Site Suitability Assessment of Native Tree Species in Angat Watershed using GIS-based Multi-Criteria Decision-Making

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Abstract

Forests are one of the Philippines' most valuable resources but due to reasons such as deforestation, its forest cover drastically decreased, requiring reforestation efforts. Reforestation efforts fail due to poor planning and inadequate consideration of success factors like the site suitability of planted trees. This study utilized Geographic Information System-based Multi-Criteria Decision Making (MCDM) to identify Reforestation Target Areas (RTA) in the Angat Watershed, established a site-suitability framework for tree species based on their respective silvical requirements, and determined the suitable sites for tree growth and survival based on species-site suitability. Using the silvical requirements of native tree species Guijo (*Shorea guiso*), Kalumpit (*Terminalia microcarpa*), and Dao (*Dracontomelon dao*), suitability scores, and weights derived from expert opinions, weighted overlay analysis determined the suitability of the tree species within the RTA. Results show that 18.88% of Angat Watershed requires reforestation. Moreover, results revealed that Guijo and Dao are highly suitable in 99.98% of this area, and Kalumpit is highly suitable in 54.78% of the area. With having the right tree species to be planted being a major driving factor for reforestation success, these maps can aid the effectiveness of such initiatives by identifying optimal sites and supporting data-driven decision-making.

1. Introduction

1.1 Background of the Study

A watershed is an area of land that receives rainfall and streams, supplying water for a variety of purposes, including economic resources and environmental advantages. Watersheds also provide habitats for flora and fauna, diminish the effects of climate change, regulate drought, and support the mining, tourism, forestry, fishery, and agriculture sectors (Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development, 2019). In the Philippines, Angat Watershed is considered one of the major watersheds, with a total land area of 62,309.10 hectares (ha). Angat Watershed provides 97% of the water supply of NCR and its surrounding provinces and, at the same time, is accountable for power generation, flood control, agriculture, and wildlife habitat in the said area (International Research Institute for Climate and Society, n.d.).

However, Angat Watershed is facing deforestation as it has lost 135 ha of tree cover from 2001 to 2023 (Global Forest Watch, n.d.). Tree cover loss negatively affects Angat and other watersheds worldwide as the decrease in wildlife populations, loss of habitat for native species, and decreased water, soil, and air quality are all direct impacts of deforestation.

To combat this, reforestation programs in the Angat Watershed are being implemented both by government and non-government institutions. The Metropolitan Waterworks and Sewerage System's Annual Million Trees Challenge supports the government's National Greening Program (NGP) which aims to plant 1.5 billion trees in 1.5 million ha of land, originally spanning from 2011 to 2016 but later extended to 2028. In 2022, the NGP planted approximately 34 million seedlings in 45,947.6 ha of land (Department of Environment and Natural Resources [DENR], n.d.). The program planted 2.26 million seedlings in the Ipo-Angat Watershed alone from 2017 to 2020, covering 5035.19 ha of reforested land (Miraflor, 2021). Another reforestation effort was held by Manila Water in mid-2024 under the Pasibol Program, in the La Mesa Ecopark in Quezon City and in adopted watershed areas in Malay, Aklan and Silang, Cavite.

Successful reforestation programs require impactful initial steps, including, but not limited to, site studies, appropriate plant species selection, site-species matching, and post-establishment silviculture (Le et al., 2012). Silvical requirements are the specific requirements that a tree species needs for it to thrive in a certain environment, including habitat, light, soil, moisture, competition, and interactions with other species (United States Forest Service, n.d.). Furthermore, site factors refer to the environmental and ecological conditions of the plant location that influence the growth, health, and productivity of a tree species in a certain area. These factors include temperature, precipitation, soil type and texture, pH levels, soil depth, and elevation, among others (Synopsis IAS, 2023). Overall, understanding and meeting the silvical requirements of tree species ensures successful reforestation, which can be fulfilled by its compatibility with the planting site's site factors.

This relationship between site factors and silvical requirements is being utilized by various local researchers, along with geographic information system (GIS) techniques, in identifying species-site suitability. A conceptual scheme must be established to establish the relationship between the real-world data of site factors and silvical requirements and GIS processes. This conceptual scheme shall translate the actual data and silvical requirements of the trees into information that can be subjected to GIS techniques. Additional methods like the analytic hierarchy process (AHP) further improve site suitability selection. AHP is a decision-making tool used in cases involving multiple criteria where priorities must be assigned based on different factors (Saaty, 1987). Dolores et al. (2020) conducted a species-site suitability assessment in the Pantabangan-Carranglan Watershed using GIS and AHP. The research evaluated the growth potential of Akle, Dita, and Almaciga tree species by considering their silvical requirements and determining factor weights through AHP. The study identified specific locations where these species were highly, moderately, or not suitable for planting. Similarly, Veran et al. (2023) performed a suitability assessment for Kalantas and Supa tree species in the Quezon Protected Landscape, integrating AHP results from Dolores et al. (2020) and using the same silvical requirements.

As it is established that identifying the suitable sites for tree species' optimal growth holds a huge weight on the success of reforestation efforts, with the aid of established methodologies, this study aims to perform a species-site suitability assessment of native tree species in the Angat Watershed using GIS and AHP. This research's goals are: (1) to determine the areas in the Angat Watershed that require reforestation, in consideration of their physiographic traits, consequently revealing the portions within the reforestation areas that are ideal for the silvical requirements of the selected tree species; and (2) to establish a site-suitability framework for tree species based on their respective silvical requirements and correspondingly locate suitable areas within the deforested areas of the Angat Watershed where the tree species are likely to grow and survive. With the proposed framework supported by the silvical requirements of the native tree species and site factors of the reforestation areas in the Angat Watershed, the results intend to aid in making the reforestation efforts more efficient and productive and to contribute to the growing body of knowledge on the flora of Angat Watershed.

1.2 Conceptual Framework

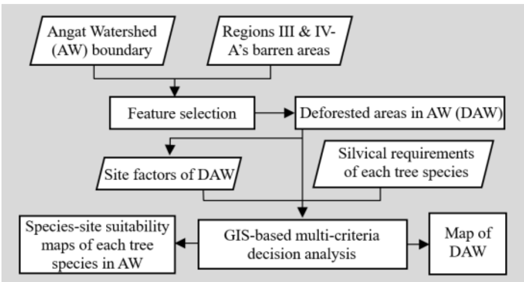

Figure 1. Conceptual framework for species-site suitability analysis using spatial data

Figure 1 shows the conceptual framework for species-site suitability analysis using spatial data. The initial inputs, namely, the Angat Watershed's boundary and the barren areas of Region III and Region IV-A, are the primary elements for determining the deforested areas in the Angat Watershed, which are satisfied by feature selection in GIS. The resulting data from this procedure reveals the deforested areas in the Angat Watershed, which will be considered the reforestation areas. The site factors are the sub-ordinate input from the identified deforested areas and are incorporated with another input, the silvical requirements of each tree species. In determining the suitability of each tree species with the reforestation areas, three elements are needed: the extent of the deforested areas in the watershed, its site factors, and the silvical requirements of each tree species. These elements go through the GIS-based multi-criteria decision analysis to reveal the results of the identification of species site suitability.

2. Materials and Methods

2.1 Description of the Study Site

Figure 2a and Figure 2c shows the extent of the study area, while Figure 2b shows its location in the Philippines. The study site boundary data was obtained from the Information Management Toolbox of the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) (National Mapping and Resource Information Authority and Philippines Statistics Authority, 2023). According to Tejada et al. (2023), the Angat watershed experiences an annual average total precipitation of 3733 mm, with the wettest months occurring from September to December as part of the monsoon transition season. In contrast, the summer months of March to May receive the least amount of precipitation.

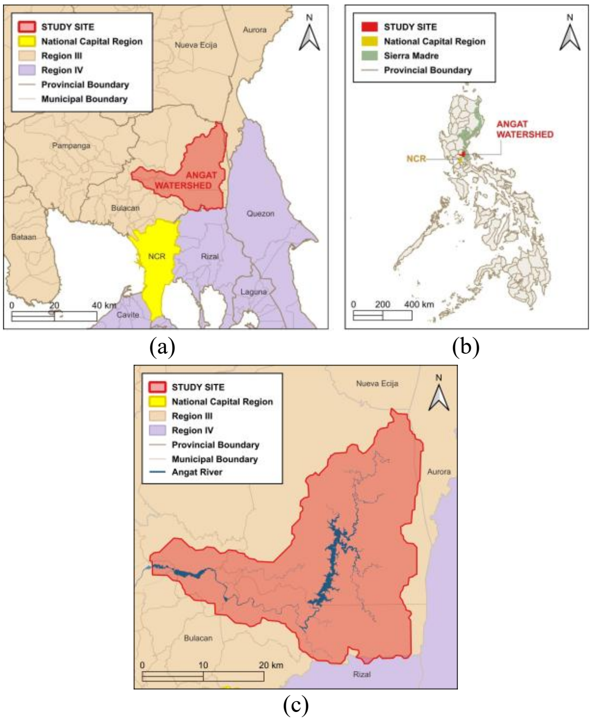

Figure 2. Area and location of the study area in relation to (a) municipality, (b) country, and (c) spatial extent of the Angat Watershed

2.2 Methodological Framework

The methodological framework in Figure 3 shows the structure implemented for the site-suitability analysis of the selected tree species on the Angat Watershed. It specifies the input values and datasets that were utilized and the processes that were applied to arrive at the eventual result of three different site-suitability maps within the study area, one for each of the selected species.

The framework can be divided into the pre-processing and processing phases of the methodology. Pre-processing includes the compilation of the required initial data as well as the preparation and cleanup that ensued in these datasets.

2.3 Pre-Processing

2.3.1 Selection of Tree Species: A 2014 statements from the National Power Corporation (NPC), the watershed's governing body, says Angat Watershed accommodates 290 indigenous tree species, including both non-woody and woody plants (Gonzalez, 2014). An NPC report mentions a cleanup drive and a tree planting that was conducted in parts of the Angat Watershed, specifically in Barangay San Lorenzo, Norzagaray, in Bulacan, on 27 July 2017 (National Power Corporation, 2017). Statistically, the event has planted 1360 seedlings of indigenous tree species. Five of the included tree species were named Guijo, Kalumpit, Dao, Rain Tree, and Balobo.

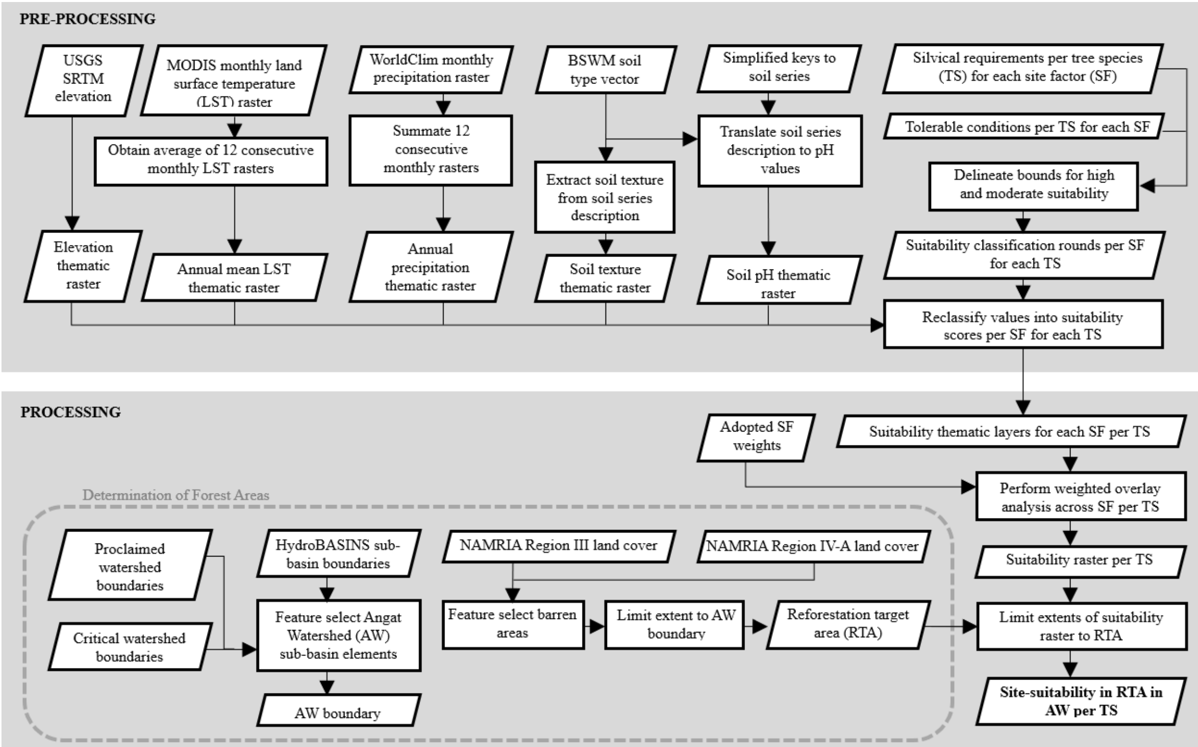

Figure 3. Methodological framework for the creation of site-suitability maps for the selected tree species in the Angat Watershed

(a) (b) (c)

Figure 4. Photographs of selected tree species: (a) Guijo, (b) Kalumpit, and (c) Dao.

Among the named tree species, only three native tree species were chosen for this study due to the availability of data and their ecological impact as key species for reforestation. This includes Guijo which is known for its efficient windbreaking ability and efficacy in soil erosion control, Kalumpit which is known to be good for soil stabilization, and Dao which is known for its role in riverbank stabilization and its superb wood quality (Rain Forest Restoration Initiative [RFRI], 2022; Aguilos et al., 2020). These aspects make these tree species great for reforestation and sustainability. Images of these selected species are presented in Figure 4a for Guijo (CABI, 2022b), Figure 4b for Kalumpit (Fagg, 2013), and Figure 4c for Dao (CABI, 2022a). The silvical requirements for the three species are summarized in Table 1.

Site Factor	Tree Species		
	Guijo (CABI, 2022b)	Kalumpit (Fern, 2020)	Dao (CABI, 2022a)
Soil texture	Sandy clay	Sandy clay loam, Sandy clay	Clay, Stone
Soil pH	6.5–7.0	5.5–6.5	3.5–5.0
Annual precipitation (mm)	1500–3600	850–1900	1800–2900
Annual mean LST (°C)	25–30	22–38	22–32
Elevation (masl)	0–400	0–750	0–500

Table 1. Silvical requirements of the selected tree species

2.3.2 Data Preparation of Site Thematic Layers: A site factor suitability scoring scheme was devised based on the different silvical requirements of each tree species discussed in Section 2.3.1. Table 2 shows the data sources, formats, and descriptions of each of the input variables used for the site suitability analysis. These datasets include the five site factors utilized in Section 2.3.3 to generate the site factor suitability scores, the reforestation target area selection criteria, and geographic extent.

The thematic raster was directly used to generate the suitability score according to elevation without prior pre-processing. Monthly precipitation values (mm) were summed to get the annual totals, while annual LST values was averaged monthly across the inclusive years, after which they are converted from Kelvin (K) to degrees Celsius (°C) using Equation 1.

$$°C = K - 273.15 \tag{1}$$

where $°C$ = LST in degrees Celsius
K = LST in Kelvin

Data	Format	Data Source
Soil Texture and Soil pH	Polygon	Bureau of Soils and Water Management (Contreras, 2013)
Annual Precipitation	Raster	WorldClim (Harris et al., 2020)
Annual Mean LST	Raster	MODIS (Wan et al., 2021)
Elevation	Raster	USGS Earthexplorer (Earth Resources Observation And Science Center, 2018)
Land Cover (Region III)	Polygon	NAMRIA (Dag-uman, 2022a)
Land Cover (Region IV-A)	Polygon	NAMRIA (Dag-uman, 2022b)
Watershed Boundaries	Polygon	HydroBASINS (Lehner and Grill, 2013)

Table 2. Summary of data sources

The BSWM Soil Type dataset is a composite of attributes soil series and soil texture, from which the values for the soil texture site factor were directly extracted (Contreras, 2013). Meanwhile, the soil series served as the basis for the determination of the soil pH. The soil series was extracted from the BSWM Soil Type dataset and was referenced to the Simplified Keys to Soil Series compiled by the Philippine Rice Research Institute (PRRI) (Philippine Rice Research Institute, 2014). The Keys to Soil Series is used to identify soil type based on their qualities, and thus, each unique value of the soil series has a corresponding description, including upper and lower bounds of pH values.

2.3.3 Generation of Site Factor Suitability Scores for each Tree Species

Tree Species: A conceptual scheme, shown in Table 3, was developed to systematically classify the suitability of the different site factors, adapting concepts from the categorization scheme by Dolores et al. (2020). This scheme defines criteria for evaluating the spatial characteristics of a study site by assessing how well site factors align with a tree species' requirements for growth. It uses conditional rules rather than fixed values, making it adaptable for other species based on their specific silvical needs and suitable for future species-site suitability assessments.

Site Factors	Suitability Scores		
	3 (high)	2 (moderate)	1 (marginal)
Soil texture	Areas with specific soil texture required by the species	Areas with soil texture belonging to similar textural groups but not the required specific soil texture	Areas with soil texture outside the requirement of the species and do not belong to a similar soil textural group
Soil pH	Areas with soil pH range within the requirement of species	Areas with soil pH exceeding the requirement of species but within tolerable soil pH	Areas with soil pH exceeding the considered comprising soil pH
Annual precipitation (mm)	Areas with annual precipitation within the requirement of species	Areas of annual precipitation typical of the habitat of the tree species	Area with annual precipitation outside of the requirement and typical habitat
Annual mean LST (°C)	Areas with annual mean LST required by the species	Areas with annual mean LST outside the requirement of species but within values typical of the habitat of the tree species	Areas with annual mean LST outside of the requirement of species and typical habitat values
Elevation (masl)	Areas with an elevation under 1000 masl and within the requirement of species	Areas with an elevation above 1000 masl and within the requirement of species OR areas with an elevation under 1000 masl outside the requirement of species	Areas with elevation above 1000 masl and outside of the requirement of species

Table 3. Conceptual scheme of the reclassification of suitability values of the different site factors

Each conditional rule corresponds to a graduated suitability category of high, moderate, or marginal. The high suitability category indicates the optimal environment conducive to the successful establishment and growth of the observed tree species. Accordingly, the species-specific silvical requirements were used to delineate the bounds of the high suitability category. Environmental conditions that significantly deviate from the optimal environment of the species but remain able to support acceptable growth are classified as moderately suitable. If the condition does not satisfy any of the two, it is then considered to be marginally suitable.

Following the conceptual scheme, the silvical requirements of the three selected native species, as enumerated in Table 1 were used to define the high suitability values. Furthermore, the moderate suitability reflects the natural habitat of these species, which is the tropical rainforest. The moderate suitability values for the site factors were adopted from the study of Dolores et al. (2020) and the precipitation indicated by Newman (2002), which are consistent with the site factor values for the tropical rainforest environment. These values are applicable generally for tree species but with an exception for cases like Kalumpit with known and established tolerable conditions, as Fern (2022) specified its particular tolerable conditions and as such, can be directly adopted as the values for the moderate suitability. The specific boundaries that were used to convert the values of each site factor into the thematic suitability scores for the tree species Guijo are enumerated in Table 4, Kalumpit in Table 5, and Dao in Table 6, using a scale of 3 for high, 2 for moderate, and 1 for marginal.

Site Factors	Suitability Scores		
	3 (high)	2 (moderate)	1 (marginal)
Soil texture	sandy clay	CONTAINS sand OR CONTAINS clay	default
Soil pH	6.5–7.0	4.5–8.5	default
Precipitation/yr (mm)	1500–3600	3600–7620	default
Annual mean LST (°C)	25–30	18–25 OR >30	default
Elevation (masl)	0–400	400–1000	default

Table 4. Reclassification boundaries of suitability values for site factors affecting Guijo (*Shorea guiso*) growth

Site Factors	Suitability Scores		
	3 (high)	2 (moderate)	1 (marginal)
Soil texture	sandy clay	CONTAINS sand OR CONTAINS clay	default
Soil pH	5.5–7.0	4.5–7.0	default
Precipitation/yr (mm)	850–1900	600–850 OR 1900–2100	default
Annual mean LST (°C)	22–38	12–22 OR 38–45	default
Elevation (masl)	0–750	750–1000	default

Table 5. Reclassification boundaries of suitability values for site factors affecting Kalumpit (*Terminalia microcarpa*) growth

Site Factors	Suitability Scores		
	3 (high)	2 (moderate)	1 (marginal)
Soil texture	clay OR stone	CONTAINS clay OR CONTAINS stone	default
Soil pH	3.5–5.0	4.5–5.5 OR 7.0–8.5	default
Precipitation/yr (mm)	1800–2900	1700–1800 OR 2900–7620	default
Annual mean LST (°C)	22–32	18–22 OR >30	default
Elevation (masl)	0–500	500–1000	default

Table 6. Reclassification boundaries of suitability values for site factors affecting Dao (*Dracontomelon dao*) growth

Thematic layers for each site factor were created for each tree species by implementing the reclassification boundaries, totaling 20 thematic layers. These thematic layers show the suitability of a species to the study site according to the individual site factors.

2.4 Processing

2.4.1 Delineation of Reforestation Target Area: The determination of suitable areas for the target species is limited to an identified Reforestation Target Area (RTA) of the Angat Watershed. This ensures that potential reforestation efforts guided by the results of the study are focused on degraded areas.

In obtaining the study site boundaries, sub-basins within the Philippines were acquired from Lehner and Grill (2008), from which the features that represent boundaries of the Angat Watershed were manually selected by cross-referencing with the Proclaimed and Critical Watershed Boundaries defined by the DENR-Forest Management Bureau (2017) and (Rabang, 2017). The output used to mask the deforested areas, which are defined as areas with land cover classifications of shrubland, brushland, grassland, or open/barren terrain. The geometric intersection of these two areas yielded the RTA, which served as the extent of the findings of the site-suitability analysis from the weighted overlay analysis. This limitation of the scope ensured that only the areas that genuinely require reforestation are indicated and analyzed, while the already forested areas are excluded.

2.4.2 Adoption of Site Factor Weights: The site factor ranks and corresponding weights produced in the study by Dolores et al. (2020) using AHP were adopted in this study to calculate the final suitability scores. These weights represent the relative importance of each site factor and their relevance to the growth and survival of trees according to the pairwise comparison of responses from five different experts from varying sectors: academe, government, research institution, and private sector, where each site factor was ranked by importance. Experts were instructed to give a score of nine (9) to what they perceive as the most significant factor, and one (1) for the factor that they think has the lowest significance among the provided site factors. For the factors that they believe have equal significance, a median score of five (5) was given. Thereafter, scores were averaged to obtain the weights of each factor. This multidisciplinary evaluation ensures that the assigned factor weights are validated against multiple perspectives and eliminates disciplinary bias.

Although the study that conducted the AHP dealt with a different set of tree species and study area, the context still follows as site factors were ranked depending on general influence on tree growth. Thus, these weights remain relevant and applicable to similar studies such as this study. Furthermore, the environmental conditions and principles for tree growth do not significantly change over short periods. These weights were also adopted by Veran et al. (2023) with a similar focus on site-suitability, demonstrating reliability across similar applications. These adopted weights are shown in Table 7.

Site Factor	Weight (%)	Rank
Precipitation	24.50	1
Soil Texture	23.04	2
Soil pH	22.48	3
Elevation	19.27	4
Temperature	10.71	5

Table 7. Adopted parameter comparison weights and ranking provided by experts (Dolores et al., 2020)

2.4.3 Generation of Overall Site Suitability per Tree Species in the Reforestation Target Area: To determine the reforestation suitability, a composite of the individual site factor thematic layers for each species was generated using weighted multivariate overlay analysis defined by Equation 2.

$$S = \sum W_i X_i \tag{2}$$

where S = Final suitability score
W_i = weight of each site factor i
X_i = suitability score of each site factor i

The suitability scores for each site factor as provided by the individual thematic layers produced in Section 2.3.2 are utilized in the weighted overlay analysis to produce the final suitability values. These were categorized into high, moderate, and marginal suitability, shown in Table 8. Based on these overall categories, suitability maps for each of the three tree species were constructed to show the geographic locations of the suitability categories of each species within the Angat Watershed.

Suitability Category	Suitability Scores
Marginal	≤ 1
Moderate	1–2
High	> 2

Table 8. Categorization of the ranges of overall suitability scores within the Angat Watershed

3. Results

3.1 Target Areas Requiring Reforestation

The resulting Reforestation Target Area is shown in Figure 5 and has been determined to have a geographic area of 161.67 sq. km, equivalent to 18.88% of the entire watershed.

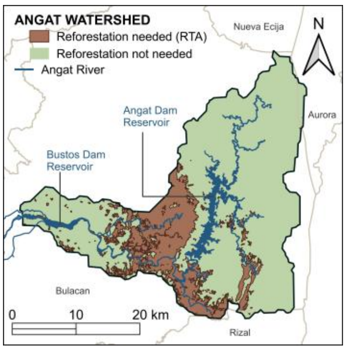

Figure 5. Angat Watershed Reforestation Target Area

3.2 Suitability of Selected Native Tree Species in Angat Watershed

This subsection presents the results of the site-suitability analysis generated from the weighted overlay analysis of the environmental conditions within the RTA of Angat Watershed for the three selected species. These maps illustrate the distribution of suitable areas for these species across the RTA.

3.2.1 Guijo [*Shorea guiso*]: Figure 6 shows the suitable areas for Guijo's growth. 99.98% of the RTA equivalent to 161.63 sq. km was found to be highly suitable for Guijo, while only 0.02% is moderately suitable. No area was identified to be of marginal suitability.

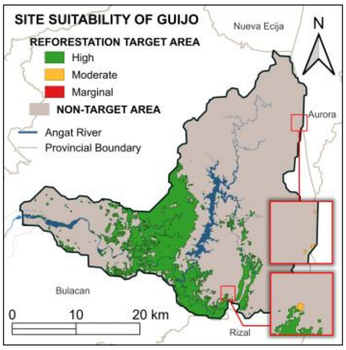

Figure 6. Suitable sites for Guijo in the Angat Watershed

3.2.2 Kalumpit [*Terminalia microcarpa*]: Figure 7 shows the site-suitability of the Kalumpit Tree. The results of Kalumpit show a more balanced distribution of suitability categories across the RTA, with 54.78% of the RTA being highly suitable while 45.22% is moderately suitable. The latter percentage corresponds to areas that have sand or clay for its soil texture, a soil pH level of 4.5 to 7.0, 600 to 850 mm or 1900 to 2100 mm of annual precipitation, 12 to 22°C or 38 to 45°C annual mean LST, and an elevation of 750 to 1000 masl, all of which fall under the moderate suitability from the Kalumpit's reclassification values.

The divergence of Kalumpit in its suitability in the RTA is rather significant, especially compared with the results of the other species, which show high suitability in nearly 100% of the area. This difference can be attributed to two factors: its annual rainfall requirements and soil texture. This lower suitability in the soil texture, together with the similarly lower suitability in annual rainfall, led to the observed large extent of moderate suitability.

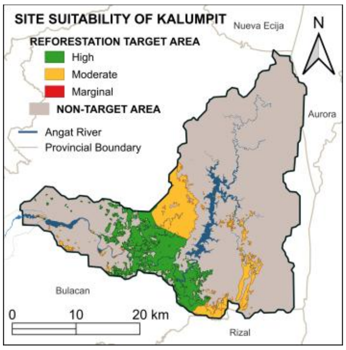

Figure 7. Suitable sites for Kalumpit in the Angat Watershed

3.2.3 Dao [*Dracontomelon dao*]: Figure 8 shows that 99.98% of the RTA is highly suitable for the Dao tree. Conversely, the remaining 0.02% falls to the moderately suitable, which is equivalent to 0.04 sq. km of land area in need of reforestation.

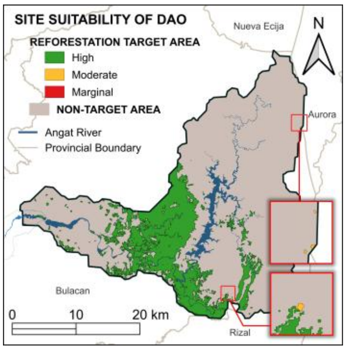

Figure 8. Suitable sites for Dao in the Angat Watershed

The result for Dao is identical to Guijo despite their differences in suitability specifications in Table 4 and Table 6 respectively. Even with varying silvical values, comparison of the thematic maps for the two species showed the same suitability scoring for all site factors except for LST. This deviation was because the majority of the RTA stays within 22–25 °C LST, which puts Dao in high suitability for the large part of the reforestation target area, while Guijo is classified as moderate. However, since LST has the lowest relevance among the site factors with a weight of 10.71%, its impact on the final suitability scoring is minimal.

4. Discussion

The generation of suitability scores through a structured site-suitability reclassification framework was foundational to this study's assessment of optimal reforestation sites. By translating silvical requirements and site factors into a standardized scoring system, the study ensured a consistent and quantifiable basis for comparing tree species' suitability with the biophysical conditions of the Angat Watershed. This approach not only enhances the objectivity of species-site matching but also enables spatial decision-making using GIS-based weighted overlay analysis.

The results of the performed GIS-based weighted overlay analysis provided a characterization of the suitability of three native tree species for reforestation in the concerned areas within the Angat Watershed. Each of these species demonstrated different levels of adaptability to the biophysical conditions in the study area. The findings of this study may aid in the planning and implementation of reforestation efforts in the Angat Watershed, one of the most important watersheds in the country.

The findings reveal that Guijo and Dao exhibit high adaptability across 99.98% of the identified Reforestation Target Area (RTA), making them strong candidates for large-scale reforestation in Angat Watershed. Their silvical requirements align closely with the watershed's environmental conditions, particularly in elevation, precipitation, and soil texture. These tree species are recognized for their ecological benefits as Guijo aids in erosion control and windbreaks (RFRI, 2022), while Dao is known to stabilize riverbanks and contributes to biodiversity (Orwa et al., 2009). Both species are also classified as vulnerable tree species under the DENR Administrative Order No. 2017-11, underscoring their importance in conservation efforts (Khou et al., 2017; DENR - Biodiversity Management Bureau., 2017).

Finally, Kalumpit was determined to be highly suitable in only 54.78% of the RTA, with the remaining percentage classified as moderately suitable. Compared to the other three species, it requires more specific soil and rainfall conditions, making it less broadly suitable. Despite this obvious difference in suitability with the other tree species, Kalumpit has evolved to withstand high humidity and substantial rainfall, making it a good option for reforestation (Aguilos et al., 2020). Although less suitable than the other species, its adaptations in root system aid the prevention of erosions for soil stabilization.

Godefroid et al. (2011) stated that the mismatch between the tree species to be planted and the site condition of the area where it will be planted leads to a high mortality rate for the trees. As Angat Watershed provides water to millions of people and supports energy production and biodiversity conservation, reforestation within this area must prioritize species that will not only survive but also enhance the functions of the watershed. Strategic planting of Guijo and Dao in highly suitable areas can maximize reforestation effectiveness, while Kalumpit can be selectively introduced in locations where it thrives.

These results impact potential policy reforms, conservation, and land management. Using species-site suitability analysis and mapping in reforestation can boost tree survival rates. It can also cut planting costs and maintenance. The methods and frameworks from this research can help with specific planting goals.With the help of the conceptual scheme and the methods established in this study, sites for the optimal growth and survival of plants with particular purposes may be located, given their silvical requirements, as the framework was designed to cater to different tree species if data on its characteristics are available. Additionally, these results and the process utilized by this study may aid projects like the ongoing Enhanced National Greening Program (E-NGP) of the DENR. As results from the work of Perez et al. in 2020 that assessed the success of the first installment of the NGP from 2011 to 2016 revealed that there was no significant increase in the forest cover, this study's methodology and results may serve as a guide for species selection in government programs like E-NGP and other similar reforestation efforts for greater chances of reforestation success.

5. Conclusions and Recommendations

The GIS-based assessment of the study area determined that 18.88% of the Angat Watershed or 161.67 sq. km., requires attention for reforestation efforts. After categorizing the site factors and silvical requirements into reclassification boundaries indicating high, moderate, and marginal suitability using the site-suitability framework formulated, this research utilized weighted overlay analysis to determine the species-site suitability of three native tree species, namely Guijo, Kalumpit, and Dao, within the concerned areas within the watershed. The results gathered from the analysis revealed that Guijo and Dao are broadly adaptable in the RTA both with 99.98% high suitability. On the other hand, Kalumpit, due to its more specific ecological requirements, was highly suitable in only 54.78% of the reforestation area.

These findings emphasize the critical role of species-site matching in enhancing the success of reforestation programs. To further maximize and increase the survival rates of the trees, selecting species that are ecologically suited to the biophysical conditions of the watershed is essential. Further studies may also incorporate climate models and future climate scenarios into the GIS analysis. Proper use and generation would also help achieve goals for long-term forest stability and viability of tree species in the face of climate variability.

This study offers useful information about Guijo, Dao, and Kalumpit. However, it is limited by the quality and availability of the sources. Gathering primary data, like testing the species' silvical needs and checking soil types, can improve the suitability criteria. This will help validate the study's results further.

It is important to understand that this study's results cannot ensure the survival of native tree species in the area. Tree site-suitability is only one part of reforestation success. Many other factors matter too, like socio-economic, institutional, policy, and management issues, as well as characteristics of the reforestation itself (Le et al., 2014). Further studies may include more native and endemic species and other success factors. They could consider species with ecological or cultural importance for a diverse selection in reforestation planning. Local knowledge, species accessibility, and community preferences may also be key variables. These factors support a participatory GIS approach, which involves human aspects in reforestation planning. This method also considers socio-economic factors as another success driver.

This study highlights how GIS-based species-site suitability analysis improves environmental planning. In the Philippines, there is a strong need for reforestation, especially in important regions like the Angat Watershed. By refining these tools and methods, we can better support successful and sustainable reforestation efforts in the future.

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