# Assessment of Factors of Mangrove Extent Growth in Eastern Leyte, Philippines

**[1,2]Cabral, Sarah Jane L., [3]Victoriano, Jayson M.**

**[1]College of Engineering, Eastern Visayas State University, Tacloban City, Leyte 6500, Philippines**

**[2] DIT Candidate, La Consolacion University Philippines, Malolos, Bulacan 3000 Philippines**

**[3]College of Information and Communications Technology, Bulacan State University, Malolos, Bulacan 3000, Philippines**

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**Abstract:** Recent satellite imagery analysis in the Eastern Leyte province indicates significant growth in mangrove forests following the destruction of approximately 86% of these forests during Typhoon Yolanda (Haiyan) in 2013. However, there are no studies that explore the process of mangrove expansion in the region and the factors influencing its growth. This study aims to investigate and analyze the climatological and anthropogenic factors contributing to the expansion of mangrove forests in the area. Using the mangrove index derived from Sentinel-2A satellite imagery, a percentile-based threshold segmentation was applied to classify and identify mangrove extent. Annual mangrove area data from 2017 to 2023 were calculated and correlated with climatological variables and anthropogenic factors. The result of the analysis shows a strong positive correlation between mangrove coverage and sea level with a variance of $r2=0.90$ and $\alpha<0.001$ which is statistically significant. The relationship of the population to the mangrove coverage shows the model has a variance of $r2=0.64$ and $\alpha=0.030$. In contrast, the rainfall shows a very weak and has no significant relationship with the mangrove coverage with a variance of $r2= 0.022$ and $\alpha=0.05$. The findings reveal the significant role of sea level and population in the mangrove expansion. This study provides significant insights into accurate rehabilitation plans and strategies for mangrove preservation and conservation in the province.

**Keywords:** Mangrove, Remote Sensing, Mangrove Index, Linear Regression, Correlation Analysis

## I. Introduction

Mangrove ecosystems, much like other forested environments, are invaluable natural resources that offer a wide range of ecological, environmental, and socio-economic benefits. They are recognized as some of the most biologically diverse and ecologically significant ecosystems globally. Typically found in tropical and subtropical regions, mangrove forests thrive along sheltered coastlines, estuaries, and river deltas where freshwater and saltwater converge. These ecosystems play a critical role in coastal protection, serving as natural buffers that mitigate the destructive impacts of storms, hurricanes, and floods. Their dense root systems reduce storm surge height and water flow velocity, thereby minimizing damage to coastal communities [1], while simultaneously anchoring sediments to prevent shoreline erosion [2].

In addition to their protective functions, mangrove forests contribute significantly to fisheries production by providing vital breeding grounds and habitats for various aquatic species, and nesting areas for birds [3]. They also function as important carbon sinks, sequestering atmospheric carbon and aiding in water purification [4]. Beyond their ecological functions, mangroves sustain the livelihoods of many coastal communities by supplying resources such as food, fuelwood, and timber, and supporting income-generating activities including aquaculture and apiculture [5]. As such, mangroves harbor immense ecological and socio-economic value.

Despite these benefits, mangrove ecosystems have faced substantial degradation, largely due to natural and anthropogenic pressures. The Philippines, located in the Pacific typhoon belt, experiences an average of 20 tropical cyclones annually, with approximately 8 to 9 making landfall [6]. Among the most catastrophic was Typhoon Yolanda (Haiyan) in 2013, which caused severe destruction to mangrove forests in Eastern Visayas, with an estimated damage of at least 86% [7]. Such extreme weather events highlight the vulnerability of these ecosystems.

Moreover, climate-related variables—including sea level rise, temperature fluctuations, and changing precipitation patterns—have been shown to influence mangrove species composition, salinity tolerance, survival, and productivity [8]. Typhoon frequency and prevailing management practices further affect mangrove dynamics [9]. Additionally, human-driven factors such as coastal development, agricultural expansion, and aquaculture, often linked to population growth, have led to widespread mangrove deforestation [10]. Consequently, multiple studies have emphasized the importance of accounting for both climatic and anthropogenic influences when analyzing mangrove extent and distribution [11][12][13].

The extensive damage caused by Typhoon Yolanda and ongoing environmental pressures underscores the urgent need for targeted conservation and restoration strategies. Interestingly, recent satellite imagery reveals a positive trend of mangrove recovery and expansion in Eastern Leyte [14]. However, limited research has been conducted to investigate the specific factors contributing to this regeneration. Understanding the response mechanisms of mangrove ecosystems to both natural processes and human

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interventions is therefore essential—not only for advancing scientific knowledge but also for guiding effective, context-sensitive conservation and management efforts.

Analyzing the distribution of mangrove extent is essential for assessing and evaluating these ecosystems. To effectively conserve and manage mangroves, it is important to employ tools and methods that can monitor spatiotemporal changes resulting from natural disasters and human activities [15]. Remote sensing (RS) is a popular tool for mapping mangrove extents. It offers a more inexpensive alternative than on-the-ground techniques. Satellite imagery from sources like Sentinel and Landsat is readily available and free. Additionally, images from past years are stored, making it easy for researchers to analyze and monitor significant changes in the distribution and covering of mangrove forests over time. Researchers have created indices to separate mangroves from other land cover types [16]. In mapping vegetation, spectral indices known as vegetation indices are commonly used. These indices enhance the visibility of certain plant characteristics, particularly those related to leaf greenness and overall health, which are key indicators of plant vigor. Each vegetation index has a unique formula tailored to highlight specific vegetation traits, often providing a more accurate representation of vegetation properties than would be possible using individual spectral bands alone [17]. These indices have their advantage and disadvantages and can be influenced by the type of soil, sensor and calibration issues, light reflectance, and atmospheric or terrain conditions, as well as other local environmental factors [18]. Other researchers used Machine Learning (ML) algorithms such as Random Forest to classify mangrove pixels however these algorithms can be computationally expensive and the slight improvement in extraction may not be worth the considerable extra effort required [19].

The focus of this study is to explore and identify the factors driving the recovery and growth of mangrove forests in Eastern Visayas, particularly in the eastern part of Leyte province. It utilized multispectral satellite data from Sentinel-2A, using historical imagery from 2017 to 2023. A mangrove index (MI) with percentile-based threshold segmentation was employed to separate mangroves from other land cover types. Additionally, the research will investigate the relationship between climate variables, human activities, restoration initiatives, and the dynamics of mangrove forests utilizing correlation analysis. With this, the study seeks to understand the complex factors influencing this recovery by asking: What are the relationships between climate variables and human-induced activities, and the recovery and growth of mangrove forests in Eastern Leyte from 2017 to 2023, based on Sentinel 2A satellite imagery? Addressing this question is vital for informing future mangrove restoration programs and ensuring the sustainable management of coastal resources in disaster-prone regions.

The findings from this research will enhance our understanding of the drivers behind mangrove forest recovery and offer valuable lessons for the government and conservationists aiming to replicate such success in other regions. Ultimately, this study aspires to contribute to the broader goal of preserving and enhancing these vital ecosystems in the face of ongoing environmental challenges.

**Study Area**

Eastern Visayas, a region in the Philippines, is composed of six provinces: Leyte, Southern Leyte, Biliran, Samar, Northern Samar, and Eastern Samar. This region, situated in the central part of the country, faces the Pacific Ocean, making it particularly susceptible to typhoons. The geographical location of Eastern Visayas places it directly in the path of many tropical cyclones that form over the Pacific, (Figure 1) leading to frequent and often devastating impacts.

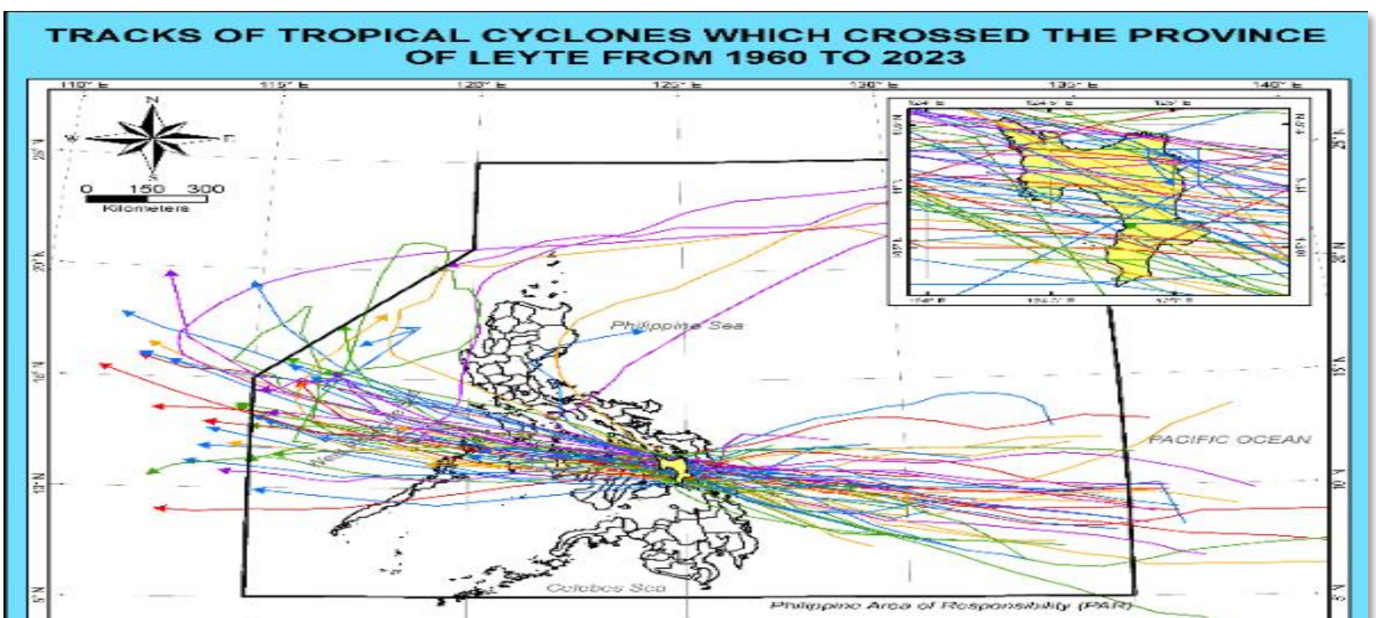


Figure 1. The Tracks of Tropical Cyclones which crossed the province of Leyte from 1960 – 2023

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Figure 2. The Study Area – Tacloban City, Municipality of Palo and Tanauan, East of Leyte Province

The study area (Figure 2) is situated in Leyte province, Eastern Visayas, Philippines, covering the municipalities of Tacloban City, Palo, and Tanauan. Bordered by Alangalang, Dulag, Tolosa, and the Leyte Gulf, this area spans approximately 2,367 square kilometers. The coordinates for the key locations within the study area are Tacloban City (11°7'N, 124°59'E), Palo (11°4'N, 124°56'E), and Tanauan (11°0'N, 124°55'E). The region features diverse topography, ranging from sea level to around 1,000 meters above sea level, with mountainous areas, coastal plains, and river valleys. A tropical monsoon climate, characterized by distinct wet and dry seasons, influences the local environment and vegetation patterns.

Significant features include the Leyte Gulf, which borders the eastern side of the area, and the San Juanico Strait to the north, which connects the Leyte Gulf to the Philippine Sea. The Leyte National Park, located in the northern part of the region, adds ecological value to the area by supporting conservation efforts and protecting biodiversity. These geographic and environmental characteristics make this region well-suited for studying mangrove dynamics, as it demonstrates the interaction between terrestrial and marine ecosystems, influenced by both climate and topography.

**Data and Method**

The data collection for this study is conducted in two phases. The first phase involves obtaining satellite imagery from the Sentinel-2 satellite, spanning the years 2017 to 2023. These multispectral images were acquired from the Copernicus Data Space (https://dataspace.copernicus.eu/) and the USGS website. Additionally, Land Use/Land Cover (LULC) data from the ESRI platform was collected to serve as validation data, providing a basis for comparison in the mangrove mapping process.

The second dataset consists of climate-related and human-induced factors. Climatological data were sourced from the Climate and Agrometeorological Data Section (CADS) of the Department of Science and Technology's Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA). This data includes annual rainfall, relative humidity, the number of typhoons per year, maximum and minimum temperatures, and sea level information. Population data was obtained from the Philippine Statistics Authority (PSA). Interventions and development programs for mangrove recovery are sourced from the Department of Environment and Natural Resources (DENR). These datasets are considered for assessing changes in mangrove coverage and understanding the factors driving its growth and recovery in the region, using linear regression and correlation analysis.

**Satellite Data**

The Sentinel-2A MSI provides high-resolution optical imagery in 13 spectral bands, ranging from the visible and near-infrared to the short-wave infrared parts of the electromagnetic spectrum [20]. The selected bands included visible near-infrared (NIR) at 0.842 µm, shortwave infrared (SWIR) at 1.161 µm, and Green at 0.560 µm, which are effective in distinguishing mangrove vegetation from other land cover types [21]. Spectral bands refer to specific ranges of wavelengths in the electromagnetic spectrum that are measured by a sensor such as a satellite or airborne instruments [20]. Each spectral band captures information about the reflectance or emission properties of the Earth's surface within that specific wavelength range [22]. These bands are essential for various applications, including monitoring vegetation, soil, water bodies, and coastal areas (Table 1). The image data has undergone pre-processing that includes atmospheric correction and cloud masking.

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Table 1. Spectral Bands for the Sentinel-2A Sensors

| Band Number | Central Wavelength (nm) | Bandwidth (nm) | Spatial Resolution (m) |
|---|---|---|---|
| 1 (Coastal Aerosol) | 442.7 | 20 | 60 |
| 2 (Blue) | 492.7 | 65 | 10 |
| 3 (Green) | 559.8 | 35 | 10 |
| 4 (Red) | 664.6 | 30 | 10 |
| 5 (Red Edge 1) | 704.1 | 14 | 20 |
| 6 (Red Edge 2) | 740.5 | 14 | 20 |
| 7 (Red Edge 3) | 782.8 | 19 | 20 |
| 8 (NIR) | 832.8 | 105 | 10 |
| 8a (Narrow NIR) | 864.7 | 21 | 20 |
| 9 (Water vapor) | 945.1 | 19 | 60 |
| 10 (SWIR – Cirrus) | 1373.5 | 29 | 60 |
| 11 (SWIR1) | 1613.7 | 90 | 20 |
| 12 (SWIR2) | 2202.4 | 174 | 20 |

Table 1 presents the spectral bands of the Sentinel-2A sensor, detailing the band numbers (1 to 13) along with their respective wavelengths, bandwidths, and spatial resolutions. Spectral bands were analyzed to formulate the mangrove index.

The Land Use/Land Cover (LULC) data was sourced from the Environmental Systems Research Institute (ESRI) platform provides a comprehensive dataset for geographic information system (GIS) analysis. This dataset is images from 2017 to 2023 which contains detailed classifications of land cover types such as forests, agricultural zones, urban areas, and water bodies. The ESRI imagery serves as the validation data and comparison for assessing the below and above 75% threshold of the Mangrove index (MI) values.

**Climatological and Anthropogenic Data**

The selection of factors and description for assessing climate-related and human-induced factors was guided by published studies on climate change and its effects on mangrove forests. This process also considered the availability of local and remotely-sensed data.

Table 2. Climate and Human-Induced Factors with Description

| Factors | Description | Period |
|---|---|---|
| Rainfall (mm) | Mean Annual Rainfall | 2017-2023 |
| Temperature ($^{o}$C) | Max Annual Temperature | 2017-2023 |
| | Min Annual Temperature | |
| Relative Humidity (%) | Mean Annual RH | 2017-2023 |
| Typhoon | Total Typhoon Count | 2017-2023 |
| Sea Level (cm) | Mean Annual SL | 2017-2023 |
| LULC | Land Use/land cover | 2017-2023 |
| Population | Annual Population | 2015, 2020 |
| Mangrove Recovery & Development Program | Recovery & Development Program Implemented by Nat’l Gov’t/Agency (DENR/LGU etc.) | 2015-2023 |

Table 2 provides an overview of the climate and human-induced factors used in this study, along with their descriptions and corresponding periods of data collection. The table includes key environmental variables such as mean annual rainfall, maximum and minimum annual temperature, relative humidity, sea level, and total typhoon count, all recorded from 2017 to 2023. Additionally, land use/land cover (LULC) data, population estimates (for 2015 and 2020), and information on mangrove recovery

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efforts under the National Greening Program (NGP) from 2015 to 2023 are included. These factors are analyzed to assess their influence on mangrove extent and dynamics over time.

Table 3. Data and its source

| Data | Source |
|---|---|
| Rainfall | Philippine Atmospheric, Geophysical and Astronomical Services Administration - Climate and Agrometeorological Data Section Division (PAGASA-CADS) |
| Temperature | |
| Relative Humidity | |
| Typhoon | |
| Sea Level | National Mapping and Resource Information Authority Client Service Unit - Hydrography Branch (NAMRIA-CSU-HB) |
| Population | Philippine Statistics Agency (PSA) |
| Satellite Images | https://dataspace.copernicus.eu |
| Land Cover/land use | https://livingatlas.arcgis.com/landcoverexplorer/ |

Table 3 shows the sources of data used in this study. Climate-related information, such as rainfall, temperature, relative humidity, and typhoon occurrences, was obtained from PAGASA. Sea level data was gathered from NAMRIA, while population statistics came from the Philippine Statistics Agency (PSA). To analyze land cover and mangrove extent, satellite images were sourced from Copernicus Data Space, and land use data was accessed through the Living Atlas platform. These datasets play a crucial role in understanding the environmental and human factors influencing mangrove ecosystems.

The collated climate and human-induced data undergo cleaning processes, where missing values are handled through techniques like imputation or deletion, outliers are detected and addressed, and consistency checks are performed to ensure uniformity across variables and datasets.

**Summary of Collated Data**

The selected climate and human-influenced factors include rainfall, typhoon frequency, annual sea level, maximum and minimum temperatures, relative humidity, population, and interventions by local government units (LGUs) and government agencies. Each of these factors affects mangrove extent in distinct ways. Through analysis, the relationships and individual impacts of these factors were examined to better understand how they contribute to changes in mangrove ecosystems. Linear regression analysis was used to analyze the correlation between mangrove extent and various climate and human-induced variables.

Table 4. Summary of Climatological Data

| YEAR | Annual Rainfall (mm) | Annual Sea Level (cm) | TEMP MAX | TEMP MIN | Relative Humidity (%) | No. of Typhoons |
|---|---|---|---|---|---|---|
| 2017 | 10.62 | 138.9 | 30.9 | 24.6 | 87 | 0 |
| 2018 | 10.62 | 154.2 | 31.3 | 24.6 | 86 | 1 |
| 2019 | 4.34 | 159.0 | 31.5 | 24.8 | 82 | 1 |
| 2020 | 7.47 | 160.0 | 31.2 | 25.3 | 85 | 0 |
| 2021 | 10.19 | 175.2 | 31.2 | 25.2 | 86 | 0 |
| 2022 | 9.17 | 184.9 | 31.2 | 25.1 | 86 | 1 |
| 2023 | 8.53 | 180.5 | 31.2 | 25.2 | 86 | 0 |

Table 4 presents a summary of climatological data from 2017 to 2023, The data shows variations in rainfall and sea level over time, with fluctuations in temperature and humidity. The number of typhoons also varies, with some years experiencing no recorded typhoons, while others had one. This dataset provides valuable insights into climate patterns that may influence mangrove growth and environmental conditions in the study area.

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Table 5. The Population of the Study Area (2015 and 2020)

| Study Area | 2020 | 2015 |
|---|---|---|
| Tacloban City | 251,881 | 242,089 |
| Palo | 76,213 | 70,052 |
| Tanauan | 57,455 | 55,021 |
| Total | 385,549 | 367,162 |

Table 5 presents the population of the study area, specifically Tacloban City, Palo, and Tanauan, for the years 2015 and 2020. The data shows an increase in population across all three locations, with Tacloban City having the highest population growth. The total population of the study area increased from 367,162 in 2015 to 385,549 in 2020. This growth may have implications for environmental changes, urban expansion, and resource management in the region.

Table 6. LGU and NGOs Mangrove Restoration Projects from the Year 2017 – 2023

| Year | Conduct Intervention/Restoration Programs? |
|---|---|
| 2017 | Yes (1) |
| 2018 | Yes (1) |
| 2019 | Yes (1) |
| 2020 | No (0) – due to COVID-19 lockdown & restrictions |
| 2021 | No (0) – due to COVID-19 lockdown & restrictions |
| 2022 | Yes (1) |
| 2023 | Yes (1) |

Table 6 summarizes the interventions and restoration programs conducted by the government, LGUs, and NGOs for mangrove restoration from 2017 to 2023. The data indicates that restoration activities were consistently carried out in most years, except for 2020 and 2021, when interventions were halted due to COVID-19 lockdowns and restrictions. This temporary pause highlights the impact of the pandemic on environmental restoration efforts. However, restoration activities resumed in 2022 and 2023, suggesting a return to conservation initiatives.

**Mangrove Index (MI)**

The Sentinel-2A spectral bands that were utilized in this study are: NIR, SWIR1, and Green wavelengths. The formula used is: (1)

where $R_{865}$, $R_{560}$, and $R_{1610}$ are the narrow near-infrared, green, and shortwave infrared 1. Based on a study [23] on mangrove vegetation properties and their spectral responses, the SWIR and NIR bands were found to be effective in characterizing water absorption in vegetation and vegetation greenness, respectively.

$$MI = \frac{R_{865} - R_{560}}{R_{1610} + R_{560}}$$

**Threshold Filtering of Mangrove Raster**

To refine the classification of mangrove areas, a percentage-based threshold filtering approach was applied to the derived Mangrove Index (MI) raster. This method ensures that only pixels with high confidence of mangrove presence are retained, reducing misclassification with other vegetation types or land cover features.

The threshold was determined based on the statistical distribution of MI values, meaning that only pixels with values in the range of upper 25% of the distribution were evaluated and then classified as mangrove-covered areas [14]. Pixels with values below this threshold were filtered out to minimize false positives, ensuring a more accurate delineation of mangrove extent. This filtering process enhances the reliability of the classification by emphasizing areas with strong spectral characteristics associated with mangrove vegetation.

After applying the threshold, the filtered raster was converted into a binary classification map, where pixels meeting the threshold were assigned as mangrove (1), while the rest were classified as non-mangrove (0). This final output provides a refined and reliable representation of mangrove distribution, suitable for further spatial analysis, ecological assessments, and conservation planning.

**Mangrove Area Mapping and Area Calculation**

The generation of Mangrove Index (MI) layers and utilizing the percentile-based threshold segmentation technique are important in identifying and mapping mangrove forests using satellite imagery. The MI spectral index derived from multispectral data from Sentinel-2A highlights the unique spectral characteristics of mangroves. Once the MI layer is generated, the next step is threshold

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selection. In this study, a specific threshold is applied to segment mangrove areas from other land cover types. Pixels with MI values within this threshold are classified as mangroves, while other features are classified as water, non-mangrove vegetation, or urban areas. To ensure the chosen threshold accurately reflects mangrove extents, it is validated by comparing the results with known datasets, such as Land Use/Land Cover (LULC) maps from ESRI website, and analyzed based on ground truth data. Field surveys were conducted to validate the accuracy of the classification.

The generation of the MI layer, the selection of threshold, extraction of the raster data, mapping, area computation and analyzing mangrove geographic information were all carried out using ArcGIS. ArcGIS is a comprehensive geographic information system (GIS) software developed by Esri that allows users to create, analyze, and manage spatial data.

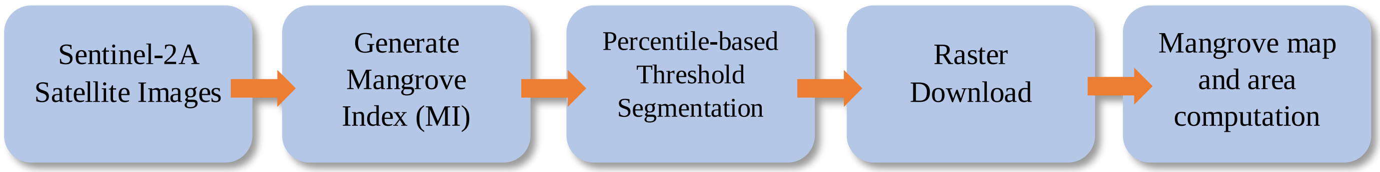


Figure 3. The workflow of generating mangrove maps and area computation

**Simple Linear Regression**

The research employed linear regression to identify the relationship of the variables against the change in mangrove cover. Linear regression, a fundamental statistical and machine learning technique is used to establish a mathematical model that describes the connection between a dependent variable and one or more independent variables [24]. It is concerned with finding an equation that uses the known values of one or more variables, called the independent or predictor variables, to estimate the unknown value of a quantitative variable called the dependent or criterion. The objective of this study is to make predictions about the dependent variable based on the values of the independent variables and to understand the relationship between the dependent variable and each of the independent variables, such as identifying which variables are significant predictors of the outcome and understanding the nature of their impact, in this case, the mangrove cover change.

The Linear regression is shown in Equation 2:

$$y = \beta_0 + \beta_1 X \qquad (2)$$

Where: $\beta_0$ represents intercept, $\beta_1$ denotes the coefficient of regression, $X$ refers to the independent variable, and y denotes the dependent variable.

**Correlation Analysis**

This study utilized Correlation Analysis to measure the relationship between two variables, in this case, the dependent and the independent variables [25]. In correlating these variables, it can be either a positive correlation, a negative correlation, or no correlation.

Pearson's Correlation coefficient method is quantitative and offers numerical value to establish the intensity of the linear relationship between two variables. It is the most potent and extensively used method to measure the level of correlation. This is used to correlate the annual mangrove forest area and the human-induced and climate factors. The equation 3 is used: (3)

where r is the correlation coefficient, $x_i$ is the values of the x-variable, $x$ is the mean of the values of x-variable and, $y_i$ is the mean of the y variable, $y$ is the mean of the values of y-variable.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

**The Mangrove Extent per Year in Eastern Leyte**

The calculation of the mangrove area was performed using Geographic Information System (GIS) software, specifically Zonal Tool in ArcGIS. The use of Mangrove Index was useful in classifying mangrove and non-mangrove area.

Table 4. Mangrove Area from 2017 to 2023

| Year | Mangrove Area (ha) |
|---|---|
| 2017 | 183.95 |
| 2018 | 321.38 |
| 2019 | 381.97 |
| 2020 | 417.16 |

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| | |
|---|---|
| 2021 | 491.32 |
| 2022 | 544.18 |
| 2023 | 656.63 |

Table 4 shows the mangrove area in hectares per year. The satellite data shows a remarkable recovery and expansion of mangrove coverage in Eastern Leyte, following the destruction caused by Typhoon Haiyan in 2013. It is observed that the mangrove area increased by approximately 256.96% from 2017 to 2023, growing from 183.949 ha to 656.32 ha.

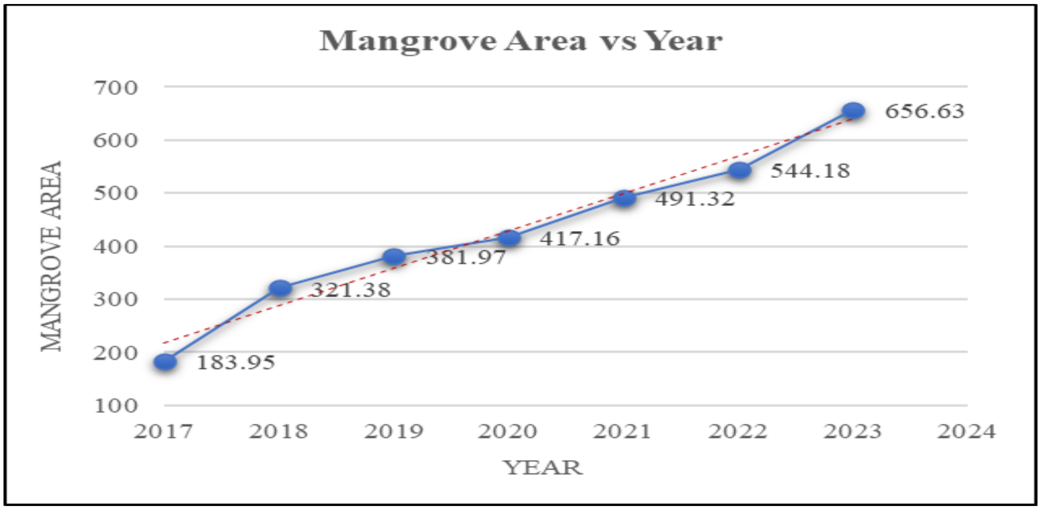


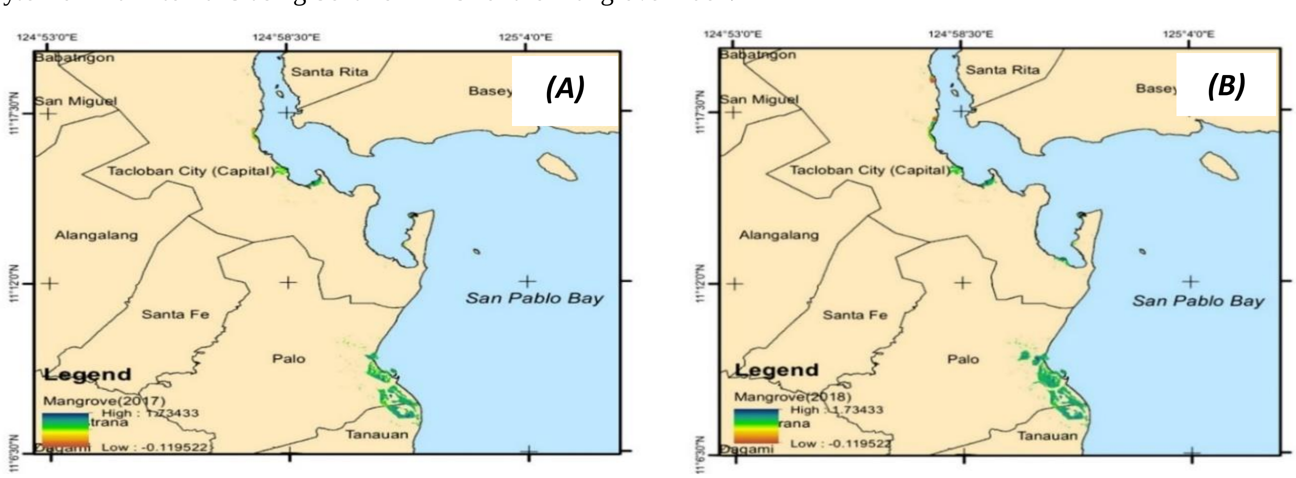

Figure 4. The Trend of Mangrove Area Per Year

The graph in Figure 4 illustrates the expansion of mangrove areas from 2017 to 2023, showing a general upward trend in coverage. In 2017, the mangrove area was recorded at 183.95 hectares. A significant increase of 74.71% occurred between 2017 and 2018, reaching 321.38 hectares. This rapid growth suggests that early post-disturbance factors, such as natural regeneration and possibly improved environmental conditions, may have played a role. However, from 2018 to 2019, the growth rate slowed to 18.85%, bringing the total area to 381.97 hectares.

In the following years, mangrove expansion continued at a more moderate pace, with a 9.21% increase from 2019 to 2020 (417.16 hectares) and a slightly higher 17.78% growth from 2020 to 2021 (491.32 hectares). From 2021 to 2022, the growth rate was 10.76%, reaching 544.18 hectares. From 2022 to 2023, the mangrove area saw a notable increase of 20.66%, reaching 656.63 hectares. This recent acceleration could indicate favorable ecological conditions, reduced disturbances, or the natural ability of mangroves to regenerate over time. While restoration efforts may have contributed, the variability in growth rates suggests that other factors, such as the resilience of pre-existing mangrove stands, hydrodynamic processes, and climate conditions, likely influenced the observed patterns. This aligns with the study [7] emphasized that mangrove recovery after Typhoon Yolanda is not just about external restoration efforts, it is likely influenced by the pre-disturbance extent and ecological condition of the forest.

**Mangrove Mapping**

Figure 5 illustrates the changes in mangrove coverage in the study area. the Municipalities of Palo and Tanauan, and Tacloban City, Leyte from 2017 to 2023 using Sentinel-2 MSI of the Mangrove Index.



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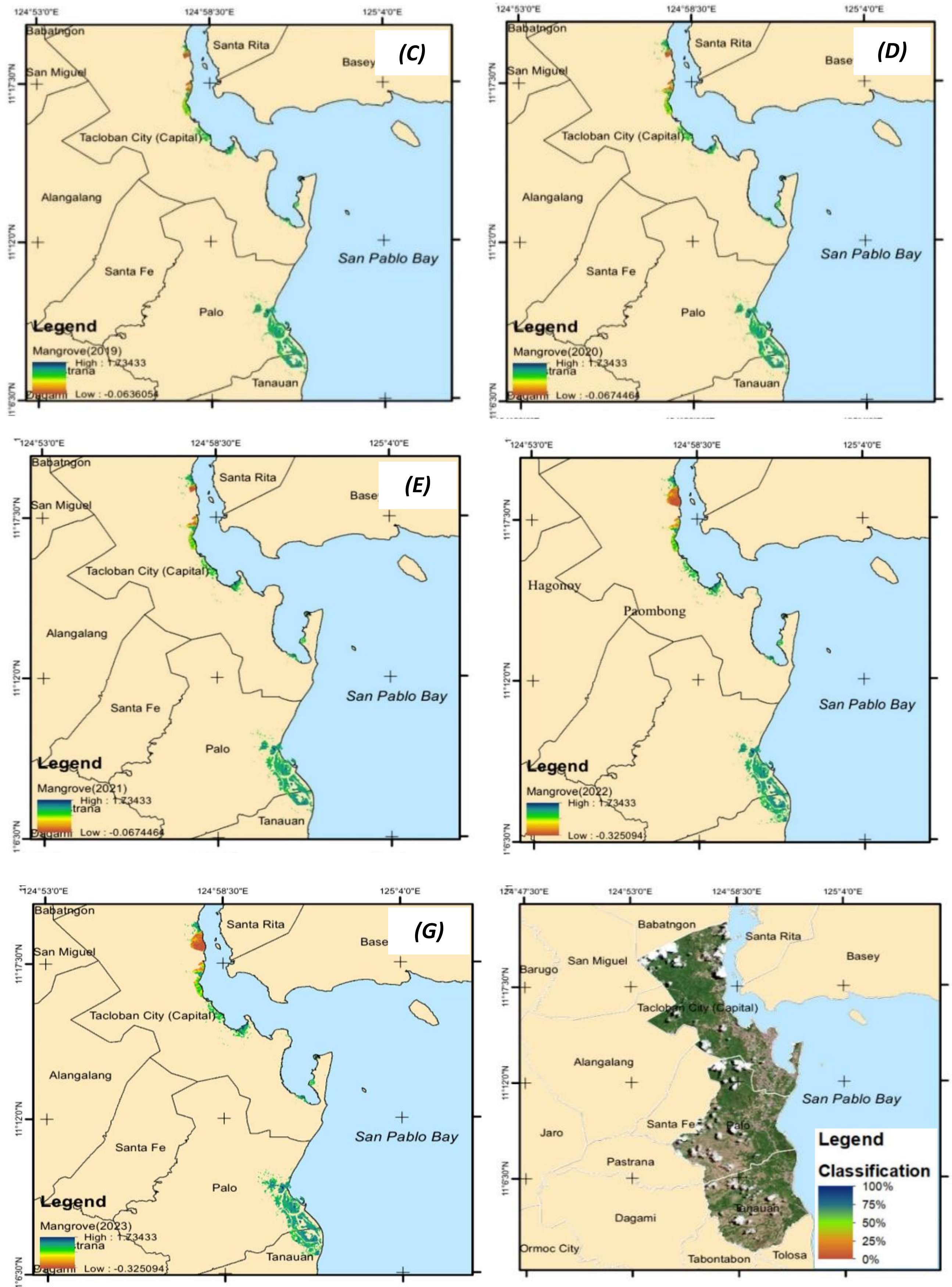


Figure 5. The Change of Mangrove Extent per Year from (a) 2017 (b) 2018 (c) 2019 (d) 2020 (e) 2021 (f) 2022 (g) 2023 and (h) the RGB Satellite Image Year 2024

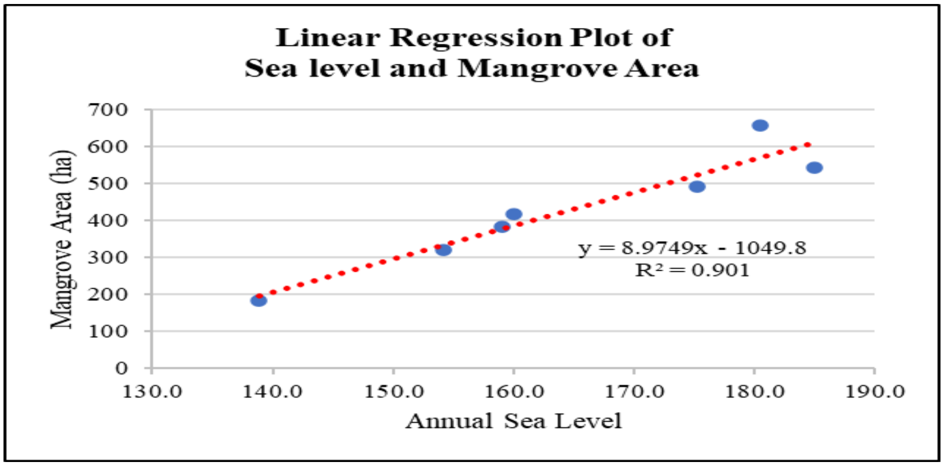


Figure 6. The Linear Regression Plot of Sea Level on Mangrove Extent

The linear regression plot in Figure 6 shows a strong positive relationship between annual sea level and mangrove area. The upward trend suggests that mangrove cover tends to increase as sea level rises, which contrasts with some studies that associate sea level rise with mangrove degradation. The $R^2$ value of 0.901 indicates a strong statistical association, meaning that approximately 90% of the variation in mangrove area is correlated with sea level changes over the study period. However, it is important to note that this analysis does not confirm causation; other environmental or anthropogenic factors may also be influencing this trend.

A study conducted in Shenzhen, China [26] found a significant positive relation between sea level rise and mangrove area expansion. This supports the findings of this study, where an increase in sea level was also observed to coincide with mangrove growth in Eastern Leyte. This correlation suggests that mangroves may be responding adaptively to gradual sea level changes, possibly through landward migration or enhanced sediment accretion.

This observation aligns with a study [27], which highlighted the inherent ability of mangrove ecosystems to cope with rising sea levels by accumulating sediment and organic material, thereby facilitating vertical growth. According to their research, gradual sea-level rise prompts mangroves to respond through natural processes such as sediment deposition and peat formation, effectively enabling the expansion and persistence of these forests. The strong correlation found in this study reinforces the notion of such adaptive mechanisms at work, indicating that the mangroves in the study area may be undergoing similar responses to changing sea levels.

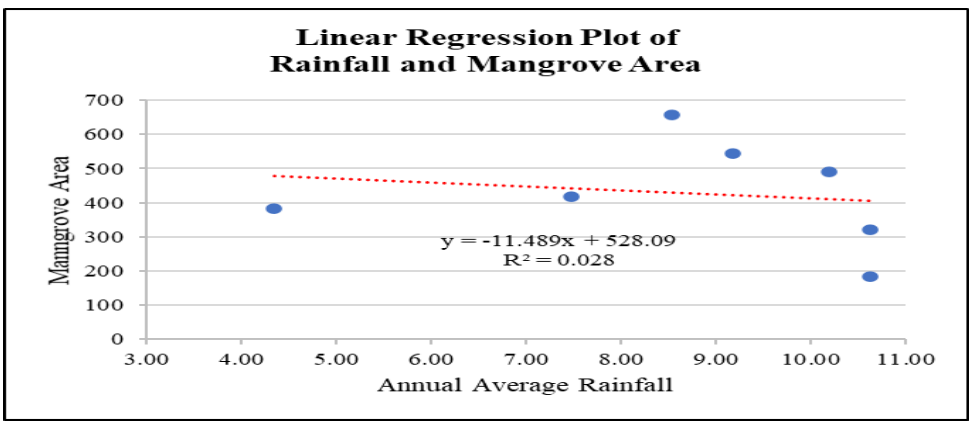


Figure 7. The Linear Regression Plot of Rainfall on Mangrove Extent

The plot in Figure 7 shows a very weak negative linear relationship between average annual rainfall and mangrove area. The regression equation $y = -11.489x + 528.09$ indicates a slight inverse trend, suggesting that as rainfall increases, mangrove area tends to decrease marginally. However, the $R^2$ value of 0.028 indicates that only 2.8% of the variation in mangrove area is explained by changes in annual average rainfall. The remaining 97.2% of the variation is attributed to other factors, highlighting the lack of a strong relationship between these variables. The dispersed distribution of data points further supports this weak correlation. These results are consistent with the findings of [26], who also reported that rainfall had little to no direct influence on mangrove area changes.

This aligns with the view that mangroves are naturally resilient to changes in rainfall since they have adapted to fluctuating water levels and salinity over time. While more rainfall can lower soil salinity and benefit some mangrove species [27], it doesn't seem to have a major impact on their overall growth. Other factors, like tidal patterns, nutrient availability, and sediment buildup, likely play a bigger role in shaping mangrove extent. So, while rainfall might have some influence, it is not a key factor driving the expansion or reduction of mangroves in the area.

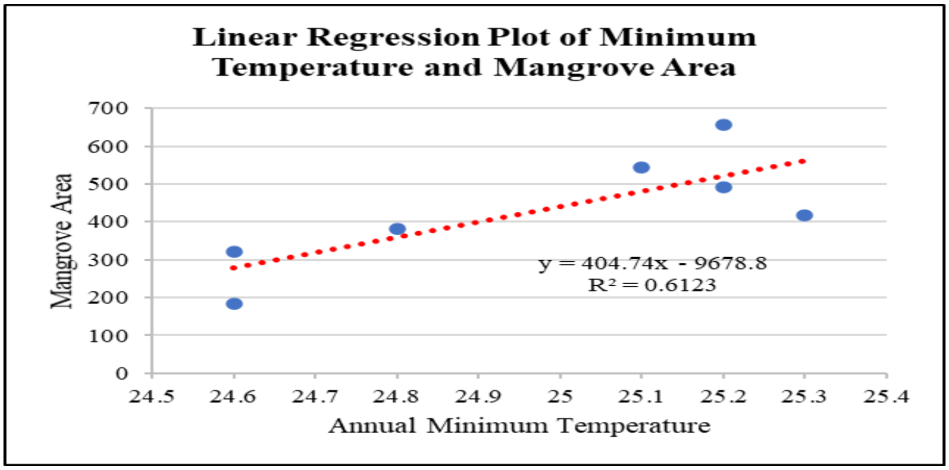


Figure 8. The Linear Regression Plot of Minimum Temperature on Mangrove Extent

Figure 8 shows a positive linear relationship between minimum temperature and mangrove area. As the minimum temperature increases, the mangrove area also tends to increase. The linear regression equation $y = 404.74x - 9678.8$ is associated with an $R^2$ value of 0.6123, indicating that approximately 61.2% of the variation in mangrove area can be statistically associated with changes in minimum temperature. This suggests a moderately strong association between these variables, though additional factors may also contribute to the observed trend.

The positive relationship between mangrove extent and minimum temperature suggests that rising temperatures contribute to mangrove expansion and resilience. Warmer minimum temperatures reduce cold-induced stress, promoting higher survival rates, particularly in seedlings, and enabling mangroves to extend into previously cooler regions. These findings are consistent with recent studies, which suggests that increasing minimum or winter temperatures facilitate the poleward migration of mangroves by reducing cold-induced mortality and enhancing survivability in previously unsuitable regions. Such thermal changes contribute not only to shifts in mangrove distribution but also to broader transformations in coastal ecosystems, as mangroves gradually replace or compete with other coastal vegetation types [28]. The findings imply that climate change may continue to drive mangrove expansion, influencing biodiversity, carbon sequestration, and coastal protection. However, while warming temperatures may benefit mangroves in certain regions, other climatic factors, such as extreme weather events, must also be considered in assessing their long-term sustainability.

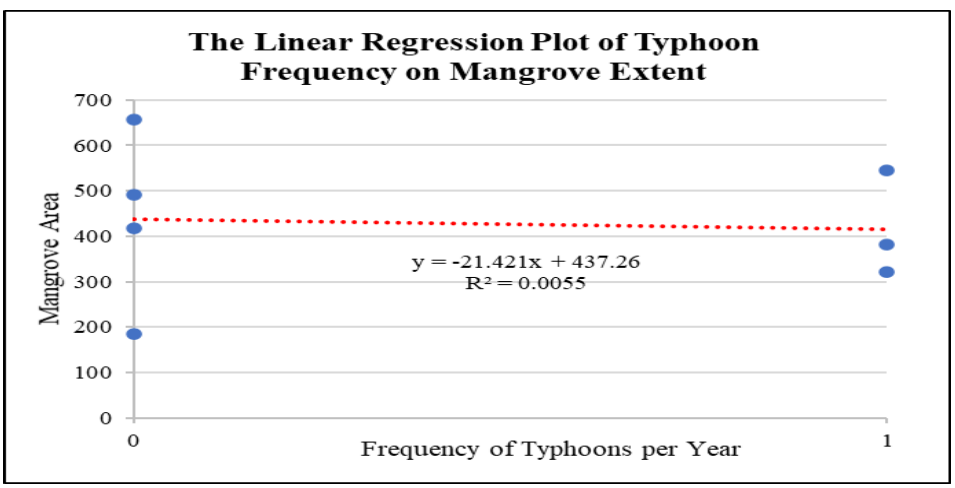


**Figure 9. The Linear Regression Plot of Typhoon Frequency on Mangrove Extent**

The trendline in Figure 9 shows a very shallow negative slope, described by the equation $y = -21.421x + 437.26$, with an $R^2$ value of 0.0055. This extremely low $R^2$ indicates that typhoon frequency accounts for less than 1% of the variation in mangrove area, suggesting a negligible statistical association. In this study, no clear correlation is observed between the number of typhoons and mangrove extent from 2017 to 2023. This may imply that mangrove forests in the region are resilient to typhoon disturbances, or that annual variations in typhoon frequency alone are not a strong driver of changes in mangrove cover during the observed period.

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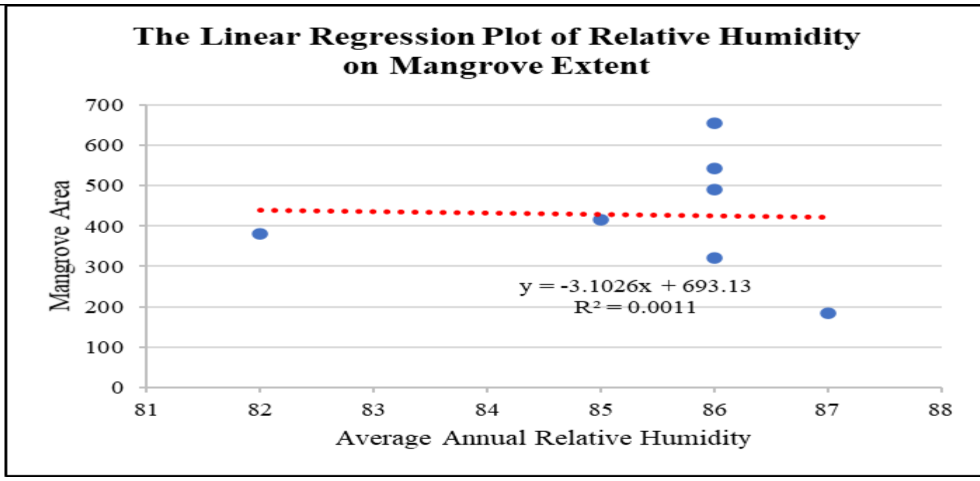


Figure 10. The Linear Regression Plot of Relative Humidity on Mangrove Extent

The graph in Figure 10 illustrates the relationship between relative humidity and mangrove area. The trendline shows a slight negative slope, with the regression equation $y = -3.1026x + 693.13$ and an $R^2$ value of 0.0011. This extremely low $R^2$ indicates that relative humidity explains virtually none of the variation in mangrove area, suggesting no meaningful statistical association between these two variables in the dataset. While relative humidity plays a role in mangrove physiology—such as transpiration, seedling survival, and buffering against cold stress, as noted in [29]—it appears to be a secondary factor compared to more influential variables like sea level and temperature. The findings suggest that mangrove ecosystems in the study area are already well-adapted to high-humidity conditions, making minor fluctuations in humidity less impactful on their spatial extent.

**The Influence of Human-Induced Factors on Mangrove Extent using Simple Linear Regression**

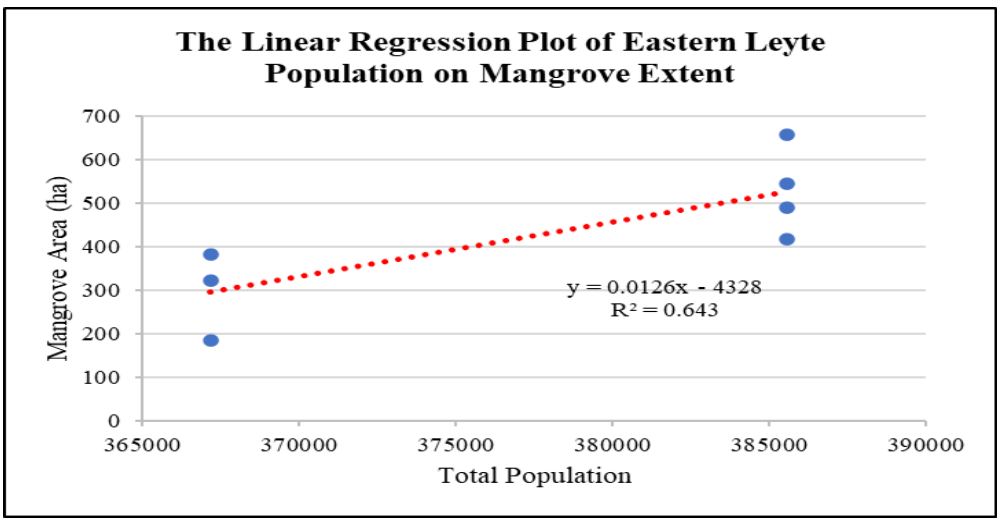


Figure 11. The Linear Regression Plot of Eastern Leyte Population on Mangrove Extent

Figure 11 illustrates the relationship between population size and mangrove area. The trendline shows a positive linear association, represented by the equation $y = 0.0126x - 4328$, with an $R^2$ value of 0.643. This indicates that approximately 64.3% of the variation in mangrove area can be statistically associated with changes in population size. While the correlation appears fairly strong, it does not necessarily imply a direct causal relationship. The observed trend may reflect the influence of population-driven factors such as increased environmental awareness, community-based mangrove rehabilitation, or government-led restoration programs that often accompany population growth in coastal areas. Further analysis would be needed to determine the specific mechanisms linking these trends.

The result of this study presents a notable deviation from traditional narratives about human-driven mangrove destruction, instead suggesting that population growth may be linked to mangrove expansion. With an $R^2$ of 0.643, the model indicates that population size explains a significant portion of mangrove area variation in the study area. This could be due to effective conservation policies, sustainable community practices, or natural expansion processes occurring alongside population growth. However, this does not necessarily mean human activities always benefit mangroves—rather, it suggests that human influence can be positive or negative depending on local conditions, policies, and ecological factors. Further research could examine whether specific human-driven initiatives (e.g., reforestation, coastal protection) are driving this trend or if it is a result of natural processes.

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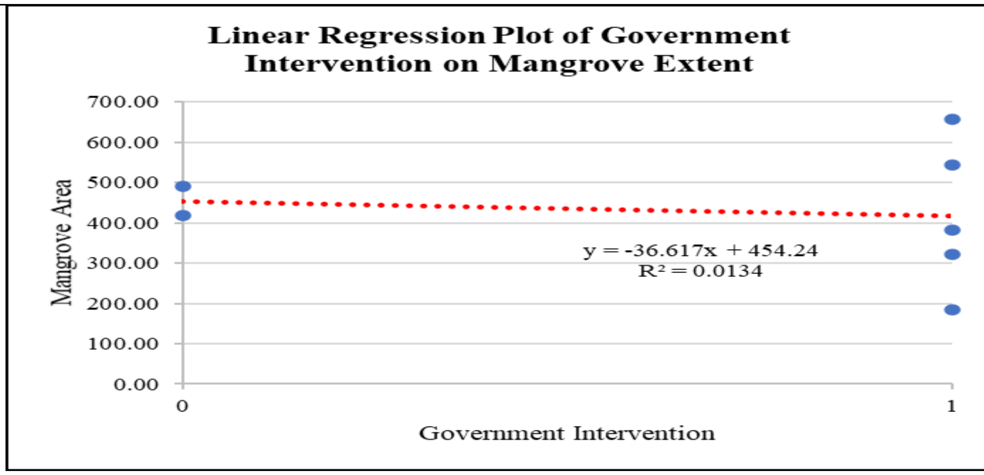


Figure 12. The Linear Regression Plot of Eastern Leyte Government Intervention on Mangrove Extent

The plot in Figure 12 shows the relationship between government-led projects and mangrove area. The trendline, represented by the equation $y = -36.617x + 454.24$, has a slight negative slope, suggesting a weak inverse correlation. However, the $R^2$ value is only 0.0134, indicating that government intervention explains just 1.3% of the variation in mangrove area within the dataset. This very low explanatory power suggests that no clear statistical association exists between the two variables. The wide dispersion of data points and the lack of a discernible trend imply that other factors—such as natural regeneration, climate variability, or local community actions—may play a more significant role in influencing mangrove extent than government interventions alone, at least during the period studied.

The analysis indicates that government intervention has little to no significant impact on mangrove area, as reflected by the weak negative correlation and a very low $R^2$ value of 0.0134. This means that only 1.3% of the variation in mangrove extent can be statistically attributed to government-led projects, suggesting that other factors may be more influential in driving mangrove expansion. Although such programs are typically designed to support protection and restoration efforts, their measurable outcomes appear limited—possibly due to inconsistent implementation, weak enforcement, or lack of sustained engagement. The scattered distribution of data points further supports the absence of a systematic relationship, implying that natural processes, climate variability, and community-based initiatives may play more critical roles. This finding underscores the need to re-evaluate how government policies are designed and executed, and whether alternative or complementary conservation strategies—such as grassroots participation or private sector involvement—could offer more effective and scalable solutions for mangrove sustainability.

**Summary of Correlation Analysis of Factors with Mangrove Area**

In determining the factors influencing mangrove extent from 2017 to 2023, Pearson's correlation coefficient (r) was used to assess the strength and direction of the linear relationship between mangrove area and selected climatological and anthropogenic variables. The correlation coefficients range from -1 to +1, where values close to ±1 indicate a strong linear relationship, and values near 0 suggest no linear association.

Table 8. The Result of Correlation of Climate and Anthropogenic Factors with respect to the Mangrove Area.

| | **r** | **$R^2$** | **p-value** |
|---|---|---|---|
| **Climatological Factors** | | | |
| Rainfall | 0.224 | 0.050 | 0.629 |
| Sea Level | 0.949 | 0.901 | 0.001 |
| Relative Humidity | 0.033 | 0.001 | 0.945 |
| Temp Max | 0.297 | 0.088 | 0.518 |
| Temp Min | 0.782 | 0.612 | 0.038 |
| Typhoon Frequency | 0.074 | 0.006 | 0.874 |
| **Anthropogenic Factors** | | | |
| Population | 0.802 | 0.643 | 0.030 |
| Intervention | 0.116 | 0.013 | 0.805 |

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Table 8 presents the correlation between various factors and mangrove area coverage. Among the climatological variables, sea level exhibited the strongest positive correlation with mangrove extent (r = 0.949), indicating a high degree of association. This aligns with ecological studies [30] suggesting that rising sea levels expand intertidal zones, thereby facilitating mangrove colonization and landward migration. Minimum temperature also showed a strong positive correlation (r = 0.782), implying that warmer seasonal lows may create favorable conditions for mangrove growth by reducing cold stress and enhancing physiological processes [31].

In contrast, rainfall (r = 0.224) and maximum temperature (r = 0.297) exhibited only weak positive correlations, suggesting minimal linear association with mangrove extent. These modest relationships may reflect the buffering capacity of mangrove ecosystems against fluctuations in precipitation and temperature extremes. Relative humidity (r = 0.033) and typhoon frequency (r = 0.074) demonstrated negligible correlations, implying that these variables had limited or no measurable impact on mangrove area during the study period. Their influence could be non-linear, delayed, or masked by other ecological factors.

Among anthropogenic variables, population density showed a strong positive correlation with mangrove area (r = 0.802). This may reflect higher environmental awareness and conservation activity in more densely populated coastal areas, or it could relate to urban planning strategies that incorporate green buffers and managed mangrove zones. In contrast, government intervention, defined here as the presence or absence of mangrove rehabilitation programs, showed a very weak correlation (r = 0.116). This suggests that such programs, while present, may have lacked the frequency, scale, or continuity needed to produce a detectable effect at the temporal resolution examined. It is also plausible that natural environmental drivers, such as sea level rise and temperature changes, exerted more direct and sustained influence over the observed period.

Overall, the results highlight that sea level and minimum temperature are the most influential climatic factors, while population density is the most strongly correlated anthropogenic factor. These findings suggest that both environmental conditions and human dynamics contribute to changes in mangrove extent, though their relative impacts vary in strength and direction.

## II. Conclusion

This study examined the factors influencing mangrove area extent in Eastern Visayas from 2017 to 2023 using Sentinel-2A imagery and correlation analysis. The results highlight that natural environmental factor, particularly sea level rise and minimum temperature, play a dominant role in driving the recovery and growth of mangrove forests in Eastern Visayas. The strong positive correlations indicate that rising sea levels expand intertidal zones conducive to mangrove colonization, while warmer minimum temperatures reduce cold stress and create favorable conditions for mangrove growth. Additionally, among human-related factors, population density showed a notable positive relationship with mangrove extent, which may reflect increased environmental awareness or effective urban planning that incorporates mangrove conservation. Conversely, government intervention in mangrove rehabilitation demonstrated only a weak correlation with mangrove area, suggesting that current efforts might be inconsistent, limited in scale, or insufficiently impactful during the study period. Other factors such as rainfall, relative humidity, and typhoon frequency showed minimal influence, indicating that mangrove ecosystems in the region may be resilient to these variables or that their effects are more complex and require further study. Overall, the findings highlight that mangrove dynamics result from a complex interplay between natural processes and human activities, emphasizing the importance of aligning conservation strategies with ecological realities.

## III. Recommendation

Based on the study’s findings, several recommendations are proposed to enhance the effectiveness of mangrove conservation and restoration efforts in Eastern Visayas. First, it is crucial that government agencies and environmental organizations design and implement mangrove rehabilitation programs that are adaptive and closely aligned with key natural environmental drivers, especially sea level rise and minimum temperature trends. Restoration efforts should prioritize sites that are ecologically suitable for mangrove growth, taking into account predicted climate change impacts to ensure long-term sustainability. This adaptive approach will help maximize the resilience and expansion potential of mangrove forests under changing environmental conditions.

Second, there is a need to improve monitoring and evaluation systems for mangrove rehabilitation projects. Establishing standardized protocols and measurable indicators will enable stakeholders to accurately assess the survival rates, growth performance, and overall ecological benefits of restoration activities. Regular and systematic monitoring will also provide essential feedback, facilitating adaptive management and helping to optimize resource allocation for conservation programs. Such efforts will contribute to identifying successful practices and areas requiring improvement, thereby enhancing program outcomes.

Third, empowering local communities through education, awareness campaigns, and capacity-building initiatives is essential to foster community-based conservation. The positive correlation between population density and mangrove area suggests that densely populated coastal communities may have a greater stake in mangrove protection, whether through traditional knowledge or local environmental stewardship. Supporting community involvement by providing technical assistance, incentives, and integrating local needs into conservation planning can improve compliance, reduce illegal activities, and strengthen sustainable management.

Fourth, mangrove ecosystems should be integrated into broader coastal climate adaptation and urban development planning. Policymakers and urban planners should recognize the multifunctional value of mangroves—not only as biodiversity hotspots but also as natural buffers that mitigate storm surges, reduce coastal erosion, and sequester carbon. Incorporating mangrove conservation in land use policies and coastal infrastructure projects can help balance economic development with environmental protection, enhancing both ecological and social resilience.

Fifth, further research is needed to better understand complex interactions and potential lag effects of environmental variables such as typhoon impacts, relative humidity, and rainfall on mangrove dynamics. Advanced statistical models and long-term ecological monitoring could help unravel these nonlinear relationships and identify thresholds or tipping points in mangrove ecosystems. This knowledge will improve predictive capabilities and guide more effective management interventions.

Lastly, improving the quality, transparency, and accessibility of data related to government-led mangrove projects is vital. Standardizing data collection methods and reporting on intervention scope, frequency, and maintenance activities will facilitate more accurate assessments of program effectiveness. Such transparency can foster collaboration between government agencies, researchers, NGOs, and local communities, leading to more coordinated and impactful mangrove conservation strategies.

In summary, a multifaceted approach involving adaptive restoration, robust monitoring, community engagement, integrated planning, continued research, and improved data management will be essential to ensure the sustained recovery and growth of mangrove forests in Eastern Visayas amidst ongoing environmental and socio-economic changes.

For future work, expanding the study to include more environmental factors—like salinity, sedimentation, and nutrient levels—could provide a fuller picture of what drives mangrove health and resilience. Using predictive models, we could also project how mangrove cover might change under different climate scenarios, potentially guiding conservation efforts. Comparing Eastern Visayas with similar regions could reveal unique and common challenges, while incorporating higher-resolution satellite imagery would allow us to capture finer details in mangrove changes. Additionally, involving local communities through citizen science and conservation programs could enrich data collection and foster community-led preservation efforts. Creating an interactive GIS tool for policymakers and stakeholders would also make it easier to share real-time data, helping to support informed conservation planning and sustainable practices in the region.

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## V. Conflict of Interest

The authors declare that they have no conflict of interest.

### Authors' Bio Notes

**Sarah Jane Cabral** is an IT educator of Eastern Visayas State University and an environmental advocate, she is passionate about understanding and reducing the effects of climate change on vulnerable ecosystems. Her research centers on using remote sensing and GIS to study changes in mangrove forests, with a recent focus on how climate factors affect mangrove cover in Eastern Visayas, her hometown. During her master's program, she designed a prototype system that uses Fast Fourier Transform (FFT) to identify sound patterns, aimed at detecting poachers and illegal loggers in Leyte—a project that highlights her dedication to applying advanced technology to real-world conservation issues. She is committed in using her expertise to shape effective conservation strategies and promote sustainable environmental practices.

**Jayson Victoriano** is the Research Director of the Bulacan State University, and a member of the National Research Council of the Philippines. His research interest are in the field of AI, Data Mining, Data Privacy and Governance. He also works in the field of Archaeology to study micro vertebrate and application of machine learning.

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