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Mangrove Land Suitability Assessment Using Weighted Linear Combination: A Case Study of La Union Province Coastline, Philippines

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Abstract: Land suitability assessments play a crucial role in determining optimal land use patterns to meet specific requirements, particularly in the context of forest restorations and plantations. However, there is a lack of studies reporting such assessments for mangrove rehabilitation and reforestation in the Philippines, leading to low survival rates (10-20%) due to improper site selection and site-species matching. This study aims to identify and narrow down suitable sites for mangrove growth in La Union Province, facilitating ground truthing for site selection and species matching. The Geographic Information System (GIS) method, specifically the Weighted Linear Combination (WLC) using ArcMap software, was employed. The study identified four suitable sites along the coastline of La Union within the jurisdictions of Aringay, Bangar, Sto. Tomas, and the City of San Fernando, all actively involved in mangrove conservation. However, mangrove planting efforts in other municipalities along the coastline of La Union, such as Agoo, Balaoan, and Bauang, were not reflected on the maps due to data resolution limitations. Nevertheless, the study's findings should be regarded as a supportive tool in the site determination process, with ground truthing and assessment remaining essential. Integrating the study's results with mangrove rehabilitation/reforestation efforts offers efficiency options that have the potential to enhance project success rates.

Keywords: *Ecological mapping, Environmental management, Land use planning, Mangrove restoration, Mangrove rehabilitation*

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1. Introduction

The Philippines is renowned for its rich biodiversity, including a diverse range of flora and fauna. However, the country's archipelagic geography makes many island species, including mangroves, susceptible to eradication (Caujapé-Castells et al., 2010; Işik, 2011). Mangroves, encompassing both the ecosystem and the preserved floral species (UNEP, 2014), exhibit remarkable diversity in the Philippines, with 35 true mangrove species compared to a combined total of 10 in North and Central America. The country also surpasses Indonesia, Australia, Papua New Guinea, and Malaysia in mangrove biodiversity (FAO, 2007), accounting for approximately 1.9% of the global mangrove environment (Giri et al., 2011).

Coastal communities in the Philippines rely heavily on productive mangrove ecosystems for sustenance, livelihoods, and protection against storm surges and typhoon-induced winds (Tariah, Abali, & Aminigbo, 2022). Despite their critical importance, anthropogenic activities continue to degrade mangrove lands, leading to a significant reduction in mangrove cover. Historical estimates by Brown and Fisher (1918) indicated that the

Philippines had approximately 400,000 to 500,000 hectares of mangroves, which declined to 240,800 hectares by 2010 (Long et al., 2014). The most substantial losses occurred during the 1950-1970 period when land conversion for stable aquaculture industries was actively promoted by national policies (Primavera et al., 2016).

The depletion of mangrove forests can be attributed to various factors, including the lack of ecological awareness, insufficient knowledge of their economic value, continuous land reclamation for commercial and residential purposes, fish pond operations, encroachment, pollution, sedimentation, improper shoreline engineering, weak implementation of zoning ordinances, and the general attitude and behavior of the populace (Salmo III et al., 2015; Gevaña et al., 2019).

Over the past two decades, efforts to conserve and rehabilitate mangroves have increased, driven by the recognition of the ecosystem services, economic value, and biodiversity they provide (Gevaña et al., 2018). However, monitoring reports vary across regions and localities, with some areas experiencing increased mangrove cover due to conservation efforts, while others lack data on mangrove extent and health. Success rates of mangrove rehabilitation projects also vary, often hampered by inappropriate site selection and species matching, as well as the lack of community participation (Primavera & Esteban, 2008; Pulhin et al., 2017).

This study focuses on addressing the challenges related to site selection for mangrove rehabilitation. Issues in site selection arise from the lack of a science-based process, tenure rights complexities, and inadequate coastal land use zoning. The reversion of unproductive aquaculture ponds to mangrove forests, mandated by Republic Act 8550, revealed that many leased fishponds had been illegally disposed of or converted to private ownership. Consequently, mangrove planting projects often resort to planting on seafront lands, which are open access public lands but unsuitable for seedlings due to strong winds and wave action, resulting in low survival rates (Primavera et al., 2013).

La Union Province, like other coastal areas, faces similar challenges in rehabilitating and reforesting its mangrove lands. Local governments often lack data on mangrove extent, health, ecosystem services, and species inventory due to concerns from pond operators and caretakers who are apprehensive about external surveys. Earth observation and Geographic Information System (GIS) methods can alleviate these issues.

In the Philippines, GIS-based land suitability analysis has been employed to determine optimal areas for specific crops, such as aerobic rice cultivation in Central Luzon (Armecin & Cosico, 2010) and banana plantation in Laguna (Bato, 2018). Similarly, GIS methods have been utilized to identify optimal sites for beekeeping in La Union (Estoque & Murayama, 2010).

Land suitability analysis encompasses two independent analyses: site search problem and site selection problem (Cova & Church, 2000). Site selection analysis helps identify the best location for a specific activity among a group of feasible locations based on specified attributes. In contrast, site search analysis involves a broader search when no candidate sites are available (Arentze et al., 1996). The Weighted Linear Combination (WLC) model is a widely used GIS-MCA approach that combines criterion weights and value functions to assess the suitability of locations. It allows for the inclusion of diverse criteria based on specific goals and enhances the decision-making process (Malczewski, 2017).

This study utilized the GIS-based WLC method to locate suitable land areas for mangrove growth in La Union Province. By aiding decision-makers in site selection for mangrove rehabilitation and reforestation programs, the study seeks to contribute to science-based solutions for current mangrove rehabilitation challenges.

2. Materials and methods

In the province of La Union, located in the northwest corner of the island of Luzon (Figure 1), the study area encompasses a land area of approximately 1,497 km2 (149,000 ha) (GOVPH, 2022b). The province's geography is characterized by predominantly hilly terrain, gradually rising eastward from the coast to the Cordillera Range. Mount Talang, with an elevation of 1,520 m (4,990 ft), represents the highest point in the province. The coastline stretches approximately 114.70 km to 155.4 km (DENR-R1, 2019). According to the 2020 Ecological Profile of La Union, the province has an estimated 152 hectares of mangrove lands (Provincial Government of La Union, 2020).

As of 2013, numerous municipalities in La Union are situated along the coast, comprising a total of 94 barangays with an estimated population of 185,038 (Table 1). The coastal communities heavily rely on fishing as a livelihood, making it a priority area for development and protection by the La Union Provincial Government (Salmo III et al., 2015). Mangrove forests within the province are declared protected areas, such as the Agoo-Damortis Protected Landscapes and Seascapes (ADPLS), covering 60 ha and declared a Marine Protected Area (MPA) by the Department of Environment and Natural Resources (DENR). The management of mangrove protected areas involves the People's Organization (PO), DENR, Protected Area Management Board (PAMB), and the Local Government Unit (LGU).

The mangroves in La Union provide essential benefits to the coastal communities. In municipalities like Agoo and Sto. Tomas, they serve as spawning grounds for fish and crustaceans, as well as habitats for migratory birds. Local livelihoods in Sto. Tomas, Aringay, Bauang, San Fernando, and San Juan depend on resources derived from the mangroves, including fish, crustaceans, mollusks, nipa shingles, firewood, and charcoal. Mangrove planting activities have been carried out by various organizations and agencies, demonstrating efforts to mitigate climate change and promote conservation.

However, the province has experienced mangrove degradation due to aquaculture conversion, illegal settlements, mangrove cutting, erosion, siltation, sedimentation, and pest infestations. The loss of mangrove lands has been exacerbated by the impacts of climate change, leading to coastal erosion, decline in fish catch, and increased vulnerability to natural disasters.

Despite these challenges, La Union still retains a total area of 140 hectares of mangrove forested lands. Some of these areas consist of old stands or secondary growth, while approximately 80 hectares are designated as plantation grounds, and 60 hectares are protected areas. Mangrove planting and coastal clean-up activities have been conducted in collaboration with various organizations and stakeholders.

To determine land suitability for mangroves, the study utilized parameters such as elevation, slope, precipitation, and air temperature. Geomorphological data, including elevation and slope, were derived from the ASTER Global Digital Elevation Map, while average air temperature data were obtained from the Global Solar Atlas. Average precipitation data were retrieved from WorldClim. All data used in the analysis had a resolution of 30-arc seconds.

The analysis employed a weighted linear combination, which is a GIS-based multicriteria analysis method. This approach combines map overlays to identify and specify suitable locations based on the ranking or weight assigned to selected parameters. The process involved three main steps, including the identification, collection, and cleaning of attribute map data (pre-processing).

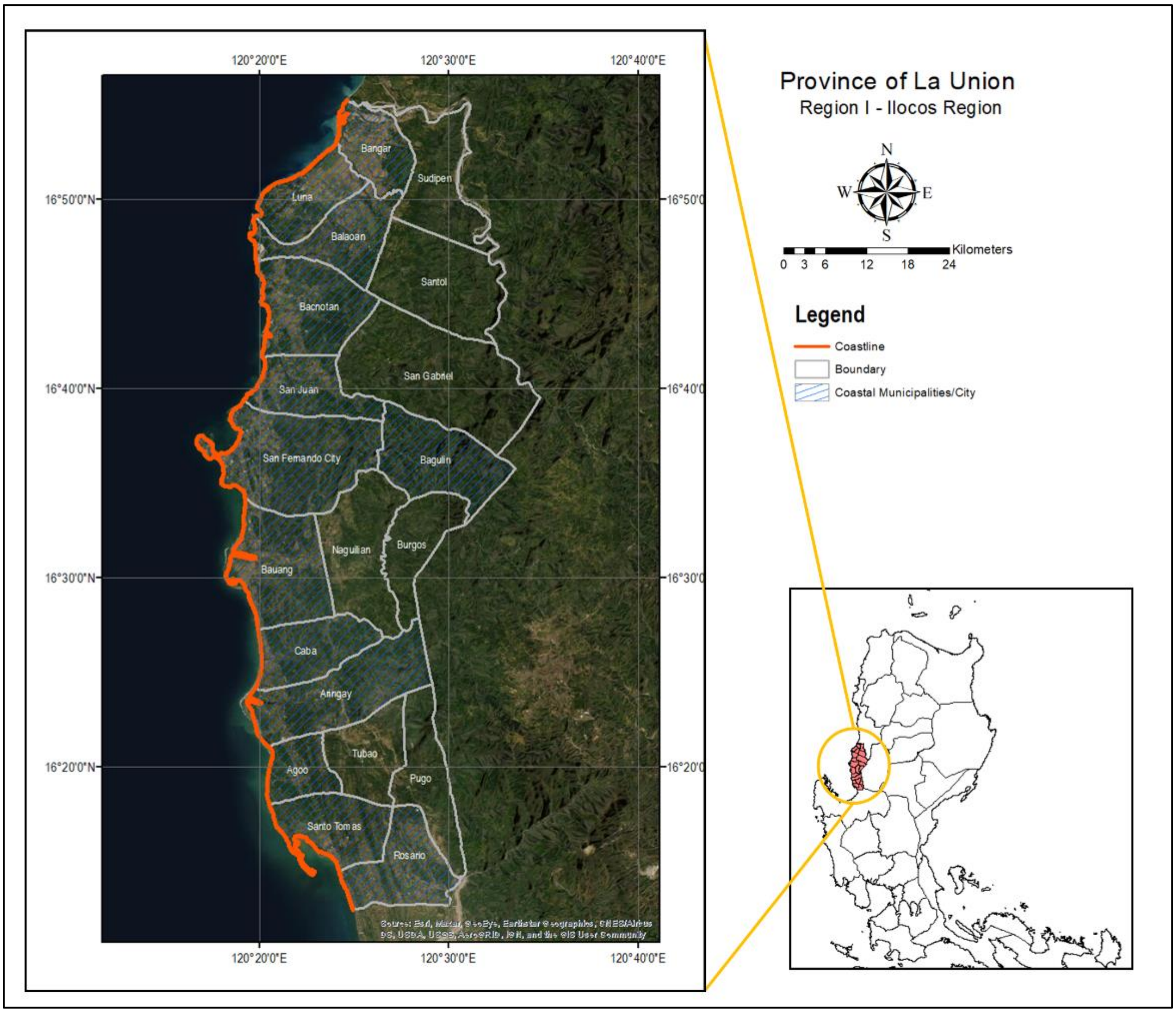

Figure 1: An administrative map of the Province of La Union showing the coastlines and the coastal municipalities and city

3. Results and discussion

3.1. Assignment of suitability classes

The goal of a land use appropriateness analysis is to determine the best future land use to meet specified demands. Each component is assigned a class based on how a given tree species responds to various environmental conditions.

Table 2 presents the specific parameters acquired from literature. Mangroves are known to tolerate air temperatures as low as 8 °C to as high as 42°C for short periods of time (Monsef et al., 2013). Aside from air temperature, mangroves are also sensitive to precipitation or rainfall, as this climatic factor controls mangrove range limits in distribution, abundance, species richness and survival (Osland et al., 2017). Surface elevation and slope also affects mangrove establishment in a specific or local area because the elevation and slope of the location dictate the tidal inundation frequency of these locations (Leong et al., 2018).

Four classes for land suitability are applied: unsuitable for 1, marginally suitable for 2, moderately suitable for 3, and highly suitable for 4. A higher score is attributed to higher or most favorable land suitability because in WLC, the higher the combined value achieved by weighing, the more suitable it is, where in the final score of the habitat/land suitability is defined as:

$$S = \sum W_i X_i$$

Where S is the final score, Wi is the weight factor, and Xi is the score of class i (Cuong et al., 2019). For the certain equation, the weight of factor was assumed to be equal. Each attribute or parameters' raster layer were mapped according to this equation and given values.

3.2. Suitability Maps

In the whole province of La Union there were four (4) identified locations in total (Figure 3): the Municipality of Bangar (orange, moderately suitable), City of San Fernando (orange, moderately suitable), Municipality of Aringay (highly suitable), and Municipality of Sto. Tomas (moderately suitable).

Figure 3: Generated mangrove land suitability map for La Union Province, Philippines. Magnified images of the detected suitable sites: (A) City of San Fernando, (B) Municipality of Santo Tomas, (C) Municipality of Aringay and, (D) Municipality of Bangar.

4. Discussion

The Municipality of Bangar is the province's northmost town and it's smallest. In the northernmost part of the small town runs the Amburayan river, which is also a source of income for the locals. However, agriculture is still the main source of income for its inhabitants (GOVPH, 2022a). The pixel was near the river by its estuary and is located by what seems like a land use for agriculture. It showed a moderately suitable area (Figure 3D).

On the other hand, the Municipality of Aringay (Figure 3C) showed high suitability for mangroves, while the Municipality of Sto. Tomas (Figure 3B) showed moderate suitability for mangroves. Both areas appeared to be located on land used for aquaculture. Both towns are known for their milkfish and oyster products, and both thrive in the fishing industry as the major occupation of the people of the coastal areas. It is possible that these areas where the suitability of mangroves appeared were once areas populated by mangroves. Due to the history of the clearing of mangroves in the country; during the 1950s there was a massive government support for the conversion of mangrove lands to make way for the aquaculture ponds (Primavera, 1995). These sites were also located along the eastern side of the Lingayen Gulf, where the Agoo-Damortis Protected Landscapes and Seascape is located. The Sto. Tomas location was inside the Santo Tomas Cove (Damortis Cove); but the Aringay town shorelines are not among the jurisdiction of the protected landscape, it is only located northside of the area.

Lastly, the City of San Fernando, revealed a moderately suitable pixel, near the harbor and airport industry area along its coastlines (Figure 3A). The area is a land used for either commercial or residential purposes. The City of San Fernando is among the coastal cities of the province. The San Fernando Bay is a rich fishing ground where its seaport is also in operation. Due to the rapid economic growth of this urbanize area, many of the mangrove forests are traded for the location's economic stability. Because of low environmental protection due to the loss of mangrove forests, the residents are susceptible to hazards. Climate change also contribute to the frequent flooding that the city experiences. The Comprehensive City Land Use Plan for 2015-2025 revealed that the Carlatan Lagoon and the various drainage systems is only about five percent (5%) of the land area of the city. It is mainly vegetated with mangroves, nipa palm, tropical shrubs, and grasses. The Carlatan Lagoon has been then since surrounded by many residential areas due to its reclamation.

Despite limitations (data availability, accessibility, reliability, and consistency) in mapping data, the results of the study were still able to display suitable areas. Although highly specific and small scale this seems to be on par with Long et al., (2014) having shown that the coastal region where La Union is located only has an estimated mangrove area of 1 – 1,000 hectares, as of 2010. The province of La Union has lesser mangrove forest area in contrast to other coastal region of the country. Moreover, there has been no current, accurate and reliable data specific for the province of La Union, at least not accessible to the public. The data that is available is fragmented and ambiguous, and it does not provide enough detail to construct metrics that will guide and monitor the sustainable exploitation of mangrove resources. Many of mangrove assessments are on a national level and only focuses on areas with greater mangrove forest extent. Although fragmented, such data are still of value because it serves as a baseline for project grounding and is still usable with proper additional pre-processing steps necessary for intended use of the material.

The United Nations Environment Programme released in 2014 a call to action to reverse the patterns of mangrove decline, mangrove land restoration, and to ensure that the remaining mangrove habitats are protected and/or sustainably managed (UNEP, 2014); and a very important factor for a successful mangrove rehabilitation or reforestation is the selection of site. Many planting efforts had shown low survival rates and have failed to effectively restore mangroves dues to an inappropriate site selection (Saenger, 2002; Xiong et al., 2021). This study contributes to alleviate this burden on mangrove management and planning. The use of remote sensing techniques and mapping mangroves helps address knowledge and data gaps that may help in mangrove conservation ang management (UNEP, 2014).

Despite yielding a small number of locations, this result is relevant for it provides a starting point for site selection discussions because many successful mangrove conservation and rehabilitation programs have already proven the influence of decisions related to site selection (Damastuti et al., 2022). This delineates a clear image of where to look if when locating and choosing a site for many mangrove rehabilitation activities; from here on decision making for planning a mangrove project can be more reliable and efficient. Furthermore, this is beneficial and relevant for mangrove restoration because field surveys for mangrove lands prove to be difficult due to the muddy conditions and structure of the ecosystem (Hu et al., 2020).

Furthermore, this study assumed that the environmental factors used as parameters influence mangrove growth equally and are then weighted equally. Most studies implementing WLC protocols use multicriteria evaluation (MCE) as a decision support operation in weighing parameters for GIS methods (Jiang and Eastman, 2010). Many studies' criteria for suitability are weighted by the analytical hierarchy process (AHP) (Cuong et al., 2019; Dashti et al., 2013; Loui Alburo et al., 2019; Masoudi et al., 2021). The AHP implements criteria weights through pair-wise comparison by expert judgements. In a multicriteria decision problem, this indicates the relative relevance of a set of activities. The AHP technique allows judgments on intangible qualitative factors to be combined with tangible quantitative criteria (Badri, 2001). However, this study does not implement the AHP method, thus, not benefiting from its advantages. Although this method extracts judgements from individual people, its disadvantage is unsatisfied consistency due to possible bias of respondents to AHP questionnaires.

Also, parameters in this study are limited to only air temperature and precipitation for bioclimatic factors and elevation and slope for topographic parameters. It lacked the hydrological conditions and physicochemical properties for mangrove growth (Xiong et al., 2021). Despite the fact that air temperature and rainfall regimes do influence the global distribution, quantity, and species richness of mangrove forests (Osland et al., 2017). Elevation is often a replacement for inundation for it is the driving factor that drive inundation rates and other features that affect flooding and draining (Schile et al., 2007). Despite lacking other factors for suitable mangrove growth, abiotic factors such as topography and temperature are enough in this case due to the objective of the study. This is the main advantage of such tool; factors can be customizable depending on the desired objectives and results. Given that this is a baseline study other parameters did not include such as water pH, salinity, and nutrient availability can be measured and studied on site; such parameters are subject to adjustment based on the specificity of species to be planted. Furthermore, the factors that are not included are said to contribute more on the diversity of mangroves (Perri et al., 2017). The main goal of the study is to delineate suitable sites in an area of possibilities, the success of rehabilitation still heavily relies on the ecohydrology of the site and the efficacy of the prepared planting strategy and site management.

All these locations scored the highest in air temperature. Air temperature is essential for mangroves. In 2021, a study in China found that the development of mangroves is sensitive to sudden changes in their ecosystem and that air temperature was the primary factor controlling mangrove development. Although the rising temperatures supposedly promote mangrove development, the intensity of human altercation in lands has reversed this tendency, leading to the current degradation in mangrove populations and lands.

5. Conclusion

The global focus on rehabilitating and reforesting mangroves has led to both successes and failures. One common problem is the lack of knowledge and data gaps in decision-making for site selection. This study provides baseline information on suitable land for mangrove rehabilitation, which can contribute to the success of planting projects.

In the province of La Union, where mangroves are a priority for sustainable development, the lack of proper training and capacity among governing bodies often leads to rushed planning, skipping important steps for project success. This study addresses these gaps by offering science-based solutions.

The study identifies suitable planting locations remotely, without the need for on-site surveys that may face resistance from local residents. While not perfect, these maps can guide diversity assessments and species selection when ground truthing is conducted.

The study demonstrates that training and capacity building for personnel involved in mangrove rehabilitation is feasible. The flexibility of the mapping tool allows for customization of criteria and parameters according to specific project goals.

However, the study's options for parameters were limited due to the unavailability of reliable satellite imagery in the Philippines. To ensure data relevance and reliability, ground truthing activities and integration with biodiversity assessments are still recommended.

Some locations identified as suitable for mangrove growth in the maps already have designated areas or ongoing planting activities, indicating the need for careful verification through ground truthing and monitoring systems.

Due to limited and fragmented data, the use of mapping and satellite imagery is limited to initial investigation and assessment. The study's results can provide a basis for provincial policy briefs and inform local environmental policies and development plans.

Choosing the right location and conducting thorough site assessments for species selection are crucial for successful mangrove rehabilitation. This study contributes to filling the information gap and emphasizes the role of GIS mapping methods like WLC in mangrove conservation efforts.

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