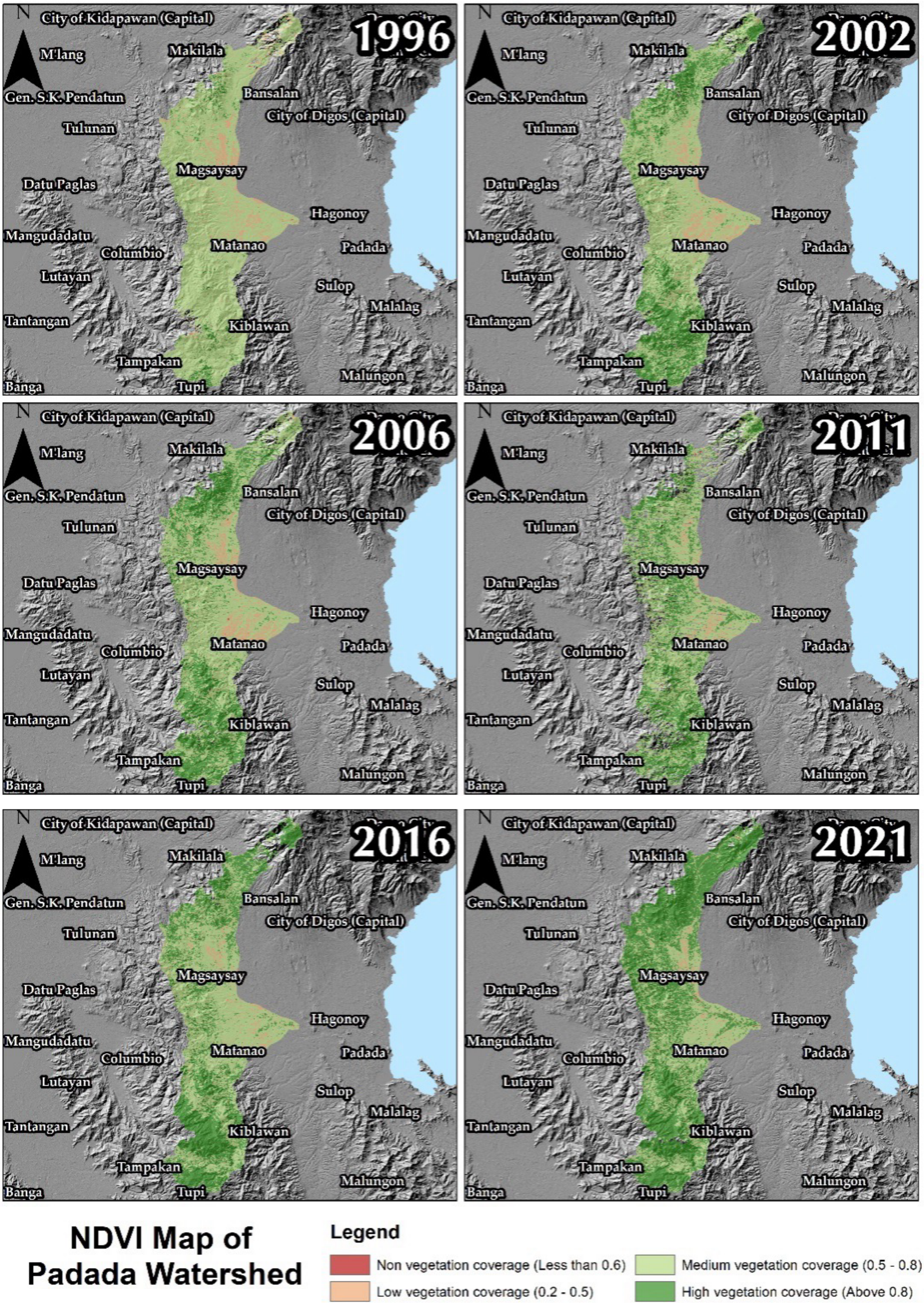

Figure 11: Representative vegetation coverage for Padada Watershed

NDVI Trends within Different Zones

Salug Daku Watershed Sampling and Trend Analysis

Trend analyses for the period of pre-2010 revealed that there were no trends within all the zones in the watershed, with p-values for the Mann-Kendall trend test and Sen's slope at 0.9514 for NGP Only areas and 0.8548 for NGP Merged areas and areas Outside NGP, respectively. This result is also consistent with the earlier trend analysis of high vegetation coverage in the watershed in the same region that yielded no significant trend.

This shows that vegetation types in the watershed for this period had no significant changes. Meanwhile, in the period post-2010 (2011 to present), it was found that purely NGP sites could not yield significant NDVI trends ($p = 0.0736$ for both Sen's slope and Mann-Kendall trend test) while the NGP Merged areas and the areas Outside NGP produced statistically significant trends ($p = 0.0073$ for the Sen's slope and Mann-Kendall trend test for the former and $p = 0.0123$ for the latter).

Trends that were observed post-2010 were compared with the forest cover changes from the with the NAMRIA land cover datasets from 2010 onwards within the zones sampled for the study. The NAMRIA land cover data revealed that forest cover for the NGP only areas decreased from 2010 to 2015 (from 45.96 hectares to 42.13 hectares) and decreased further from 2015 to 2020 (down to 41.59 hectares). Meanwhile, forest cover in the NGP Merged areas and areas outside NGP also were found to have increased from 2010 to 2020, with the NGP Merged areas increasing from 94.41 hectares in 2010 to 104.07 hectares in 2020 and the Outside NGP areas increasing from 5,088.45 hectares in 2010 to 5,326.31 hectares in 2020.

Figures 12 and 13 show the annual average NDVI within the different zones for the pre-2010 and post-2010 periods, respectively, while Tables 5 and 6 show the summary statistics for the NDVI sampling and trends analysis for pre-2010 and post-2010, respectively.

Table 5: Summary of statistics for trend analyses of NDVI sampling in Salug Daku watershed (Pre-2010)

ZONE PRE 2010	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	-0.0002407366	0.9514	-0.0256	0.95135	No trend
NGP Merged	0.0005103712	0.8548	0.0513	0.85478	No trend
Outside NGP	-0.0004863027	0.8548	-0.0513	0.8548	No trend

Table 6: Summary of statistics for trend analyses of NDVI sampling in Salug Daku watershed (Post-2010)

ZONE POST 2010	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	0.008411125	0.07364	0.467	0.073638	No trend
NGP Merged	0.0116244	0.00729	0.689	0.0072904	Positive trend
Outside NGP	0.01044642	0.01227	0.644	0.012266	Positive trend

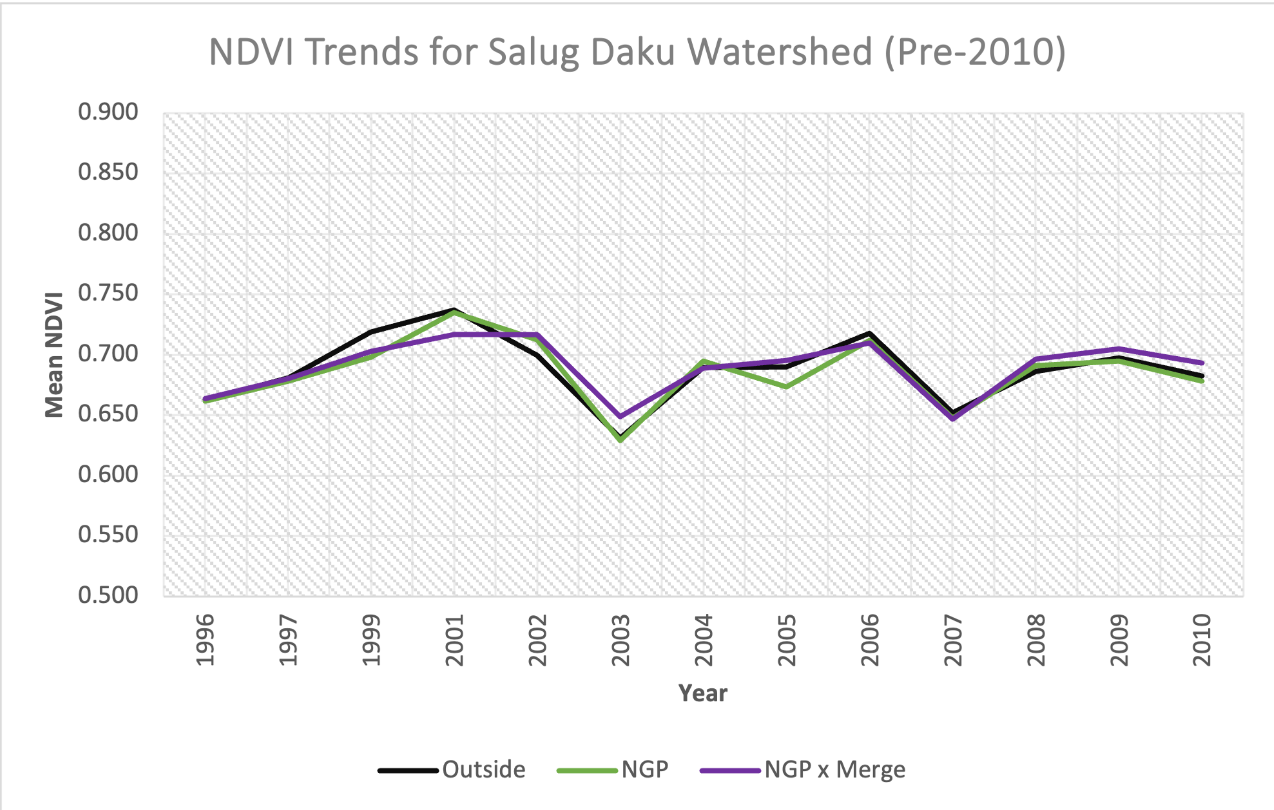

Figure 12: NDVI Trends for Salug Daku Watershed (Pre-2010)

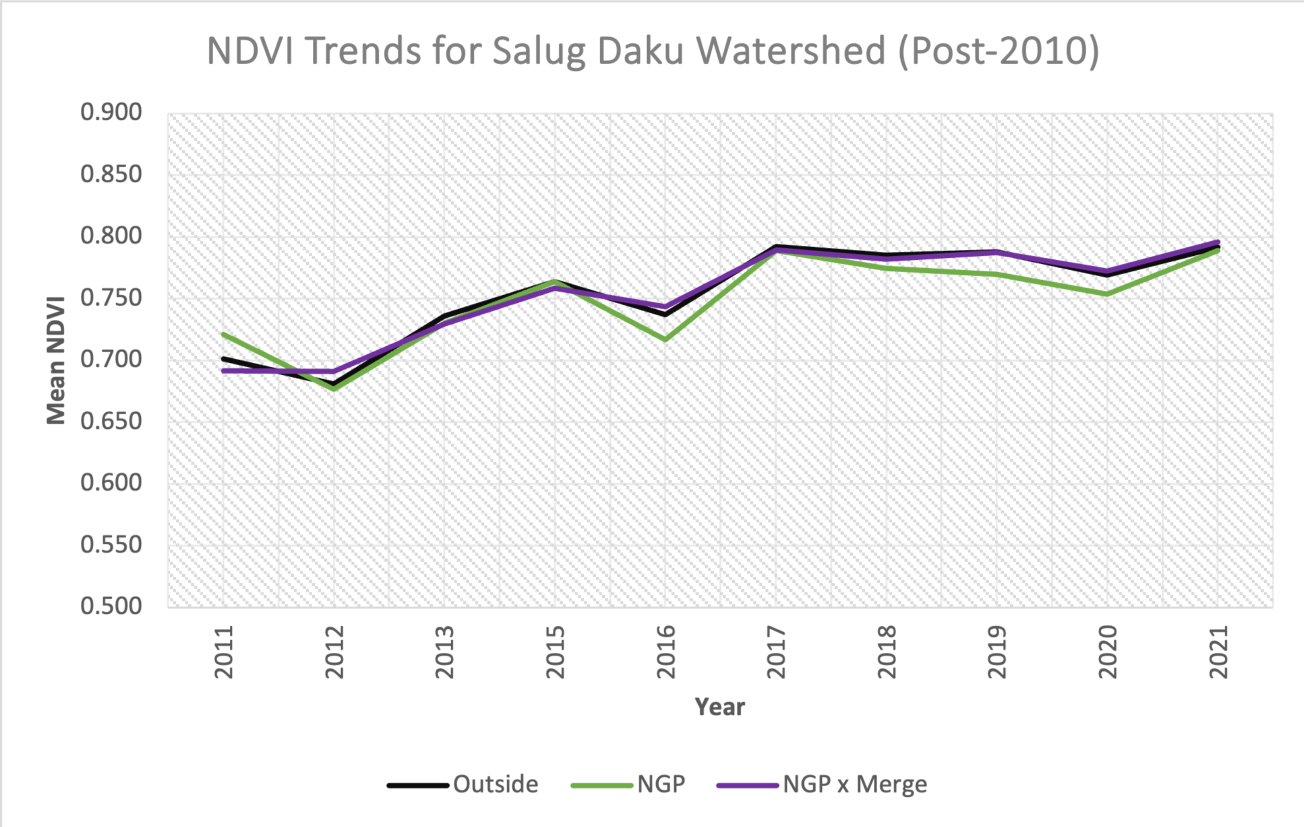

Figure 13: NDVI Trends for Salug Daku Watershed (Post-2010)

Labangan Watershed Sampling and Trend Analysis

Trend analyses for the period of pre-2010 (1996 to 2010) showed that all the zones (were found to have statistically significant positive NDVI trends, with: the NGP only zone having p-values for the MK test and Sen's slope of 0.0075332 and 0.0075330, respectively; the NGP Merged zone's p-values for the tests at 0.010072 and 0.01007, respectively; and the outside NGP zone's p-values for the tests at 0.013348 and 0.01335, respectively.

However, in the period post-2010 (2011 to present), it was observed that both the NGP Only and Outside NGP zones had no significant trends, with p-values for the MK test and Sen's slope for the former being 0.16112 and 0.1611, respectively, and 0.11947 and 0.1195, respectively, for the latter. Only the NGP Merged zone was found to have statistically significant trends for the post-2010 period, with p-values for the MK test and Sen's slope at 0.04296 and 0.04296.

Trends that were observed post-2010 were compared with the forest cover changes with the NAMRIA land cover datasets in the zones sampled for the study from 2010 onwards. The NAMRIA land cover data revealed that forest cover for the NGP only areas decreased from 2010 to 2015 (from 150.21 hectares to 130.22 hectares) and did not recover much from 2015 to 2020 (increased to 134.69 hectares). Meanwhile, forest cover in areas outside NGP also decreased from 2010 to 2015 (from 1776.90 hectares to 1,596.31 hectares) but had a significant increase from 2015 to 2020 (increased to 1,881.35 hectares). Further time periods are needed to validate the significance of the trends.

Figures 14 and 15 show the annual average NDVI within the different zones for the pre-2010 and post-2010 periods, while Tables 7 and 8 show the summary statistics for the NDVI sampling and trends analysis for pre-2010 and post-2010.

Table 7: Summary of statistics for trend analyses of NDVI sampling in Labangan watershed (Pre-2010)

ZONE	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	0.004014129	0.007533	0.524	0.0075332	Positive trend
NGP Merged	0.00407868	0.01007	0.505	0.010072	Positive trend
Outside NGP	0.003037955	0.01335	0.486	0.013348	Positive trend

Table 8: Summary of statistics for trend analyses of NDVI sampling in Labangan watershed (Post-2010)

ZONE	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	0.001144282	0.1611	0.345	0.16112	No trend
NGP Merged	0.004680686	0.04296	0.491	0.04296	Positive trend
Outside NGP	0.004683419	0.1195	0.382	0.11947	No trend

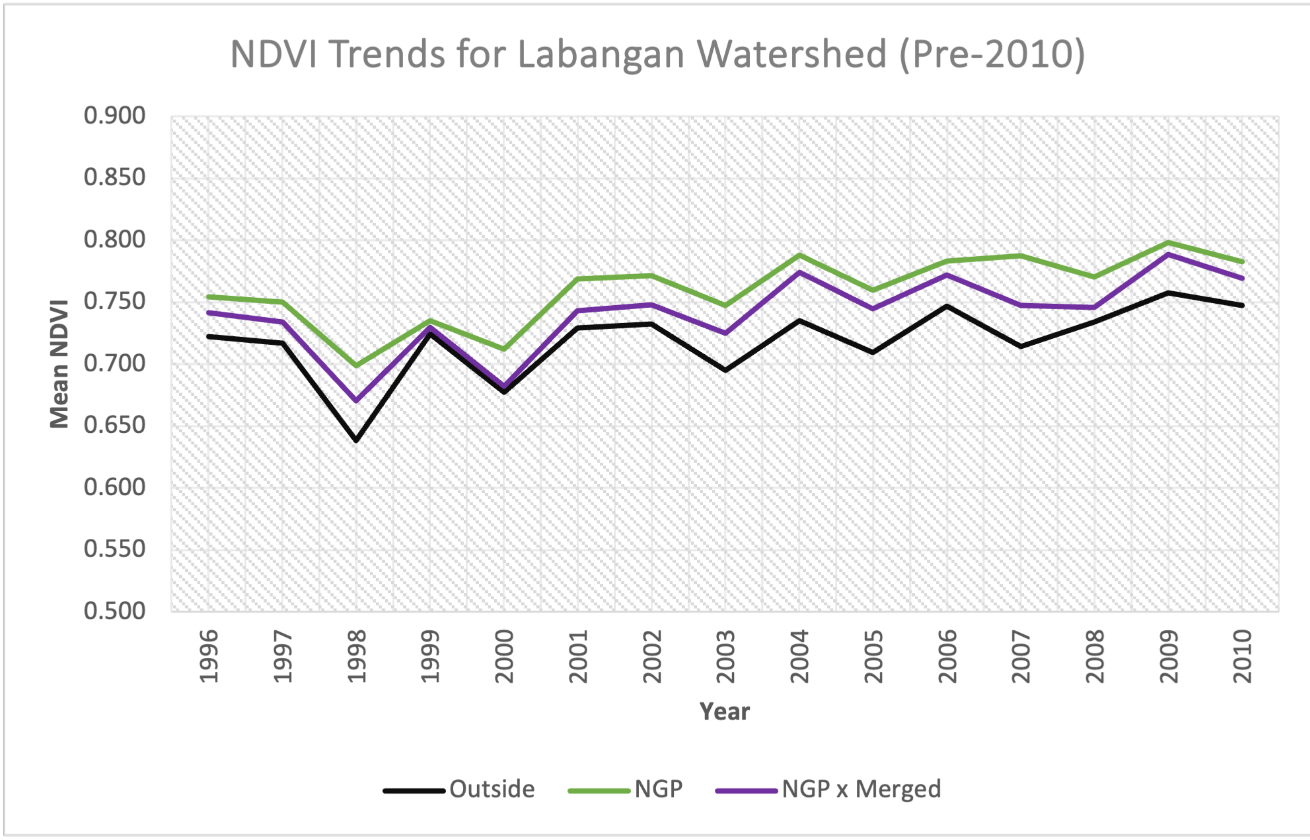

Figure 14: NDVI Trends for Labangan Watershed (Pre-2010)

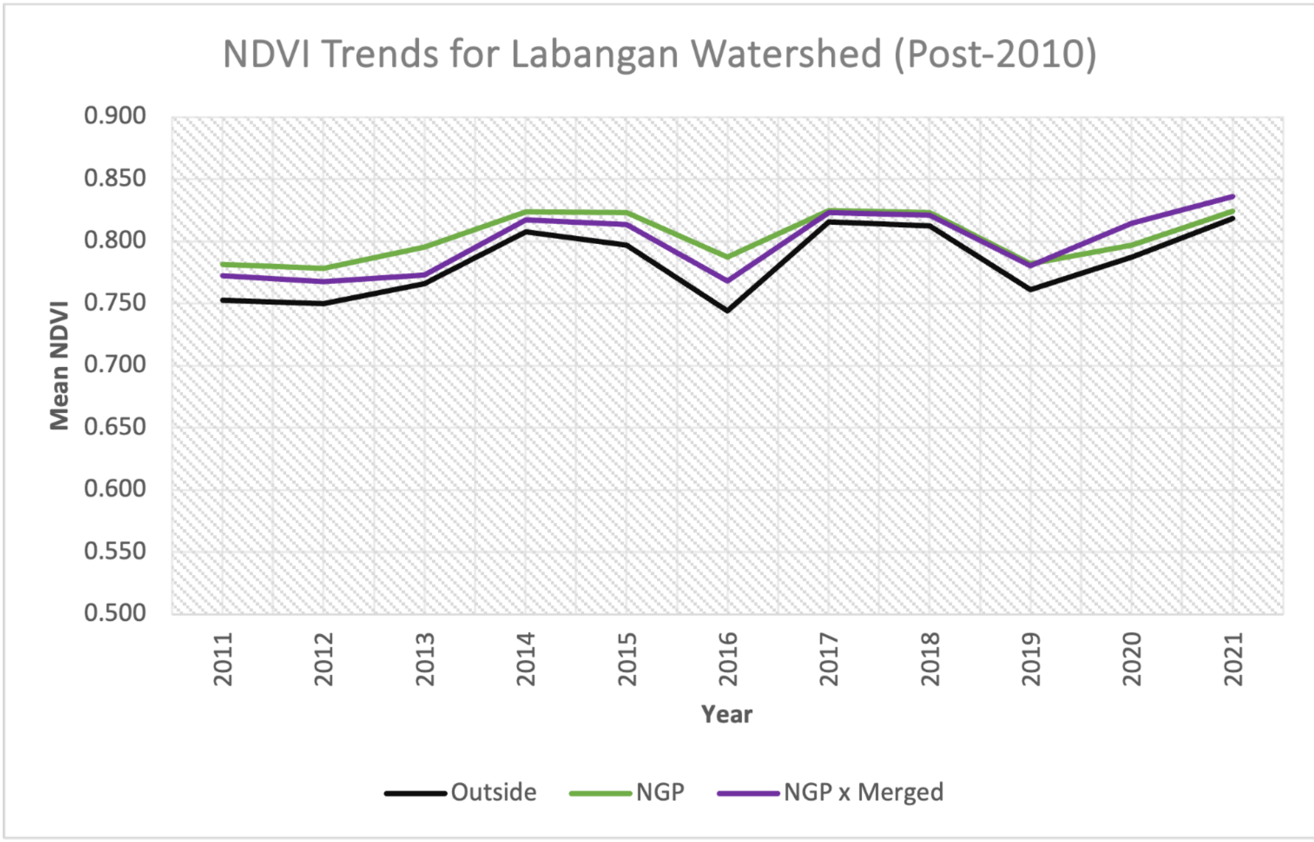

Figure 15: NDVI Trends for Labangan Watershed (Post-2010)

Padada Watershed Sampling and Trend Analysis

Trend analyses for the period of pre-2010 (1996 to 2010) showed that the NGP Only and NGP Merged zones failed to produce statistically significant NDVI trends, with p-values for Sen's slope and Mann-Kendall Trend test for both zones at 0.1179 and 0.11785, respectively. Meanwhile, the zone outside the NGP areas was found to have a statistically significant positive NDVI trend, with p-value for Sen's slope and Mann-Kendall Trend test at 0.02857 and 0.028568, respectively.

More than 95% of the watershed is part of the zone outside the protected areas and in the earlier trend test for the high vegetation coverage area, the whole watershed also showed statistically positive trends. This indicates that, for this period, the area and greenness of high vegetation coverage is increasing for most of the watershed. Meanwhile, in the period post-2010 (2011 to present), it was observed that the Outside NGP zone and NGP Merge zones both had significant positive trends, with p-values for Sen's slope and Mann-Kendall Trend tests for the Outside NGP zone at 0.0491 and 0.049098, respectively, and values for the NGP Merged zones at 0.03182 and 0.031823, respectively.

On the other hand, the NGP Only zones were found to have statistically insignificant trends, with p-values for Sen's slope and Mann-Kendall Trend tests at 0.0736 and 0.073638, respectively. Comparison with the NAMRIA land cover data reveals that the forest area within the NGP only zone was found to have been decreasing from 2010 (at 15.25 hectares) to 2020 (at 12.25 hectares).

This also shows that the vegetation in this watershed cannot be said to have increased or decreased within the period. Future trends may reveal improved results the average NDVI of the zone as the time series increases in length (Wang et al., 2020). Figures 16 and 17 show the annual average NDVI within the different zones for the pre-2010 and post-2010 periods, while Tables 9 and 10 show the summary statistics for the NDVI sampling and trends analysis for pre-2010 and post-2010.

Table 9: Summary of statistics for trend analyses of NDVI sampling in Padada watershed (Pre-2010)

ZONE	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	0.01100664	0.1179	0.444	0.11785	No trend
NGP Merged	0.01100664	0.1179	0.444	0.11785	No trend
Outside NGP	0.00970114	0.02857	0.611	0.028568	Positive trend

Table 10: Summary of statistics for trend analyses of NDVI sampling in Padada watershed (Post-2010)

ZONE	SEN'S SLOPE		MANN-KENDALL TREND TEST		REMARKS
	Estimate	p-value	Kendall's Tau	p-value	
NGP Only	0.007212518	0.07364	0.467	0.073638	No trend
NGP Merged	0.00661613	0.03182	0.556	0.031823	Positive trend
Outside NGP	0.00517846	0.0491	0.511	0.049098	Positive trend

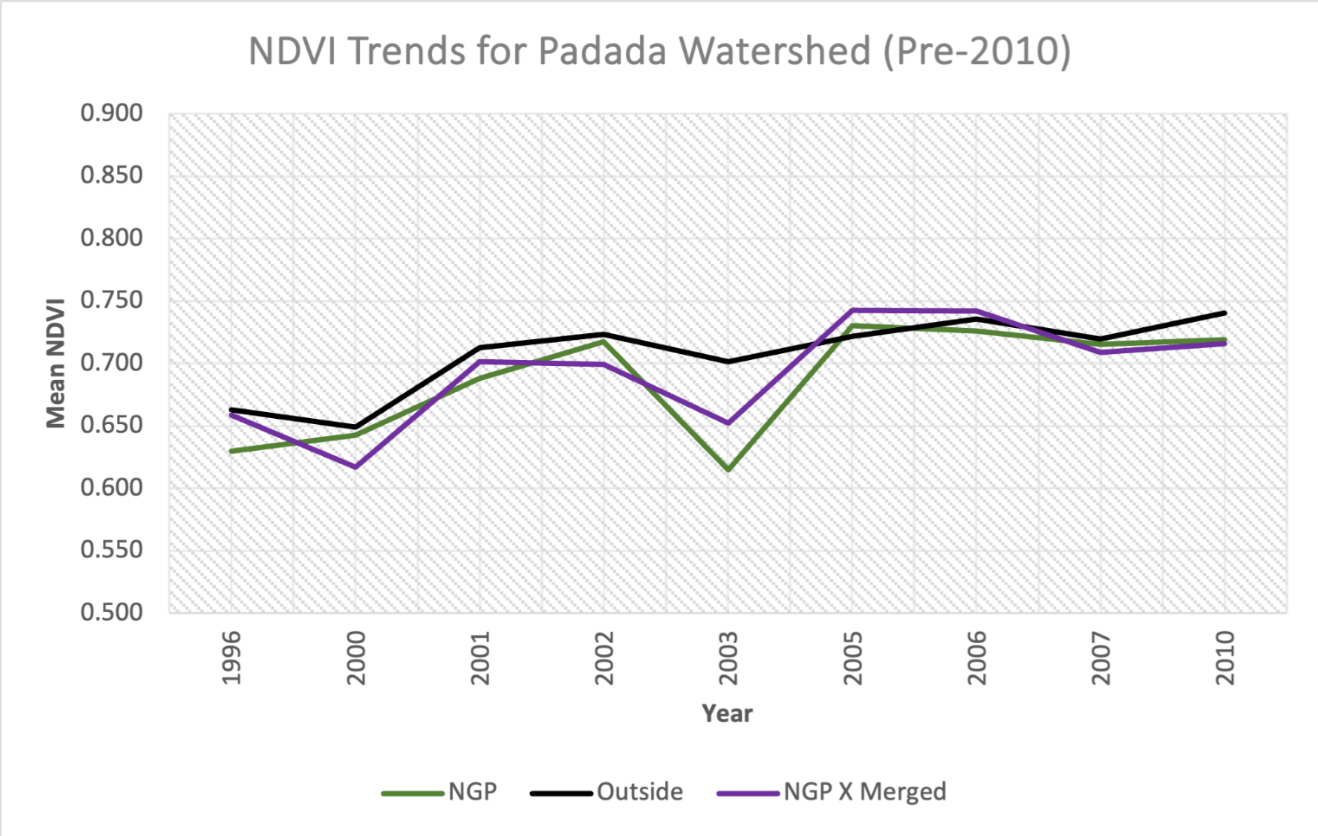

Figure 16: NDVI Trends for Padada Watershed (Pre-2010)

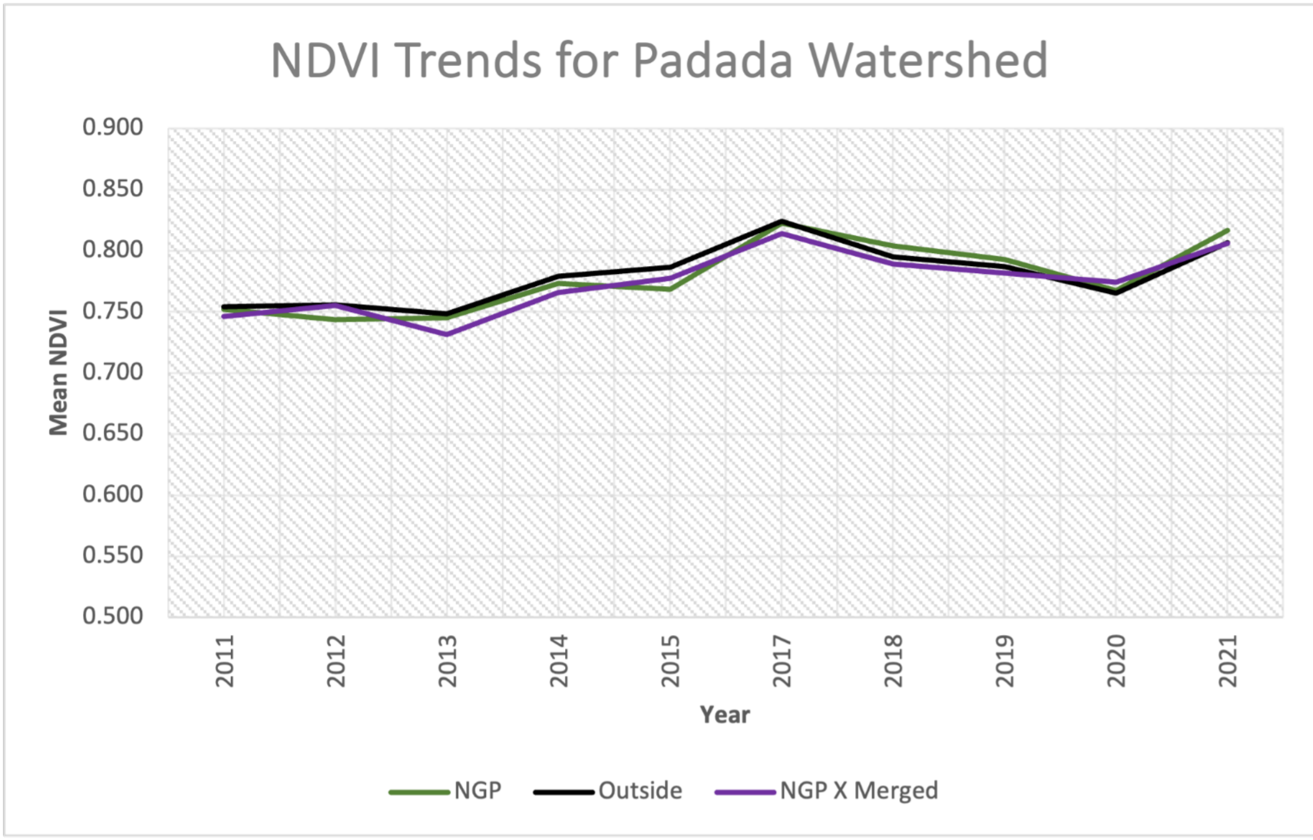

Figure 17: NDVI Trends for Padada Watershed (Post 2010)

Comparison with the NAMRIA land cover data from 2003 revealed that 98% of the NGP and NGP merged area are nonforest, dominated by grasslands and perennial crops. Decrease in mean NDVI may be attributed to this lack of canopy cover.

Comparison of NDVI Trends among Watersheds

Comparison of the results among the different watersheds reveal that the purely NGP areas, or the "NGP Only" zones for all the watersheds were all observed to have failed in establishing statistically significant trends for both the Sen's slope and the Mann-Kendall trend tests in the post-2010 period. With Labangan watershed, prior to the implementation of NGP, a positive trend was still observed all throughout the watershed, but the conduct of the NGP within established reforestation zones and policy interventions has yielded a statistically significant trend. This shows that in areas which are purely part of the NGP and are not part of any protection or tenurial instrument, no trends in vegetation are detected.

Meanwhile, the areas outside NGP were observed to have varied results for all the watersheds in terms of how the trends were observed, with only Padada watershed having both positive trends in both periods. Table 11 shows the comparison of the trends among watersheds between the pre-2010 and post-2010 periods.

Table 11: Comparison of the trends among watersheds between the pre-2010 and post-2010 periods

WATERSHED	ONLY NGP		NGP MERGED		OUTSIDE NGP	
	Pre-2010	Post-2010	Pre-2010	Post-2010	Pre-2010	Post-2010
Salug Daku	No trend	No trend	No trend	Positive trend	No trend	Positive trend
Labangan	Positive trend	No trend	Positive trend	Positive trend	Positive trend	No trend
Padada	No trend	No trend	No trend	Positive trend	Positive trend	Positive trend

Comparison with Similar Studies

The study of Zhang et al. (2024) conducted a spatiotemporal analysis of the characteristics of NDVI in Qinghai Province in China, where the Chinese government had implemented several ecological policies aimed towards natural resources protection and restoration. They also performed NDVI trend analysis on different phases of the vegetation recovery. Their results show a positive NDVI trend during the rapid growth phase (2000 to 2009), a negative NDVI trend during the stabilizing stage (2010 to 2016), and again a positive NDVI trend during the steady growth phase (2017 to 2023), all with statistically significant results. Overall, the Mann-Kendal test performed for the NDVI trend from 2000 to 2023 revealed a significant upward trend. Their results show a similar outcome to this study, with areas of multiple policy implementations yielding positive NDVI trends.

A similar study implemented NDVI trend analysis on a river basin scale. Chen et al. (2021) examined the effects of long-term and large-scale ecology projects on the forest dynamics in the Yangtza River Basin in China. They looked at the NDVI trends during different periods: 1982 to 1999 and 2000 to 2015, and the overall trend from 1982 to 2015. They observed statistically significant NDVI trends in all periods.

The study also observed NDVI trends within different zones in the river basin: Type I – areas affected by ecology projects only and Type II – areas affected by both ecology and climate change projects. They found that NDVI trends within these areas have significantly higher slopes than the entirety of the study area. Their result also aligns with the results of this study, wherein areas with combinations of projects yield significant NDVI trends.

Meanwhile, the study of Zhao and Dai (2024) quantified trends in NDVI since the implementation of ecological restoration projects in the Qinghai-Tibet Plateau (QTP). They also explored the relationship between NDVI and ecosystem services. Their study revealed that since the implementation of these ecological restoration projects, around 21.80% of the area was found to have a statistically significant increase in NDVI. They also found an increase in the total ecosystem index after the implementation of these projects. This could also be a reference to further observe the effects of NGP and other forest restoration projects in the provision of ecosystem services in these ecosystems.

CONCLUSION AND RECOMMENDATION

Satellite data has proven to be useful in monitoring forest restoration in the critical watersheds in the country. The availability of cloud platforms, such as Google Earth Engine (GEE), facilitates analysis of changes in vegetation cover, since it has a large volume of data in their repository. Thru GEE, image processing of these large, time-series data becomes easier, and the need for large volumes of storage is eliminated.

With the presence of pre-processed Landsat imageries in the GEE cloud libraries, the need for pre-processing is eliminated. With this, the amount of time and effort spent on data processing is shortened and more time can be allotted in the processing of more data. This is crucial for this study since annual data is computed within at least 20 years. Also, since most of the data processing is done in the cloud, this removes the need for large volumes of data storage. The integration of the GEE platform with the Google Drive storage facilitates efficient data storage and organization. Since outputs from GEE cloud processing are also in GIS format, the management of data inputs and outputs is easier.

This study made use of GEE to detect changes in vegetation across three (3) critical watersheds. In terms of area coverage, the trends for the high vegetation coverage (NDVI > 0.8) for all the watersheds were observed to have statistically significant results, looking at the trends from the 90s to the present. This indicates that from the 1990s to the present, the forest cover also increased within the watersheds.

Results show that no significant changes occurred in areas with only NGP as the implemented reforestation intervention. Results also show that NGP implementations that overlap with existing policy implementations and reforestation programs yielded statistically significant trends. Changes in vegetation cover in these areas may be attributed to the preexisting program before the NGP. This result highlights the importance of ground monitoring and validation of the mortality of planting stock in these reforestation areas. Results from vegetation assessment within GEE may guide decision-makers in crafting policy interventions to make sure that the goals of these reforestation programs and other policy interventions are achieved.

Since the study only made use of 30-m spatial resolution imagery, the results of the data analysis can be further improved or supported by the collection of validation data on the ground. Looking at these areas on the ground level may give further insights as to how the program affected the vegetation cover.

The conduct of forest inventories on these sites may also provide a clearer picture on how the forests perform in terms of species diversity and survival. In this case, the collection of baseline data is important in measuring growth, in terms of incremental changes in tree heights and diameters. The survival of the different species used in the program may also be assessed to discern which species may be suitable for specific habitats. This may capture the changes in the vegetation cover that the satellite imagery failed to do.

Further studies are highly encouraged to observe if the current trend results in the NDVI will be consistent or will it change along with the modifications to the other external factors in play. It is also interesting to see if the non-significant trends within the current length of the post-2011 period would yield more desirable results. Wang et al. (2020) suggest that the time of the series should be lengthened to improve the power of the Mann-Kendall trend test in future studies. Also, with the rise of higher resolution satellite imagery, the data collection methodologies for further studies can also be improved. The Sentinel imageries, which have a spatial resolution of 10 meters, have been available since 2014. These datasets can provide finer inputs for data analysis, which can give more accurate and precise values. Since Sentinel-2 is also available in the GEE platform, the finer resolution would not give more problems in terms of data storage and analysis.

Further research in mapping and modelling biomass using earth observation satellites is also encouraged, Several applications have been explored in different reforestation endeavors, such as in mangrove restoration (Nesha et al., 2024), deciduous forests (Zuo et al., 2023), and temperate broadleaf forests (Picoli & Helsen, 2024) to name a few examples, The study of de Almeida et al. (2024) reviewed pathways for monitoring forest restoration and emphasized on recent developments in biomass and biodiversity estimations. They highlighted that to generate more accurate models, methodologies should be upscaled with field data and very high-resolution data.

A challenge in processing satellite data is the presence of cloud cover, which can be inevitable. To eliminate this problem, the use of unmanned aerial vehicles (UAVs) is also recommended. Since the flying height of these UAVs (around 120 meters) is significantly lower than those of the satellites in orbit (between 160 to 2,000 kilometers), the capture of clouds in the image mosaics can be avoided. Also, since UAVs do not share the temporal limitations of the satellites, shorter duration trends can be generated for monthly or quarterly progress. Although, this also means more data storage requirements and hardware and software processing.

Currently, UAVs can be armed with near-infrared (NIR) cameras which enable the computation of NDVI and other vegetation indices for specified areas that may require very high-resolution data. This may also be helpful in monitoring the progress of reforestation in the post planting or in the nursery setting (Raddi et al., 2022).

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Kyle Pierre R. Israel: Conceptualization, Methodology, Data Collection, Processing, & Analysis, Writing – Original Draft, Writing – Review & Editing, Visualization.

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