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USING GIS AND ANALYTICAL HIERARCHY PROCESS (AHP) FOR SUITABILITY MAPPING OF POTENTIAL SITES OF BAMBOO SPECIES PLANTATION IN AGUSAN DEL NORTE

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Abstract: *The Philippines is focusing on cultivating a high-value bamboo species for global markets, particularly targeting paper production and construction materials. Agusan del Norte has been identified as a key area for this initiative. Using Key Informant Interviews (KII) and surveys within the Multi-Criteria Decision Making (MCDM) framework, and employing the Analytic Hierarchy Process (AHP), the study aims to create a sustainable bamboo production system through suitability mapping. This research reveals that 14.50% of the province's land is highly suitable, 85.44% is suitable, and only 0.06% is less suitable for bamboo cultivation. Notably, the Buenavista municipality, which encompasses 24% of the highly suitable areas, is identified as particularly promising. Agusan del Norte, with its potential for high-value bamboo species cultivation, requires a comprehensive assessment to identify areas best suited for bamboo production.*

Keywords: *Bamboo, Suitability, Agusan del Norte, AHP-MCDM*

1. INTRODUCTION

Bamboo stands out as an exceptional natural resource due to its fast growth rate and sustainability, making it a highly renewable material in various industries, from construction to textiles. Its ability to sequester carbon at a rate comparable to, or even greater than, many trees emphasize its potential as a significant element in climate change mitigation efforts. Economically, bamboo creates opportunities for communities through cultivation and processing, providing jobs and fostering local industries. Ecologically, bamboo forests contribute to soil stabilization and water conservation, preventing erosion and supporting biodiversity. Additionally, bamboo has health benefits when used in products like charcoal air purifiers and bamboo fiber textiles, which offer natural antibacterial properties. Bamboo, as the most widely recognized non-wood forest product in the Philippines, receives significant government support for its use in community livelihoods, environmental protection, furniture production, and economic recovery, overseen by the Philippine Bamboo Industry Development Council [1]. As global interest in sustainable resources grows, bamboo's versatile applications and environmental benefits position it as a key material in the shift towards greener practices.[2].

Agusan del Norte has diverse ecosystems and natural resources. With its tropical climate and abundant rainfall, the region possesses favorable conditions for bamboo cultivation. However, systematically establishing a bamboo species requires careful organization and a deep comprehension of the land's suitability, which can be achieved by integrating Geographic Information Systems (GIS) techniques [3]. The suitability of a bamboo species (Bamusa) in Agusan del Norte, Philippines, with the use of Geographic Information Systems (GIS) techniques. Bamboo's ecological, economic, and health benefits have gained prominence with the global emphasis on sustainable resource management and climate change mitigation. Agusan del Norte's favorable climate and ecosystems provide a suitable setting for bamboo plantations, but systematic planning is essential.

GIS has been used for suitability mapping. For instance, suitable areas for White-fleshed (Hylocereus undatus) and Red-fleshed (Hylocereus costaricensis) Dragon fruit Farming in Butuan City were identified using GIS [4]. Another study used GIS to map and estimate road traffic emissions in Caraga Region [5].

This research seeks to identify suitable areas for bamboo species based on the criteria [6]. The study aims to identify suitable areas for establishing bamboo species. The study seeks to determine the relevant parameters and factors that influence the suitability of different areas for bamboo species. By mapping these parameters, the goal is to pinpoint locations with the highest potential for prosperous bamboo species. Specifically, the study aims to identify parameters and factors for Key informant interview (KII) and conduct survey to various agency for factor ranking, determine weights and map areas that are potential sites of the bamboo species using AHP-MCDM method and identify the most highly suitable areas using a map and table. This study essential since it aims to help bamboo cultivators on what area they could plant bamboo efficiently and effectively. By devising a suitability map for Bamboo, we could identify area where bamboo could grow. The study scope involves leveraging GIS techniques to identify and map optimal sites for the Weighted Overlay Analysis in Agusan del Norte [7]. The findings of the study are specific to bamboo species and not be directly applicable to other types of plantations. The research mainly focuses on suitability mapping of bamboo species plantations in Agusan del Norte. The researchers will prioritize the utilization of openly accessible spatial dataset to incorporate Local Government Unit (LGU) of Agusan del Norte.

Bamboo, a symbol of resilience and sustainability, is increasingly recognized for its potential to address environmental challenges while supporting economic growth. This renewable resource, notable for its fast growth and high carbon storage capacity, offers a promising solution for sustainable development and climate change mitigation. In the context of Agusan del Norte, a province rich in natural diversity and climatic advantages, the introduction of bamboo cultivation could not only enhance local ecosystems but also provide substantial economic opportunities [8]. This study utilizes Geographic Information Systems (GIS) to assess land suitability for bamboo cultivation in Agusan del Norte, providing a scientific basis for informed decision-making in the establishment of bamboo plantations. By analyzing soil quality, topography, climate data, and existing vegetation, the study identifies optimal areas for bamboo growth. This GIS-based approach allows for precise mapping and evaluation of potential sites, ensuring that the selection of land for bamboo cultivation maximizes both environmental sustainability and economic viability. The results are intended to guide policymakers and farmers in developing strategies that leverage the ecological and economic benefits of bamboo, thereby enhancing local agriculture and contributing to broader environmental goals.

2. MATERIALS AND METHODS

2.1 Study Area

Agusan del Norte (Fig.1) located in the northeastern part of Mindanao Island within the Caraga Region of the Philippines, is characterized by its tropical, hot, and humid climate, with heavy rainfall supporting dense forests and rich biodiversity. Geographically positioned at approximately 8.9456° N latitude and 125.5319° E longitude, its varied topography includes rolling hills, expansive plains, and lush river valleys, fostering diverse ecosystems [9]. The province's significant river systems, particularly the Agusan River, are crucial for irrigation, transportation, and providing water for various uses. These natural features not only define the region's identity but also promote ecotourism and serve as vital resources for environmental and geographical research.

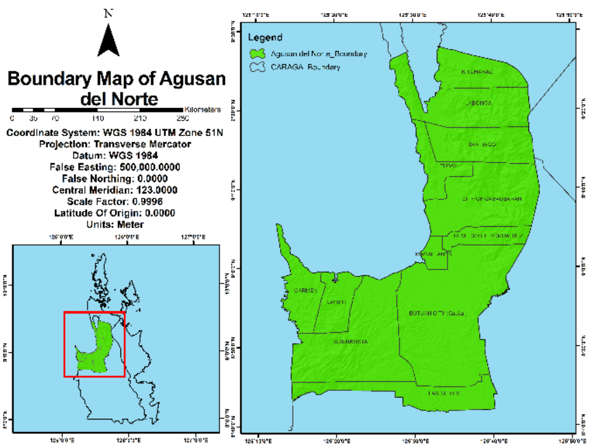

Fig. 1. Location map of Agusan del Norte, Mindanao, Philippines.

2.3. Datasets

Diverse datasets are utilized, including IMERG precipitation data from NASA's POWER website, soil texture data from CReATe, Digital Elevation Model (DEM) data from USGS Earth Explorer, temperature data from the World Climate website, and Land Use/Land Cover data from ESRI's Sentinel-2 Land Cover Explorer. These datasets offer various resolutions and information crucial for environmental and geographical research, enabling detailed analyses and accuracy assessments.

2.4. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), devised by Thomas L. Saaty in the 1970s, is a systematic approach for complex decision-making that combines mathematical and psychological insights. Applied to bamboo species cultivation, AHP involves defining the decision problem and relevant criteria such as soil type, climate, water availability, and economic factors, structured into a hierarchical model. Expert assessments are then captured in a Pair-wise Comparison Matrix (PWCM) to evaluate the relative importance of each criterion, using a scale from 1 to 9. This matrix facilitates the calculation of criterion weights by normalizing the eigenvector associated with the matrix's principal value. To ensure the accuracy of these assessments, a Consistency Ratio (CR) is computed; The CR requirements facilitate the identification of potential errors; thus, judgment improvements depend on these values. According to Saaty (1998), the pair-wise comparison results are relatively consistent if the CR value is ≤ 0.1. Otherwise, it indicates inconsistency and should be re-evaluated by the experts. However, dealing with multiple criteria can make achieving a CR ≤ 0.1 difficult. CR value of ≤ 0.2 or ≤ 0.3 is considered favorable, as it allows for greater flexibility in decision-making while avoiding non-compliance with the CR ≤ 0.1 [10].

In order to calculate the weights of each variable, a pair-wise comparison matrix was used. To determine whether the comparison between criteria in a matrix of pairwise comparison are consistent, the consistency ratio was then calculated using Equation 1.

$$CR = \frac{CI}{RI} \qquad Eq.1$$

Where, CI represents Consistency Index represented by Equation 2, and RI represents Random Index.

$$Cl = \frac{max - n}{n-1} \qquad Eq.2$$

The weights derived from this process are used in a weighted overlay analysis within Geographic Information Systems (GIS) to produce a composite suitability map, highlighting optimal areas for bamboo cultivation. This structured and transparent decision-making process, which integrates expert opinions, supports informed planning and management in environmental and resource management contexts.

2.5. Potential Parameters of Bamboo species

Bamboo plantations thrive under specific environmental and climatic conditions, making the selection of plantation sites a crucial factor for their successful cultivation. Rainfall is particularly important as bamboo plants require a consistent and ample water supply to maintain soil moisture and support their rapid growth. Adequate rainfall prevents stress on the plants and aids in the robust development of their root systems [11].

Temperature also plays a significant role in bamboo cultivation; it influences the plant's metabolic rates and physiological processes. Optimal temperature ranges are essential as they affect growth rates and overall health, making it necessary to consider regional climate conditions when planning bamboo plantations [12].
Soil texture and elevation are equally important factors in determining the suitability of an area for bamboo growth. Loamy soils are often considered ideal for bamboo because they provide a good balance of moisture retention and drainage, which supports healthy root development and ensures an adequate supply of water and nutrients [13]. Elevation affects the microclimate conditions, such as temperature and moisture levels, which in turn influence the growth and survival of bamboo. These microclimatic variations can significantly impact the geographical distribution and viability of bamboo plantations [14], emphasizing the need for detailed environmental assessments when selecting sites for bamboo cultivation to ensure sustainability and the long-term success of the plantation.
Moreover, based on the literature, the relevant criteria for bamboo growth requirements include rainfall, temperature, soil texture, elevation and land use land cover [15].

Table 1. Potential factors and parameters of bamboo species based on different literatures.

Factors	High Suitable	Suitable	Less Suitable
Rainfall	More than 1,200 mm per year	1,200 – 750 mm per year	Less than 750 mm per year
Temperature	26 – 21 degrees Celsius	20 – 18 degrees Celsius	17 below degrees Celsius
Soil Texture	Loamy soil	Clay and Sand	none
Elevation	1600 - 900 meters	900 - 200 meters	Below 200 meters (sea level)
LULC	Forest	Grassland, Barren	Fishpond, Inland water, swamps, built-up

2.6. Reclassification of Data

Reclassification of data is a crucial process in geographic information systems (GIS), where values in a dataset are transformed or categorized into a more manageable and interpretable format to facilitate easier analysis and support effective decision-making. This technique is particularly valuable when dealing with diverse and complex spatial data, allowing for the simplification of data into classes that represent ranges of values, such as risk levels, suitability scores, or vegetation types.

2.7. Assigning of weights

The weight for each factor was calculated using the Analytical Hierarchy Process (AHP) method of Multi-Criteria Decision Making (MCDM). In order to compute the weights for each factor, Key Informant Interview (KII) will be the initial action. Experts from various related agencies of the study will be interviewed; their responses will be important in a pair-wise comparison matrix, which will determine the weight of each factor. Each criterion of each agency will be compared to each other and calculated; the results will then be inputted into a matrix. The geometric mean of each row and column will be calculated. The geometric mean of the row is divided by the geometric mean of the column; then, the result will be the criteria weights. The criteria weights will then be normalized to ensure that the sum of all weights equals one, thus providing a consistent basis for decision-making [16].

2.8. Suitability Mapping

The utilization of ArcMap 10.1 software forms the cornerstone of the data processing workflow for the spatial analysis of bamboo species suitability. The process begins with an essential check to ensure that all datasets are aligned under the same projection and transformation settings. Should discrepancies exist, datasets are uniformly projected into the WGS 84, UTM Zone 51 N system to standardize the spatial reference across all data. Subsequently, all shapefile datasets, except for those already in raster format, are converted into raster format to maintain consistency in data handling. Critical to this step is ensuring that all raster data possess the same spatial resolution to preclude potential errors in subsequent analyses.
Once the datasets are harmonized in their format and resolution, they are then subjected to reclassification using ArcMap's reclassifying tool. This process involves categorizing the raster data into three suitability classes for bamboo growth: 'High suitable' (3), 'Suitable' (2), and 'Less suitable' (1). Following the reclassification, each raster dataset undergoes a weighted overlay analysis. Here, the weights, derived from Key Informant Interviews (KII) and the Analytic Hierarchy Process (AHP), are applied as the "Influence" factor within the software to determine the overall suitability. The final output from this methodological approach results in a map distinctly labeled into three classes, reflecting the varying degrees of suitability for bamboo cultivation based on the analyzed environmental and geographical data. Field surveys were carried out to identify bamboo locations across various municipalities. Each area was thoroughly surveyed, and the collected samples were used to validate the suitability map that was generated.

3. RESULTS AND DISCUSSIONS

3.1. Analytical Hierarchy Process Result

The Pairwise Comparison Matrix, a fundamental tool in the Analytical Hierarchy Process (AHP), was rigorously evaluated to derive weights for various criteria essential for assessing bamboo cultivation sites. This evaluation involved input from five experts in related fields, each bringing a specialized perspective to the analysis. The matrix allowed these experts to compare the importance of each criterion relative to others, facilitating a structured and systematic approach to decision-making. Each criterion such as soil texture, rainfall, temperature, land-cover type, and elevation were compared against one another in a pairwise manner. The responses from the experts were then used to calculate numerical weights for each criterion, reflecting their relative importance in the context of bamboo cultivation. These calculated weights are critical as they directly influence the outcome of the suitability analysis by prioritizing certain environmental factors over others based on expert judgment. Table 1 presents the calculated weights for various criteria essential for bamboo cultivation, as determined through the Analytical Hierarchy Process (AHP) involving five experts. The criteria evaluated include soil texture, rainfall, temperature, land-cover type, and elevation, each critical to the viability of bamboo growth. These weights are derived from a Pairwise Comparison Matrix, where experts ranked each factor relative to the others based on their importance for bamboo cultivation. This method ensures a systematic and quantitative approach to decision-making, reflecting expert consensus on the priority of each criterion. The use of AHP in this context allows for a nuanced analysis, ensuring that factors crucial to bamboo growth are appropriately weighted in the land suitability assessment. Consequently, this data-rich approach facilitates informed and strategic decision-making for establishing bamboo plantations.

Table 2. The environmental factors and their weighted importance in Bamboo plantation distribution analysis

Factors	Criteria Weights (in%)
Rainfall	23.85 %
Temperature	22.84 %
Soil Texture	27.98%
LULC	8.69%
Elevation	16.63%

In evaluating the reliability of derived weights in multi-criteria decision-making, the Consistency Ratio (CR) plays an important role. For the study, the CR was calculated to verify the consistency of judgments made in the pairwise comparison matrix, essential in the Analytic Hierarchy Process (AHP). The computed CR value was approximately 0.045474652, rounded off to 0.05. By setting the random index (RI) constant at 1.11 for five criteria, the CR value indicates a consistent decision-making process among the experts. According to Saaty's guidelines, a CR value of 0.1 or less is indicative of reasonable consistency, thus validating the coherence and reliability of the expert evaluations.

This level of consistency is critical as it underscores the robustness of the decisions made during the pairwise comparisons. The acceptance of a CR value below 0.1, as observed in this analysis, reassures stakeholders of the methodological soundness underlying the weight derivation process. As a result, the relative importance assigned to each criterion by the experts is confirmed to be consistent. The findings, supported by an acceptable CR value, reinforce the validity of the conclusions drawn from the AHP analysis, ensuring that the derived weights reflect a reliable assessment of the criteria's relative significance.

3.2. Weighted Overlay Analysis

The implementation of the Weighted Overlay Analysis, an integral component of Geographic Information Systems (GIS), was effectively leveraged to assess potential bamboo cultivation sites throughout Agusan del Norte. This analysis thoroughly incorporated a suite of environmental and geographical variables, including rainfall, temperature, soil texture, land-cover type, and elevation, to construct a comprehensive evaluation of land suitability for bamboo growth. Each variable was weighted according to its significance in fostering optimal bamboo cultivation conditions, with these weights meticulously derived from expert assessments and thorough reviews of relevant literature. The analysis utilized the Weighted Overlay Analysis tool within ArcMap software, enabling the synthesis of these varied datasets into a cohesive suitability map. This crucial map played a pivotal role in delineating regions that fulfill the essential conditions for bamboo cultivation, thereby facilitating precise agricultural planning and efficient resource distribution. This strategic approach not only enhances the accuracy of land suitability assessments but also supports sustainable agricultural practices by pinpointing areas best suited for bamboo cultivation based on scientific and expert analysis. Table 3 in the study presents the area distribution in hectares per reclassification criterion, quantifying the extent of land under each suitability category. This table is a pivotal element of the analysis as it translates the weighted criteria into tangible figures that stakeholders can use to gauge potential bamboo cultivation areas. The data reveals not only the total hectares available for cultivation but also highlights regions where conditions are less than ideal, necessitating interventions such as soil improvement or irrigation. Such detailed spatial analysis supports the decision-making process by providing a clear breakdown of land suitability across different environmental conditions, thereby optimizing the management and development strategies for bamboo cultivation in the region.

Table 3. Area Distribution for each Reclassified Criteria

Criteria	Area Distribution (ha)		
	High Suitable	Suitable	Less Suitable
Rainfall	9, 658	26, 656	2, 311, 595
Temperature	6, 049	25, 006	236, 014
Soil Texture	80, 490	93, 182	94, 291
LULC	18, 460	29, 860	219, 589
Elevation	326, 057	1, 044, 788	1, 537, 866

3.3. Bamboo Suitability Map

Table 4. Area distribution of each municipality with respect to the suitability of Bamboo Species

Municipality	Area Distribution (ha)		
	High Suitable	Suitable	Less Suitable
Buenavista	10222	33264	0
Butuan City	6064	58304	0
Carmen	2028	10154	0
Cabadbaran	6771	26481	3
Jabonga	66	26374	58
Kitcharao	5	13990	1
Las Nieves	1892	16673	0
Magallanes	0	3605	0
Nasipit	4412	6377	0
Remedios T. Rumualdez	2048	6152	3
Santiago	3023	16435	14
Tubay	1676	7361	76
Total	**38207**	**225170**	**155**

The suitability map of bamboo crop in Agusan del Norte, as depicted in Figure 2, categorizes the region into three distinct suitability statuses: High suitable, Suitable, and Less Suitable. The highly suitable areas are located in Buenavista, Las Nieves, Nasipit, Remedios T. Rumualdez (RTR), Santiago, and Tubay. These areas are identified as prime locations for bamboo cultivation due to the optimal growing conditions such as soil type, climate, and elevation that are favorable for bamboo species. Additionally, the natural vegetation in these areas provides an environment that enhances the growth and sustainability of bamboo, making it an ideal choice for agricultural expansion and forestry projects. Conversely, areas such as Tubay, Jabonga, Santiago, Cabadbaran, Remedios T. Rumualdez (RTR), and Kitcharao are classified as less suitable for bamboo cultivation. This lower suitability can be attributed to factors such as suboptimal soil conditions, inadequate rainfall, or less favorable topographical features that hinder the growth of bamboo. Despite these limitations, the presence of some bamboo cultivation in these areas suggests that with proper management and possibly some modifications to agricultural practices, the cultivation of bamboo could still be viable. This detailed mapping and analysis serve as a crucial tool for local farmers, policymakers, and environmental planners to make informed decisions about land use and agricultural development, prioritizing areas with high suitability while considering potential improvements in less suitable regions.

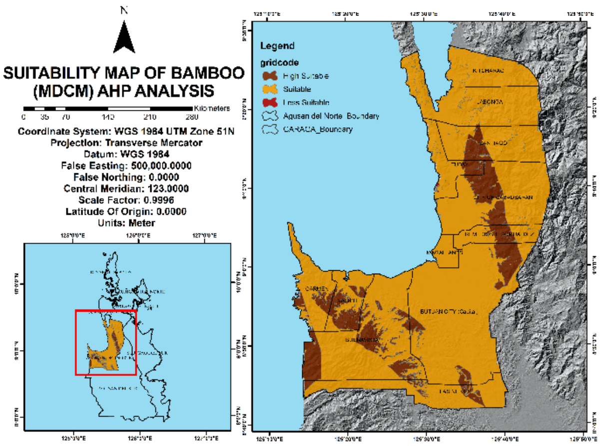

Figure 2. The Bamboo suitability map generated using AHP

4. CONCLUSIONS

The use of the Analytical Hierarchy Process (AHP) within the framework of Multi-Criteria Decision Making (MCDM) has proven to be a robust method for assessing the suitability of land for bamboo cultivation in Agusan del Norte. By integrating factors such as soil texture, rainfall, and temperature into a comprehensive decision-making matrix, stakeholders can better understand the environmental and climatic nuances that dictate the viability of bamboo cultivation in the region. In this analysis, soil texture emerged as the most influential factor, with a significant weight of 27.98%, underscoring its critical role in bamboo growth due to its impact on root development and water retention. Rainfall and temperature also play crucial roles, with respective weights of 23.85% and 22.84%, highlighting the importance of adequate water supply and suitable climatic conditions for optimal bamboo growth.

Further detailed by the Weighted Overlay Analysis, the findings revealed that a substantial portion of Agusan del Norte, approximately 38,207 hectares, offers highly suitable conditions for cultivating bamboo. This indicates a promising potential for agricultural and commercial forestry developments focused on bamboo. Conversely, the analysis identified only a minimal area of 155 hectares as less suitable, suggesting that most of the province can support bamboo cultivation to some extent. The 225,170 hectares deemed suitable, though not optimal, could still support bamboo growth with appropriate management practices and enhancements such as soil amendments and irrigation systems. This detailed spatial analysis not only aids in the strategic planning of bamboo cultivation but also serves as a model for similar agricultural assessments in other regions. The research findings demonstrate that 14.50% of the province's land area is highly suitable for bamboo cultivation, 85.44% is moderately suitable, and only 0.06% is deemed less suitable. Notably, the municipality of Buenavista, accounting for 24% of the highly suitable areas, emerges as a particularly promising location for such agricultural endeavors.

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