GIS-Based Land Suitability Analysis for Adlai Grits (Coix Lacryma-Jobi L.) Cultivation in Agusan Del Sur Using Multi-Criteria Decision-Making Approach - Analytical Hierarchy Process Technique

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GIS-Based Land Suitability Analysis for Adlai Grits (*Coix Lacryma-Jobi L.*) Cultivation in Agusan Del Sur Using Multi-Criteria Decision-Making Approach – Analytical Hierarchy Process Technique

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Abstract: *Adlai (Coix lacryma-jobi L.) is a nutritious and adaptable grain crop that is gaining popularity because of its resilience and advantages to one's health. This study presents the suitability maps and spatial data using Geographic Information System (GIS) for the cultivation of adlai grits under several sets of criteria encompassing the biophysical, economic profile, and climatic conditions in the province of Agusan del Sur. Nine experts in the field responded and used the results of an Analytical Hierarchical Process (AHP) to generate suitability ratings. The results showed that biophysical factors accounted for 66% of suitability, economic factors for 10%, and climatic factors for 24%. Suitability was classified into four classes: High, Moderate, Low, and Not Suitable. In Agusan del Sur, 25.4% (203,714 ha.) of the land is highly suitable, 41.7% (333,524 ha.) is moderately suitable, and 26.2% has a low suitability rating for adlai grits farming. There are also 6.83% (54,785.26 ha.) of areas not suitable for farming. Overall, 93.17% of the province's total area is suitable for AGC, which is 747,526.89 ha out of 802,312.06 ha.*

Keywords: Adlai; Cultivation; Suitability; AHP; GIS

1. INTRODUCTION

Population increase, climate change, and development placed pressure on both natural and agricultural resources. By 2050, the demand for food is anticipated to rise by anywhere from 59% to 98%. Farmers all throughout the world will need to enhance crop production, either by adding more area for farming or by improving productivity [1]. One of the major problems facing the Philippines is the lack of rice, which is a basic food for Filipinos. To meet the need, rice had previously been traded in, but the cost was high. Finding a different staple crop to replace rice and maize, such as adlay (*Coix lacryma-jobi L.)*, was one of the choices cooked grains taste like rice and have a similar morphology to rice [2] [3].

Adlai, like corn and rice, is a grass with long stalks that grows largely in tropical parts of Eastern and Southern Asia. It is also known as Chinese pearl barley or Jobs' Tears because the grains have a tear-like form and have become a staple diet for many indigenous people [4]. Adlai is grown as a cereal crop in the tropics and subtropics, including India, China, South Korea, the Philippines, Thailand, and Malaysia, and is currently being propagated as a staple meal in some areas of Mindanao [5].

Supposedly, the potential of land suitability for agricultural use is governed by an evaluation process of the climate, soil, water resources, and topographical and environmental components under the criteria given as well as the understanding of local biophysical limitations. Both climatic and non-climatic factors can have an impact on the suitability of a place for a certain plant species as well as its dispersion [6]. Climate conditions have a bigger influence on species dispersion on a larger geographic scale [7].

This study was focused on the assessment and generation of maps using GIS-based land suitability analysis for the cultivation of Adlai grits in the province of Agusan del Sur in various cultivation conditions. This study utilized a multi-criteria decision-making approach and Hierarchical Process technique. Different sets of parameters such as Biophysical (i.e., Land Use and Land Cover (LULC), Soil Texture, Soil Ph, Soil Type, Slope, Aspect, Elevation, Water Sources) climate conditions (i.e., Rainfall, Temperature, Evapotranspiration), Economic profile such as access to road networks and farm-to-market roads will be included in the study.

Thus, information concerning the suitability of land assessments and knowledge of farmers about adlai grits cultivation is valuable. Furthermore, this study forecasts to determine and recommend suitable areas for adlai grits cultivation in Agusan del Sur. The findings served as baseline information that can help Local Government Units (LGUs) and other stakeholders prioritize and target Adlai-related projects.

The study was conducted to determine the suitable areas for Adlai Grits cultivation (AGC) using a Gis-based land suitability assessment, the Multi-Criteria Evaluation Approach (MCDA) through the AHP technique in the province of Agusan del Sur. Specifically, it aims to (1) Assess Key Important Factors (KIF) for AGC which are the Biophysical, Economic, and Climatic factors; (2) Determine the land suitability by employing a multi-criteria decision-making approach through pairwise comparisons and AHP technique; (3) Evaluate the land suitability and generate a suitability map for Adlai grits cultivation in the province of Agusan del Sur, Philippines through GIS weighted overlay analysis.

2. MATERIALS AND METHODS

The general methodological framework of the study was to analyze and identify the land suitability of Agusan del Sur for Adlai grits cultivation, accurate selection of criteria was done, and various data was collected from different credible sources both primary (interview) and secondary (open source) sources.
An MCDM approach was used through the AHP technique—a pairwise comparison method to determine the weights of each important criterion to create maps. Processing and management of the gathered data sets were done with ArcGIS version 10.8, which is needed to generate suitability maps.

2.1 Study Area

The study was conducted in the province of Agusan del Sur, a landlocked province of the Philippines located in the Caraga Region in Mindanao. Prosperidad, its capital, shares borders with Agusan del Norte, Surigao del Sur, Davao Oriental, Davao de Oro, Davao del Norte, and Bukidnon, in that order. The province of Agusan del Sur is known as a big producer of rice and some agricultural products in the Caraga region in Mindanao.The climate map of the Philippines based on the modified coronas classification shows that the province falls under Type II [8].

2.2 Data Collection

In data collection, different data was acquired from various credible sources. These include the Geographic information data sets that are needed to process and generate maps. These were gathered from government agencies and institutions, open sources, and on-site validation, as well as the actual interview through questionnaires with the identified experts. The sources of data are tabulated in Table I below.

Table I. Data Collection Sources

Criteria	Data	Data Type/Project-ion	Sources
Bio-physical	Land Use and Land Cover (LULC)	Shapefile (SHP) (WGS_1984_ UTM_Zone_ 51N)	PAVO-Agugsan del Sur, Raster-Open Topography Open sources (2020)
	Soil Texture, Soil pH, and Soil Type	Shapefile (SHP) (WGS_1984_ UTM_Zone_ 51N)	CreATe, Food and Agriculture Organization (Open Sources)
	Slope, Aspect, and Elevation	Raster (TIFF) (WGS_1984_ UTM_Zone_ 51N)	Raster- Open Topography, NASA-DEM (2022)
	Water Sources	Vector file (WGS_1984_ UTM_Zone_ 51N)	Small Scale Irrigation Project (SSIP)- Caraga, CreATe (2022)
Economic	Road Networks	Vector file (WGS_1984_ UTM_Zone_ 51N)	Shapefile- Open Sources Map, PAO-Agusan del Sur.
Climate	Temperature	NetCDF (.nc) (WGS_1984_ UTM_Zone_ 51N)	Climatic Research Unit, (2021-2022)
	Rainfall	NetCDF (.nc) (WGS_1984_ UTM_Zone_ 51N)	Climatic Research Unit, (2021-2022)
	Evapotrans-piration	NetCDF (.nc) (WGS_1984_ UTM_Zone_ 51N)	Terraclimate (2022)

The following criteria or factors were identified as contributing to the set of suitable options. Proper selection of KIF for Adlai cultivation is critical to achieving optimal yield and quality of the product. Biophysical factors such as potential AGC sites, soil properties, topography, and water sources ensure that Adlai grows in the best possible conditions. Economic factor or the availability of access roads for accessibility and marketability of the produce. By monitoring climate factors like temperature, rainfall, and evapotranspiration, farmers can adjust their farming practices to optimize crop growth and yield. All these factors contribute to producing high-yield and quality Adlai grits, which are more valuable and more marketable. The proportional weight that should be given to each component in comparison to the weight given to the other factors; in other words, between each pair of criteria. In most cases, this is determined by the domain experts and their opinions. The Consistency Ratio (CR) was applied to evaluate the whole set of pairwise comparisons to determine how consistent they were [9]. On the other hand, AHP was employed in this study. It is a method for organizing and analyzing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then [10]. AHP is one of the most well-known and often used multicriteria. This method integrates the procedures of assessing alternatives and aggregating them to locate the most important ones. The method is used to rank a set of alternatives or to choose the best option from a set of alternatives. Rankings and selections are made considering a broad objective that is divided into several factors [11] that follows the pairwise comparison consistency. Thus, a series of actual interviews to nine (9) identified experts were conducted in various government agencies, private sector organizations and farmers and/or practitioners of Adlai grits cultivation. Each respondent was given AHP questionnaires indicating the three factors namely, Biophysical, Economic, and Climatic, where they are tasked to give rating on which they think are the most important factors to consider using the intensity of relative importance scale. Each weight of the parameters was computed using an AHP calculator by Goepel namely AHP Analytic Hierarchy Process (EVM multiple inputs) version 15.09.2018. The AHP calculator by Goepel was used to determine the weights of each parameter in the hierarchy. This tool considers multiple inputs and calculates the relative weights of each criterion or sub-criterion, which helps in determining their importance in the overall decision-making process [12].
Once the weights were calculated, they were integrated into the ArcGIS ArcMap 10.8 along with the thematic maps. This allowed for the generation and extraction of a suitability map for AGC from different datasets. The resulting map would show the areas that are most suitable for adlai cultivation on the criteria and parameters that were established in the AHP hierarchy.

2.3 Data Analysis

The first important phase in land suitability analysis mapping is data preparation. In this research methodology, interpolation and overlay using a GIS domain based on multi-criteria analysis and an AHP were used to evaluate the appropriateness of the land. The following datasets and raw maps were compiled for this purpose and were collected from the various offices, agencies, and open sources involved as well as primary data gathered through interviewing experts, especially in determining the weights of each of the criteria. Before integrating the raw maps into the GIS domain, the raw maps were first processed. To establish uniformity in the GIS mapping processes, the Land Use Map created from this data was used to cut all other maps. All these procedures were carried out on a platform running ArcGIS Software version 10.8. The guide in scaling the factors in AGC suitability with its corresponding description was classified on a scale from 1-4 as follows: not suitable (1), low suitable (2), moderately suitable (3), and highly suitable (4) [13]. The final suitability map has been processed following the generation of the overlaying maps in the system. To determine the percent significance of each of the primary criteria, the final weights (Eigenvector values) were employed. The study area's suitability maps based on different biophysical, economic, and environmental aspects are then identified.

3. RESULTS AND DISCUSSIONS

This section focuses on addressing the research questions and objectives outlined, presenting results, and discussing the analysis of the collected data. Results derived from data analysis are presented, interpreted, and discussed in relation to existing literature and theoretical frameworks. The suitability map for Adlai grits, which is the aim of the study, has been developed by compiling and processing several maps.

3.1 Weighted Suitability Criteria Matrix

The weighting matrix for processing the suitability map can be defined by the Analytical Hierarchy Process used in the decision-making assessment technique. The final weight evaluation is completed using Eigenvector vectors computed using AHP. The final weights for each parameter and criterion applied in overlaying maps using weighted overlay analysis in ArcGIS are shown in Table II. The consistency of the eigenvector values was also examined using the consistency ratio (CR), which must not be more than 0.10. All the eigenvector values fall within the permitted consistency ratio.

The sub-criteria were summed up to determine the final hierarchy of the main criteria where it was found that the Biophysical factors rank first constituting 0.66 (66%) of the overall final weight. The weights were heavily influenced by the expert's decision-making based on their firsthand experiences and expertise. Aside from these, the decision that arranges their selection of the Biophysical factor is the main consideration in AGC, because they directly affect the growth and development of the adlai crop. This was followed by the Climatic factor garnered a weight of 0.24 (24%) which included rainfall, temperature, and evapotranspiration. While biophysical factors encompass a broader range of environmental conditions, climate plays a crucial role due to its long-term influence on the overall suitability of a region for adlai cultivation. The last main criterion that accumulates the least weight which values 0.10 (10%) of the total final weight was the Economic factor or the existing access roads in the study area. Based on the result of the experts' interview, Agusan del Sur was least likely to prioritize generating the suitability map for adlai since the fact that most of the municipalities and one city of the province have already implemented projects in farm-to-market roads, transportation networks, and other extension services concerning AGC and other crops.

3.2 Suitability Maps

In order to complete the study's objective of creating a map showing the suitability of the adlai grits cultivation in the province, the thematic maps were then processed and created. The final Adlai Grits Cultivation Suitability Map was created from the weighted maps, including the biophysical, economic, and climatic maps.

3.2.1 Biophysical Suitability Map

The Biophysical Map shown in Figure 1 was generated using the criteria maps which are the Potential AGC Site Map (0.06); Soil Properties Map (0.38); topography map (0.10) and water sources map (0.12) presented in the said weighting matrix. With a total area of 802,312.06 hectares, 141,287.15 ha. (17.61%) is found to be highly suitable, 502,086.88 ha. (62.58%) is moderately suitable and 158,938.02 ha (19.81%) is at low suitability. This indicates that the province of Agusan del Sur is suitable for AGC in terms of its biophysical aspects. The fertile soils in the province of Agusan del Sur are typically suited for cultivation. Loam, sandy loam, and clay loam are just a few of the several types of soil that Adlai thrives on. There are certain constraints that may limit the suitability of an area for adlai cultivation. One of these constraints is the land use of the area. Built-up areas, such as urban or residential areas, are not appropriate for adlai cultivation since they are already developed for other purposes. Protected forest areas are also not suitable for adlai cultivation since these areas are protected to conserve natural resources, biodiversity, and ecological balance. Marshland areas and other water bodies may also be unsuitable for adlai cultivation since these areas are characterized by wet, saturated soil conditions that may not be compatible with the growth and development of adlai plants.

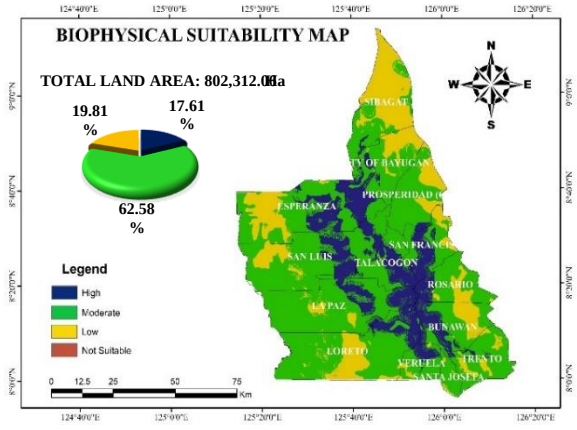

Figure 1. Biophysical Suitability Map and its distribution.

Table II. Final Weights of each of the Criteria

Main Criteria	Weight	Sub-Criteria	Weight	Criteria	Weight
BIO-PHYSICAL	0.66	Potential AGC Sites	0.06	Land Use and Land Cover	0.09
		Soil Properties	0.38	Soil Type	0.28
				Soil Ph	0.30
		Topography	0.10	Slope, Aspect, Elevation	0.15
		Water Sources	0.12	Distance from Rivers, Streams, and other water sources	0.18
ECONOMIC	0.10	Road Map	0.10	Road Networks	1.00
CLIMATE	0.24	Climate Map	0.24	Rainfall	0.44
				Temperature	0.37
				Evapotrans-piration	0.19

3.2.2 Economic Suitability Map

The economic component of the study geographic area evaluates the marketability and accessibility of farm-to-market and key roadways. Figure 2 shows that the area is suitable for adlai grits cultivation in terms of its economic aspect. A total land area of 758,509 hectares (94.16%) is suitable for adlai grits cultivation where 415, 649 hectares (51.8%) is Highly Suitable, 264, 783 hectares (33%) is Moderately Suitable and 75,076 hectares (9.36%) is Lowly Suitable which leaves an area of 46,804 hectares (5.8%) as Not Suitable. A network of roads and agricultural trails provide easy access to the different municipalities of Agusan del Sur, allowing farmers to efficiently transport their Adlai produce. This accessibility is critical for timely delivery to markets and processing plants, reducing post-harvest losses, and increasing farmer profitability.

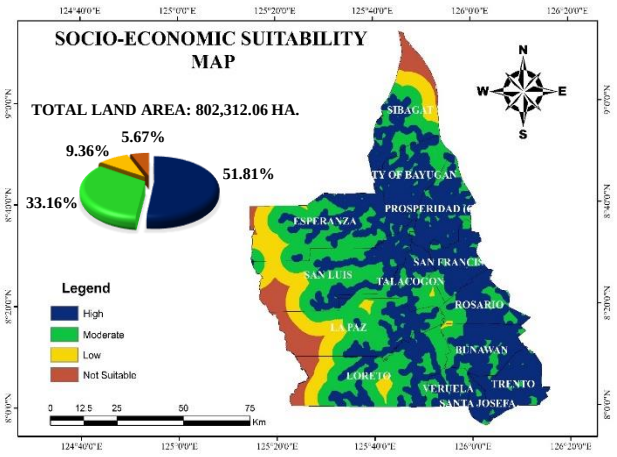

Figure 2. Economic Suitability Map and Its Distribution.

3.2.3 Climate Suitability Map

Agusan del Sur's suitable climate, characterized by warm annual temperatures, abundant rainfall, and moderate evapotranspiration, provides favorable conditions for adlai grits cultivation, supporting optimal plant growth and water availability. The Climate Suitability Map presented in Figure 3, can be seen as suitable at first glance. It indicates that the province can achieve suitably moderate adlai yield potential in terms of its climatic conditions. About 27,108.6 ha (3.4%) are highly suitable and 775,096.87 ha (96.6%) are moderately suitable. Agusan del Sur is only moderately suitable for adlai grit cultivation in terms of its climatic factors such as high rainfall and temperature. According to a study published by the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD), adlai performs best in areas with moderate rainfall and temperatures ranging from 20-30°C. However, Agusan del Sur receives high rainfall levels throughout the year, which can hinder adlai growth and increase the prevalence of fungal diseases.

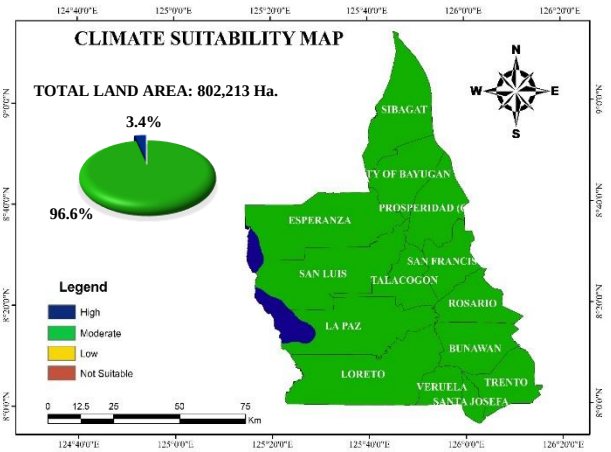

Figure 3. Climate Suitability Map and Its Distribution.

3.2.4 Comparison between the Main Criteria

The results stipulate that the area is suitable in terms of biophysical, economic, and climate factors presented in the figure below. Both biophysical and climatic aspects are suitable since the fact that province was comprised mainly of suitable topographical setting that is favorable for adlai cultivation. Adlai, which is a type of millet, thrives in warm weather conditions and requires a well-distributed water supply. The region's climate provides an optimal environment for adlai cultivation. The province is highly suitable for adlai grits cultivation with respect to its biophysical conditions as well as its climate conditions. Figure 4 shows the graphical representation for the comparison of the three main criteria: biophysical, economic, and climate.

3.3 Final Suitability Map for Adlai Grits Cultivation

The GIS domain's Weighted Overlay Analysis was used to process the three primary criteria. The three key criteria—biophysical, economic, and climate—have weights of 0.66 (66%), 0.10 (10%), and 0.24 (24%), respectively, according to the weights determined from the calculated Eigenvector values in the AHP. Figure 6 displays the map that was produced using the earlier-mentioned approach. Considering the biophysical, economic, and climatic factors, it can be concluded that the province is suitable for the production of adlai grits.

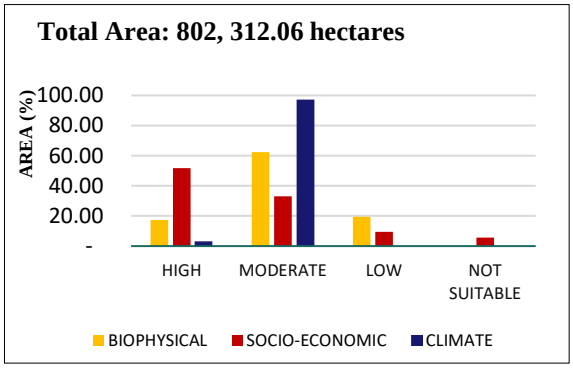

Figure 5. Comparison between the Three Main Criteria

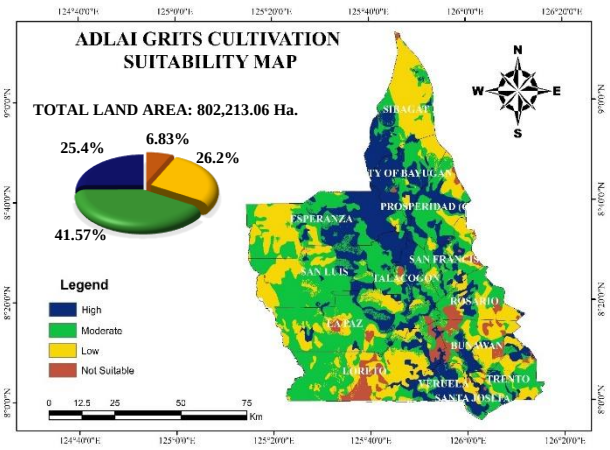

Figure 6. Adlai Grits Suitability Map and Its Distribution.

Results shows that the province of Agusan del Sur was evidently suitable for the adlai grits cultivation with an overall land area of 747,526.8 hectares (93.17%) and a total land area of 203,714 hectares (25.4 %) that is highly suitable. The overall moderately suitable area was 333,524 hectares (41.57%). Only a small land area that was suitably low at about 26.2 % of the total area equivalent to 210,205.76 hectares. On the other hand, 54, 785.26 hectares (6.83%) was found out to be not suitable. This covers with marshlands, swamps, closed canopy forests, and built-up areas. Adlai requires well-drained soils for optimal growth. Marshlands and swamps have waterlogged conditions, which hinder root development and can lead to waterlogging stress, root rot, and overall poor plant health. Also, Adlai is a sun-loving crop that requires full sunlight for its growth and development. Closed canopy forests have dense tree cover that restricts sunlight penetration, depriving adlai plants of the required light levels. As a result, adlai would struggle to photosynthesize and achieve optimal yields in such shaded environments. The final suitability map as shown in the figure also presented a good result as it showed that most of the highly suitable areas were the existing adlai farms key areas. It infers that adlai grits cultivation is in high to moderate suitability within the province of Agusan del Sur.

3.4 Distribution of Suitable Areas per Municipality and City

According to the findings presented in Table III, Esperanza has the largest suitable area for the cultivation of adlai grits, measuring 106,074.79 hectares (14.86%), followed by San Luis, which has a total suitable area of 101,399.11 hectares (14.20%), and La Paz, which has the third-highest suitable area at 92,592.68 hectares (12.97%). These areas are mainly covered with undisturbed forests and cultivated grasslands. Santa Josefa has a lowest suitable area of 9,820.29 hectares (1.38%). The major factor affecting its suitability is the land area of the said boundaries for each of the 13 municipalities and one city.

Table III. Suitable Area for Adlai Grits Cultivation per City/Municipality

City/ Municipality	Area (ha.)	Suitable Area (ha.)	% Suitable area	Rank
Esperanza	106,713.58	106,074.79	14.86%	1
San Luis	102,049.29	101,399.11	14.20%	2
La Paz	96,833.96	92,592.68	12.97%	3
Loreto	107,774.73	90,410.21	12.66%	4
Sibagat	69,071.99	67,962.76	9.52%	5
City of Bayugan	47,697.62	47,326.42	6.63%	6
Prosperidad	47,338.70	46,236.84	6.48%	7
Bunawan	46,498.35	37,073.57	5.19%	8
Trento	38,878.24	37,230.99	4.98%	9
Talacogon	35,283.59	34,427.81	4.82%	10
San Fransisco	35,268.46	33,696.32	4.72%	11
Rosario	37,974.00	23,360.28	3.27%	12
Veruela	20,496.19	19,914.82	2.79%	13
Santa Josefa	10,433.35	98,20.29	1.38%	14
Total	802,312.06	747,526.89	93.17%	

The municipality of Esperanza has been ranked as the top location for Adlai rice grits cultivation due to its favorable climate, soil characteristics, and accessibility to road networks. The study conducted by the Department of Agriculture-Bureau of Soils and Water Management (DA-BSWM) also showed that the soil in this area has a pH level of 5.5 to 6.5, which is slightly acidic, making it suitable for Adlai cultivation. The town is accessible through major transportation routes, giving farmers easier access to buyers and markets for their Adlai products.

3.5 Site Validation

To confirm the map suitability data, Figure 7 below shows the validation area with the actual production of the Adlai grits was identified. In this study, Brgy. Doña Maxima with an approximate 3.5 hectares of adlai grits (18 bags of harvest), Brgy. Doña Flavia with 1.25 hectares (11 bags of harvest) and lastly Brgy Nuevo Trabajo with a total area of 1 hectare (12 bags of harvest), serves as the validation area for the suitability map relating with its production per hill. Based on the suitability map generated for Adlai Grits Cultivation, Brgy. Doña Maxima belongs to Highly Suitable are for AGC, while the two Barangays; Nuevo Trabajo and Doña Flavia situated in the Moderately Suitable site. San Luis, located in the province of Agusan del Sur, where adlai is being piloted. However, despite its promising prospects, the yield of adlai production in the municipality is comparatively low compared to the average 3,000 kg./ha (yield). Adlai is a relatively new

crop in the area, and farmers may not have had enough time to fully understand its growing requirements. It is important to note that adlai is in pilot testing in the area. With the right practices and resources, farmers in San Luis can be enable to successfully cultivate adlai, leading to increased yield and improved livelihoods in the province.

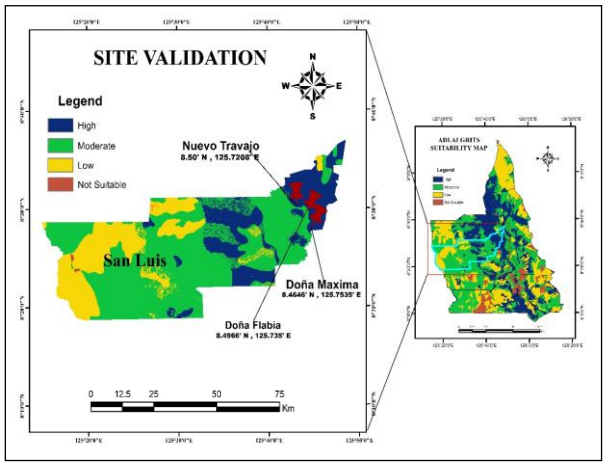

Figure 7. Validated Sites Cultivating Adlai Grits.

4. CONCLUSION

In order to promote sustainable development, the decision-making processes involved in the establishment of land uses and land use policies necessarily require the precise and credible land evaluation. The aim of this study is on mapping the suitable areas for adlai cultivation in the province of Agusan del Sur utilizing the Geographic Information Systems (GIS) domain. The biophysical, economic, and climatic factors that define the research area are all covered by various specified criteria. To accomplish the aim of the study, the following thematic maps are created: Land Use and Land Cover, soil texture map, digital elevation model (DEM), road map, water sources map, rainfall map, mean temperature map, and evapotranspiration map.

Through several interviews with various experts and professionals on the subject, the identified Key Important Factors (KIF) to produce adlai grits have been weighted. By using pairwise comparisons and a multi-criteria decision-making technique, these elements are combined to get the appropriateness ratings. In order to determine priority scales, the AHP, also known as the Saaty Method, primarily uses pairwise comparisons. The values of the generated Eigenvectors have been combined as the weights of the various specified parameters and criteria used to create the maps.

ArcGIS Software 10.8 was used in the GIS domain to generate and execute the thematic maps. Through GIS weighted overlay analysis, the degree of appropriateness for AGC was determined by indicating computed weights of the biophysical, economic, and climatic of 66.49%, 10.01%, and 23.5%, respectively. Four suitability categories—High, Moderate, Low, and Not Suitable—are given in descending order.

According to the interpretation of the findings, Agusan del Sur was obviously favorable for the production of adlai grits. The overall land area is made up of 333,524 hectares (41.57%) of moderately suitable land and 203,714 hectares (25.4%) of highly suitable land. Only 210,205.76 hectares, or around 26.2% of the entire area, was suitably low. However, 54,785.26 hectares (6.83%) were found to be unsuitable.

The researchers concluded that the pairwise comparisons used in the multi-criteria decision-making process which is the AHP suggestively enable in providing a reliable and precise evaluation of the land area through the GIS domain. The final suitability map for the cultivation of adlai grits has been generated using GIS domains, particularly the weighted overlay analysis.

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