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GIS-Based Land Suitability Analysis for Solar Powered Irrigation System in Non-Irrigated Rice Production Areas of Davao Del Norte

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Abstract

The Solar-Powered Irrigation System (SPIS) flagship program of the Department of Agriculture (DA) has been undertaken with the purpose of creating a vibrant agricultural economy, but its provision is currently limited due to its budget allocation. Because of this, detailed information and accurate planning are essential in identifying the most suitable locations for SPIS installation, optimizing system potential and maximizing limited resources. This study aimed to develop a provincial land suitability map of SPIS that will serve as a tool for farmers, Local Government Units, and other interested entities. Its result was obtained by combining the Analytical Hierarchy Process and the Geographical Information System Weighted overlay technique. The obtained data indicates that 0.10% (334.93 ha), 29.40% (102,696.34 ha), 37.24% (130,078.61 ha), 4.79% (16,746.29 ha) and 28.47% (99,439.60 ha) of Davao del Norte province are positioned in extremely, highly, moderately, less, and unsuitable areas, respectively. Extremely suitable areas are found in Samal (314 ha), Sto. Tomas (15 ha), and Panabo (7 ha), with non-irrigated rice production areas of 67 ha, 288 ha, and 125 ha, respectively. Asuncion and Kapalong have the highest non-irrigated rice areas of 739 and 721 hectares, respectively, with a total rating of 90% for highly suitable (22,097.95 ha) and 29% (11,241.40 ha) for moderately suitable. Non-irrigated rice areas intersect mostly in highly suitable regions; it is highly recommended that these municipalities are prioritized in establishing SPIS projects.

Keywords: solar power, irrigation, analytical hierarchy process, multiple criteria decision-making

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World population is growing exponentially at a rate of 82 million people per year, with latest projections showing that the global population will reach 11 billion by 2088 (Roser, Ritchie, & Ortiz-Ospina, 2019). Along with this, food demand will also increase, necessitating more farming and irrigation all over the world (Mohammed Wazed, et al. 2018). According to FAO, there were over 324 million hectares equipped for irrigation worldwide as of 2012, of which 111 million hectares use pumps to supply water from the source to the field. These pumps are powered in several ways, but the ones most commonly used in agriculture are electric and diesel motors, with the latter used in areas without ready access to electricity (Alves, et al. 2014). However, widespread use of fossil fuels like diesel has significantly degraded the environment, diffusing greenhouse gases, polluting particles such as CO_2, SO_2, NOx, and other harmful gases (Asakereh, Soleymani & Sheikhdavoodi, 2017; Dickmann, 2006; Shao & Chu, 2008).

As of 2016, the Philippines has about 3,128,631 hectares of irrigable land, with only 1,855,982 hectares (about 60%) having irrigation systems. Of these, 848,617 hectares are served by the National Irrigation System, 648,417 hectares by Communal Irrigation Systems, and 358,949 hectares by Private Irrigation Systems and Outside Government Association-assisted (OGA) Irrigation Systems. The remaining 1,272,649 hectares are non-irrigated (PSA, 2019). Davao del Norte has almost a similar operational service area percentage, with the national data provided by the NIA Region XI. The total existing irrigated area in the province is about 65.8 percent out of its 34,818 hectares of potential serviceable area.

Global crop production is estimated to increase by as much as 20% if current rainfed croplands are instead replaced with irrigated croplands (Siebert & Döll, 2010). With the current population growth rate, the country has to irrigate an additional 80,000 hectares every year to feed a new generation of Filipinos. This propelled the Department of Agriculture (DA) to implement solar-powered irrigation projects in different areas of the country, with the vision to increase production yield by harnessing surface water sources and solar energy, while also offsetting the use of harmful fossil fuels and the need to extract water from underground sources (Flora, 2018).

Solar energy is arguably the cleanest and most unlimited form of renewable energy. It can be harvested from almost all locations (sunny), decentralizing energy supply while enhancing energy security (IEA, 2013). It also potentially reduces dependency on limited fossil fuel reserves, which mitigates the impact on climate change (Shafiee & Topal, 2009). Solar power does this by converting solar radiation into electricity either through the direct method, using photovoltaic (PV) cells, or the indirect method, using concentrated solar power

(CSP). The former is perhaps one of the best options to supply the world future energy demand sustainably (Razykov, et al. 2011), with the International Energy Agency (IEA) reporting that solar electricity output is projected to increase by 20–25% in 2050. This makes it possible to generate 9,000 TWh electricity by PV and CSP systems while reducing CO_2 emissions by about 6 billion tons per year (IEA, 2010).

As solar panels become more affordable, PV technologies become more identified as high-potential solutions for rural electrification, as well as water extraction for both domestic and irrigation purposes. This makes solar PV pumps an important emerging technology for smallholder farmers; in fact, solar PV-based pumping can be more economically viable in urban and rural areas compared to both diesel- and electricity-powered pumps (Chandel, Naik, and Chandel, 2015).

In recent years, the Geographical Information System (GIS) has become increasingly popular for various site selection and energy planning studies (Noorollahi, et al. 2016), and GIS-based mapping has been used effectively to assess the suitability and feasibility of renewable energy, water resources, or even specific crop systems (Akyol, Kaya, & Alkan, 2016; Palmas, et al. 2012; Schmitter, et al. 2018; Worqlul, et al. 2017).

The objective of this study was to develop a suitability map for SPIS installation, particularly in Davao del Norte's non-irrigated rice production, as well as the following: prepare criteria layers that will influence the land suitability of SPIS projects, determine the weight of the criteria identified using the Multiple-Criteria Decision-Making (MCDM) tool, and produce a provincial-level land suitability map for SPIS installation in non-irrigated rice production areas.

Identifying suitable locations for the installation of solar-powered irrigation system, as with other engineering projects, necessitates detailed information and accurate planning. In harnessing solar energy, along with the necessity of solar insolation potential in the region, it is important to investigate different places while considering various technical, socioeconomic, and environmental criteria (Noorollahi et al. 2016). Since the Philippine government aims toward sustainable agriculture while protecting the natural environment by introducing solar power irrigation systems in the country, the researchers authored this study and envisioned it to provide a resource for aiding local farmers, Local Government Units (LGUs), and other interested planners in effective project management.

Materials and Methods

Description of the study area

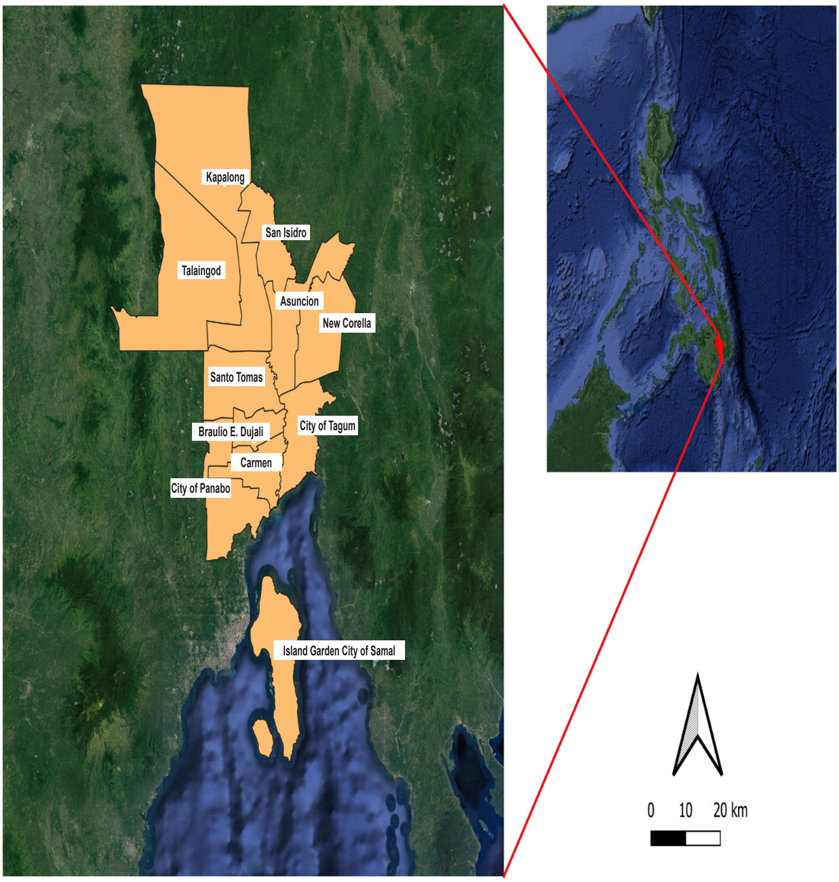

Figure 1. Boundary Map of Davao del Norte Province

The province's total rice production area is about 19,000 hectares (5.45% of the total area), of which 83 percent is irrigated, 15 percent is rainfed lowland ecosystem, and 2 percent is rainfed highland ecosystem. Figure 2 (see next page) shows that large areas for rice are found in the municipality of Asuncion, Dujali, Carmen, Kapalong, New Corella, and Santo Tomas.

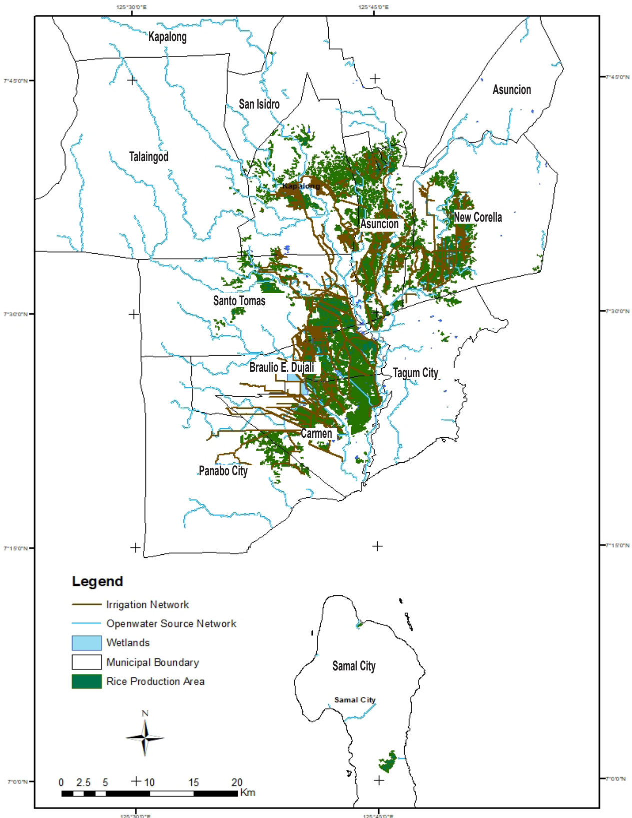

Figure 2. Rice Production Areas, Irrigation network and Open Water Source in Davao del Norte

Data Collection

The data collection was initiated after identifying the criteria that will influence site selection for SPIS establishment. The stream network was processed in GIS using the Spatial Analyst Tool-Hydrology and Synthetic Aperture Radar (SAR) Digital Elevation Model (DEM) collected from Light Detection and Ranging (LiDAR) project. Similarly, the slope layer was also processed in GIS using Spatial Analyst Tool-Surface and SAR-DEM. Table 1 shows the sources of data collected.

Table 1. Criteria Layers for SPIS Land Suitability Analysis

Layer/Map	Source	Type of Data	Resolution
Solar Insolation	SolarGIS	Raster	0.008mx0.008m
Average Annual Temperature	PhilGIS	Raster	913mx913m
Road Network	PPDO, Davao del Norte	Vector	
Stream Network	Processed	Raster	10mx10m
Irrigation Network	Lidar	Vector	
Groundwater Availability	DA-CIRDUP	Georeferenced image	
Slope	Processed	Raster	10mx10m
Elevation	Lidar	Raster – SAR DEM	10mx10m
Land use/Cover	PPDO, Davao del Norte	Vector	
Rice Production Area	Planning Division of each municipality	Vector	
Irrigation Service Area (Partial data)	NIA Region XI	Vector	

Study Outline

In this study, GIS with a multi-criteria decision-making approach was utilized to identify the most suitable locations for SPIS installation in Davao del Norte, the outline of which is illustrated in Figure 3. Primary and secondary data were collected before land suitability processing.

All digitization, conversion, and analysis of map processes were performed using GIS. The calculations related to MCDM were done utilizing both manual computation and Expert Choice software.

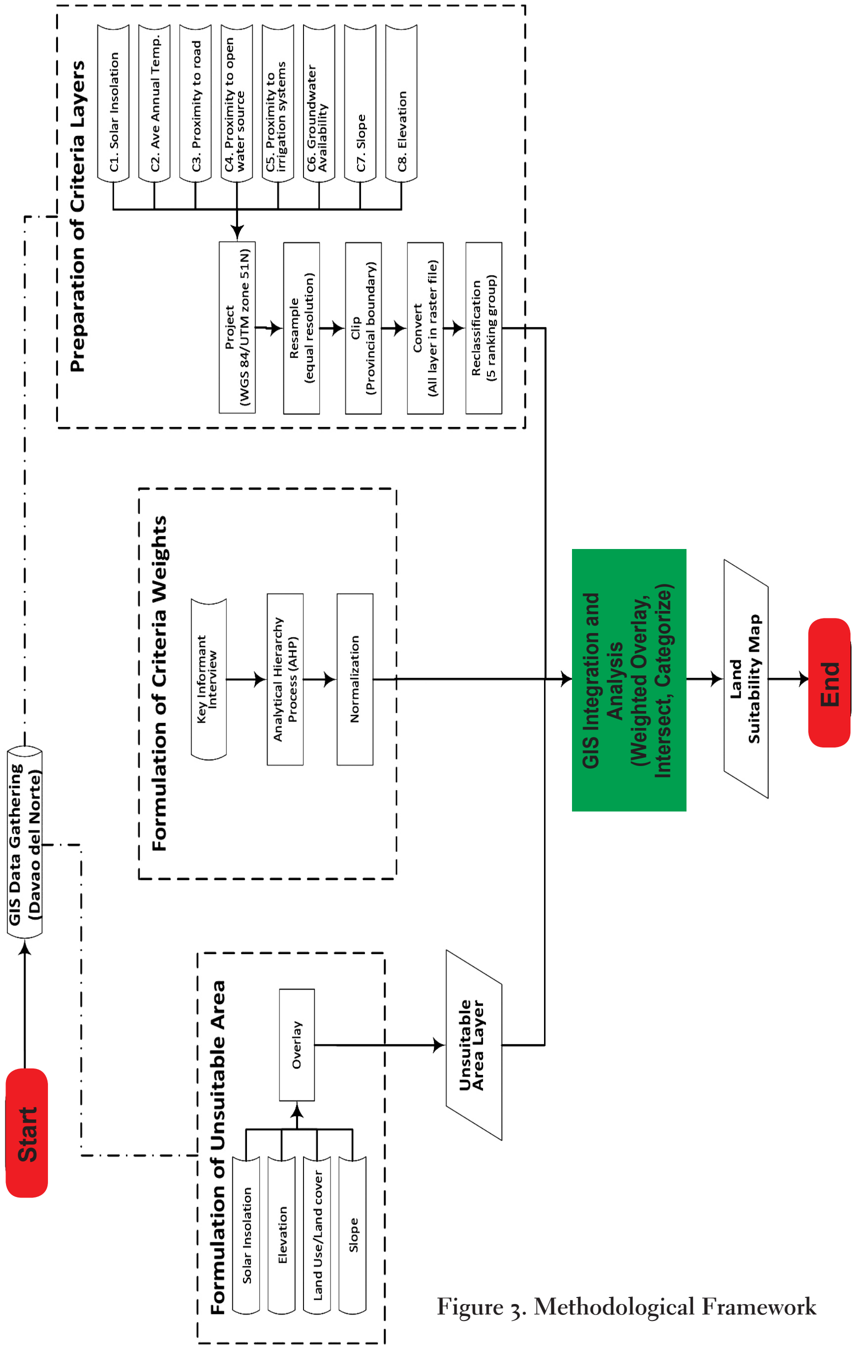

Figure 3. Methodological Framework

Constraints factors and evaluation criteria layers were identified based on data availability within the area of the study. After identification of said factors, land suitability analysis was begun. The layer formulation involved GIS processing of the different spatial datasets. Key informant interviews (KII) were likewise conducted to determine the weight of each evaluation criterion, and these then were normalized and integrated using land suitability analysis modeling.

Formulation of unsuitable area

This process aimed to investigate the different constraints that will formulate the unsuitable area map for harnessing solar energy in Davao del Norte. Considering the different constraints is essential in using the SPIS's maximum potential. According to Ong, et al. (2013) and Schmitter, et al. (2018), harnessing solar energy in areas with these following conditions (Table 2) is uneconomical.

Table 2. Constraints Factors

Factor as Constraint	Ranges of values as constraints within the factor
Land Cover	Land cover other than agriculture, grass, shrub, and bare land is not a suitable option for SPIS installation
Elevation	Elevation higher than 2.2 km above sea level
Slope	Slope greater than 8% for irrigated agriculture
Solar Insolation	Areas with solar insolation lower than 1,300 kWh $m^{-2} y^{-1}$

Preparation of Evaluation Criteria Layers

The concept of selecting the most suitable sites of a new project is normally studied in the form of different group categories, such as environment, economic, geographical, demographic, land-use, hydrological, security, and technical. However, the site selection criteria in this study were based on the integration of literature reviews on harnessing solar energy both for agriculture and electric power generation. Figure 4 shows the influencing criteria classified into three categories: climatology, location, and environment. Questionnaires were given to experts to determine the importance of each criteria factor in selecting the suitable site.

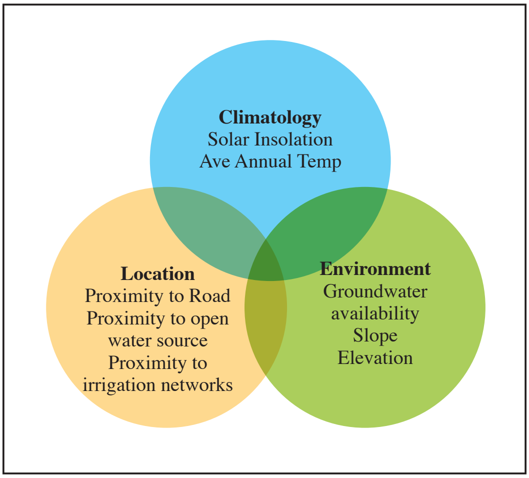

Figure 4. Categories of Criteria Factor Influencing Site Selection for SPIS

Criteria 1. Solar insolation. Solar irradiance is the power received from the sun in the form of electromagnetic radiation per unit area, measured in watts per square meter (W/m^2). Solar panels, a component of SPIS, depend primarily on the solar radiation, making year-round sunlight sufficiency critical. Solar panel efficiency is directly proportional to solar intensity, with sunnier sites considered as ideal places for SPIS installation (Kiatreungwattana, et al., 2013). But while sites having solar insolation lower than 1,300 kWh/m^2y were removed, solar insolation higher than 2,000 kWh/m^2y can also impair the solar panel performance due to the subsequent increase in ambient temperature (Noorollahi et al., 2016).

Criteria 2. Average annual temperature. According to the law of thermodynamics, with increased heat comes decreased power output; this applies to SPIS solar panels. This means that warmer temperatures will always mean less output for PV cells, with a productivity reduction of about 10 to 25 percent. In solar panels, the temperature is a result of ambient temperature and solar radiation intensity. The performance of the modules of PV systems declines with an increase in ambient temperature. For every 1°C rise in the cell temperature at temperatures above 25°C, the amount of generated energy decreases by about 0.4%–0.5% (Huld & Amillo, 2015).

Criteria 3. Road proximity. Potential SPIS sites that are more accessible will have cheaper installation costs, so potential sites for SPIS near roads are given more weight to ease the cost of transporting equipment.

Criteria 4. Groundwater availability. A nearby available water source is a primary requirement in planning irrigation projects. Based on the Comprehensive Irrigation Research and Development Umbrella Program (CIRDUP) of the Department of Agriculture, the groundwater map of the Philippines is classified into three major groups: shallow well areas, where water can be found within 20m below the ground; deep well areas, where water is present at a distance greater than 20m below the ground; and lastly, difficult areas.

Since there are only three categories, the highest score was given to shallow well areas, the average score to deep well areas, and the lowest score to difficult areas.

Criteria 5. Proximity to open water sources. An open water source is equally important with the groundwater source, and this can be determined using the hydrology tool in the GIS application. Stream networks were mapped out using the digital elevation model dataset. In this study, the distance away from the stream network was considered, with areas located near the source deemed more suitable compared to areas located far from the open water source.

Criteria 6. Irrigation network proximity. Irrigation is particularly vital in rice production because it increases production yield. To date, Davao del Norte has a total of sixteen irrigation networks. Since the focus of this study is aimed to prioritize rice areas without access to irrigation networks, areas located near the irrigation networks were given the lowest score while the farthest the highest score.

Criteria 7. Slope. This is the steepness of the hill, which can be measured in both units of degrees or percent. Using GIS, determining the slope is simplified using the spatial analyst tool, which calculates the maximum rate of change in value from that cell to its neighbors. The maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell.

Slopes are also critical in irrigated agriculture, with those higher than 8 percent deemed not acceptable due to soil erosion susceptibility. Despite recent technological advancements now allowing for slopes greater than 15 percent (Noorollahi, et al. 2016), the slope was limited to 8 percent for the purposes of this study.

<u>Criteria 8. Elevation.</u> The height above or below a fixed reference point is called elevation. The lower the elevation of a region from sea level, the greater the atmospheric thickness, giving high-altitude sites more solar radiation potential compared to lowland sites due to atmospheric thickness interfering less (Piazena, 1996).

Formulation of Criteria Weights

<u>Key Informant Interviews (KII).</u> KIIs were conducted to obtain the weight of each site selection criteria for SPIS installation. The ratings were based on the experts' judgment on the importance of the criteria. The KII team was composed of field experts coming from the academe, LGUs, agriculture sector, and suppliers with relevant experience on renewable energy (e.g., solar power). Representatives for each category were randomly selected. There were six experts interviewed, as shown in Table 3.

Table 3. Summary of Key Informant Interview Experts

Category[1]	Name of Office	Field of Expertise
LGU	DA RFO XI, PRDP	PRDP Solar Panel Irrigation Networks (SPIS) Project - Focal Person
LGU	DA RFO XI, PRDP	RAED Solar Panel Irrigation Networks (SPIS) Project - Designer
Solar Panel Supplier		Solar PV Products - Design, Integrate, Install, Market, and Retail
Solar Panel Supplier		Solar PV Products - Design, Integrate, Install, Market, and Retail
Academe	USeP, Obrero	Electrical Engineering - Renewable Energy
Academe	USeP, Obrero	Electrical Engineering

[1] Names of interviewees and commercial companies are withheld.

Computation using Analytic Hierarchy Process (AHP). The Analytical Hierarchy Process (AHP), introduced by Thomas Saaty, has been accepted by the international scientific community as a robust and flexible Multi-Criteria Decision Making (MCDM) tool to deal with complex decision-making. Several studies utilized this method and presented a framework for prioritizing alternatives.

AHP has three general underlying concepts: structuring the complex decision as a hierarchy of goal, criteria, and alternatives; pairwise comparison of elements at each level of the hierarchy to each criterion on the preceding level; and finally, vertically synthesizing the judgments over the different levels of the hierarchy.

In processing the suitable site for SPIS installation, the relative weights of the defined criteria were determined using the above technique. After that, the final map of land suitability of different areas in Davao del Norte was obtained by overlaying these criteria layers based on the calculated weights.

A simple questionnaire was designed to gather the expert's weighted scale for each criterion. The data was collected from experts corresponding to the hierarchic structure, and the pair-wise comparison matrix was used to weigh the factors. Eight major factors were compared one by one and scored using a scale from Saaty, as illustrated in Table 4.

Table 4. The Fundamentals Scale of Absolute Numbers (Saaty, 2008)

Score of criteria *i* to criteria *j*	Definition	Score Values Interpretation
1	Equal Importance	Criteria *i* and *j* are of **equal** importance
3	Moderate Importance	Criteria *i* is **slightly** more important than *j*
5	Strong Importance	Criteria *i* is **moderately** more important than *j*
7	Very Strong Importance	Criteria *i* is **strongly** more important than *j*
9	Extreme Values	Criteria *i* is **extremely** more important than *j*
2, 4, 6, 8	Intermediate Values	Intermediate values, when compromise is needed

The consistency of the results is crucial for more accurately represented judgments. For each expert's opinion, the consistency of results was calculated by consistency index (CI), and if there were any inconsistency, the expert was asked to amend the inconsistent part from the survey. The consistency index (CI) and consistency ratio (CR) can be calculated, as illustrated in Equation1 and Equation 2, respectively, where *n* is the size of the pairwise comparison matrix, and *RI* is the random index. When CR ≤ 0.1, the consistency test is passed (Uyan, 2013).

$$CI = \frac{\lambda_{max} - n}{n-1} \quad \text{Equation 1}$$

$$CR = \frac{CI}{RI} \quad \text{Equation 2}$$

Land Suitability Analysis Modeling

Land suitability analysis is a method of land evaluation, which measures the degree of appropriateness of land for a particular use. The Land Suitability Index (LSI) was determined based on the share of each of the defined classes, where higher scores represent more suitable sites for installation of SPIS.

Land Suitability= (*SI*+*AAT*+*R*+*OWS*+*IS*+GA+*S*+*E*) Equation 3

where:

SI – Solar insolation
AAT – Average Annual Temperature
R – Proximity to Road
OWS – Proximity to Open Water Source
IS – Proximity to Irrigation Networks
GA – Groundwater Availability
S – Slope
E — Elevation

Results and Discussion

The DA's Solar-Powered Irrigation System (SPIS) flagship program was undertaken in pursuit of the government's vision by creating a vibrant agricultural economy, but its provision is delimited by its budget allocation. This makes detailed information and accurate planning essential in identifying the most suitable SPIS installation areas, in order to optimize system potential and maximize limited resources.

Thematic Maps of Unsuitable Areas

According to Ong, et al. (2013) and Schmitter, et al. (2018), certain conditions are considered unacceptable and uneconomical when harnessing solar energy as a source of electricity. Thus, constraints were identified and integrated to form an unsuitable area map for SPIS installation to achieve the solar panel's maximum potential. Four factors were considered as constraints: land cover, elevation, slope, and solar insolation.

Based on the result of using land cover as a constraint, 26 percent of 349,296 hectares are classified as unsuitable for SPIS installation. Figure 5 illustrates the sites of the identified unsuitable areas in Davao del Norte. The unsuitable sites come from the following categories: open canopy forest, mossy forest, mature tree covering, developed areas, fishponds, and other unclassified areas.

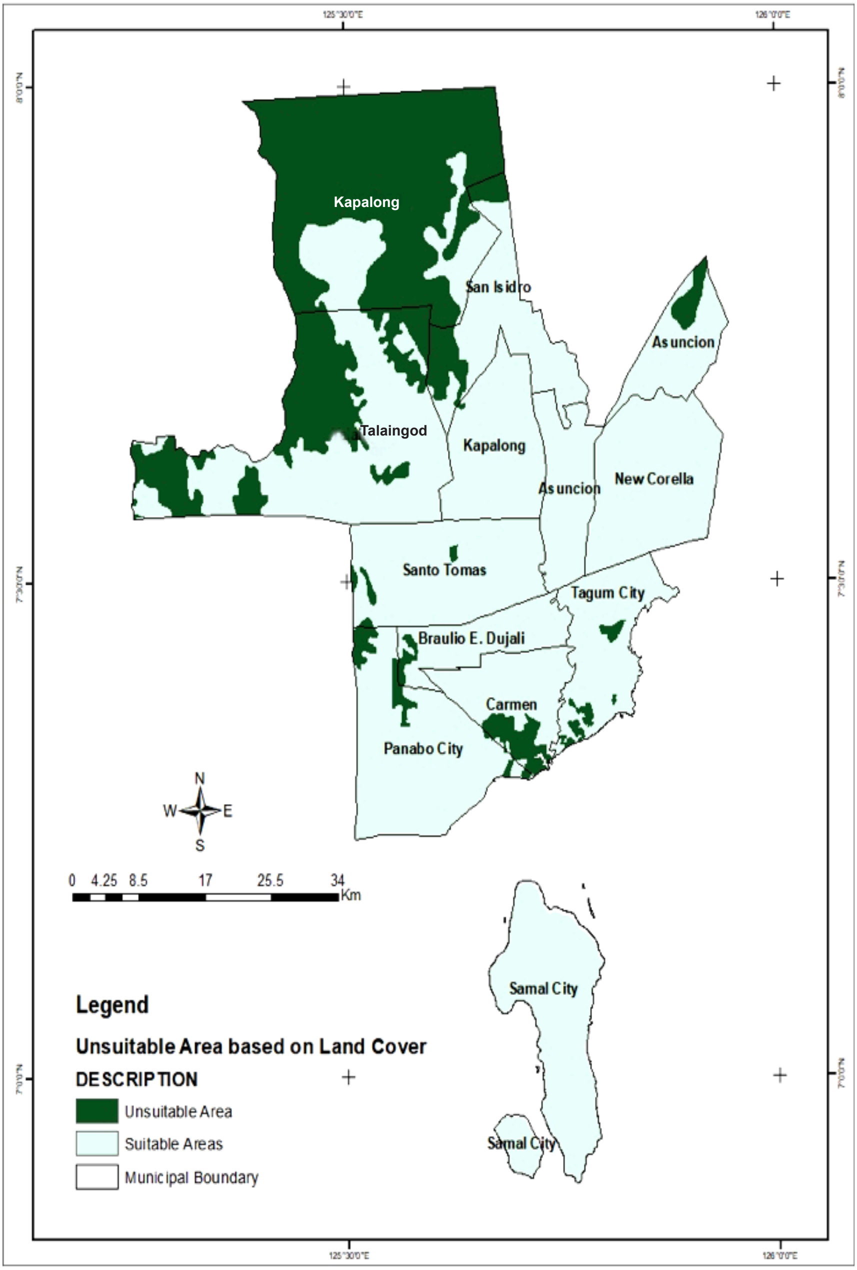

Figure 5. Thematic Map of Unsuitable Area in terms of Land Cover

Steep slopes can lead to soil loss due to their high susceptibility to erosion. Hence, slopes greater than 15 percent are considered constraints. Fifty-one (51) percent out of 349,296 hectares fall into this category (see Figure 6).

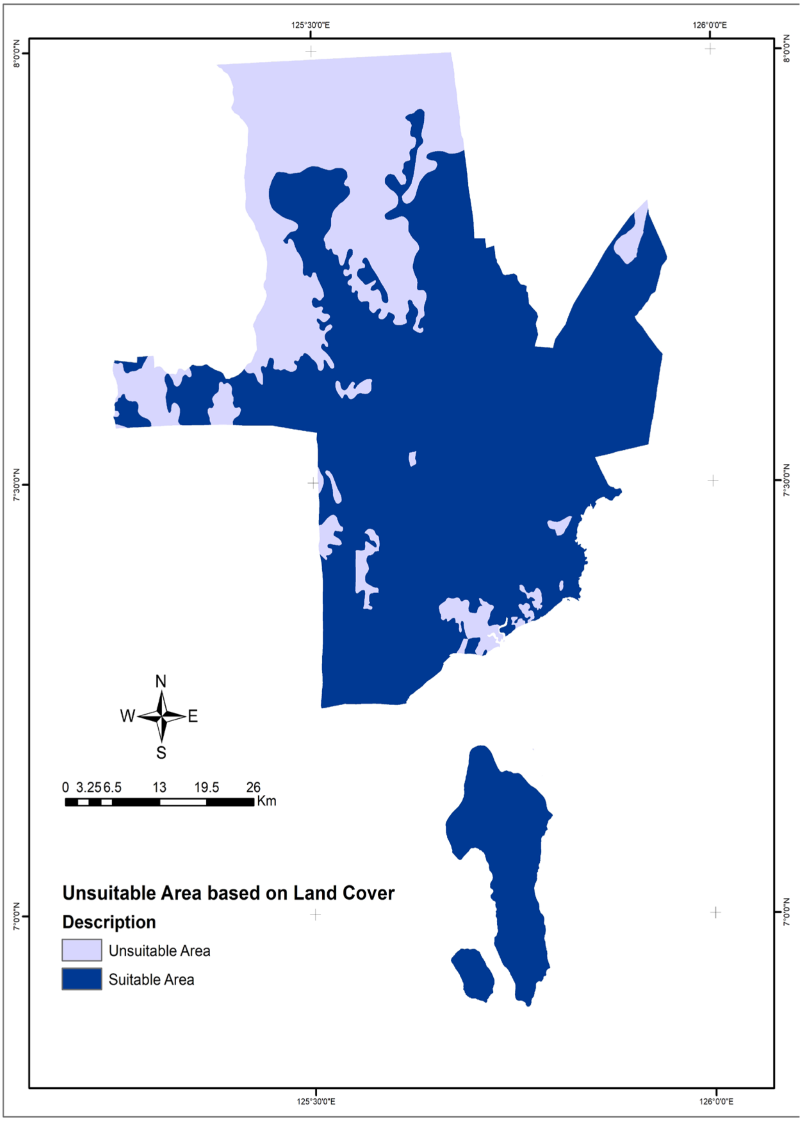

Figure 6. Thematic Map of Unsuitable Area in terms of Slope

The study area is typically considered to be hilly, with rice parcels being more prevalent in the southern parts, such as Asuncion, Braulio E. Dujali, Carmen, New Corella, and Santo Tomas. There are few observable rice parcels in the northern region, with some areas rainfed and irregular in shape, while most areas are elongated and follow the terrain in equal contours.

However, no constraint map was generated for both solar insolation and elevation, because elevations within the study area fall below the limit of 2.2 kilometers above sea level, while the lowest solar insolation is 1,510 kWh/m^2y, the latter being a higher value compared to the set limit of 1,300 kWh/m^2y.

Evaluation Criteria

The final suitability map was generated once the different evaluation criteria were identified. In this study, the results of various studies were used to determine the relevant factors that would influence the decision-making process in selecting the most appropriate SPIS installation site, while giving more priority to rice production areas with no access to the irrigation systems provided by the government, cooperatives and private sectors. Eight factors exhibited in Figures 7 and 8 were chosen to achieve the aim of this study.

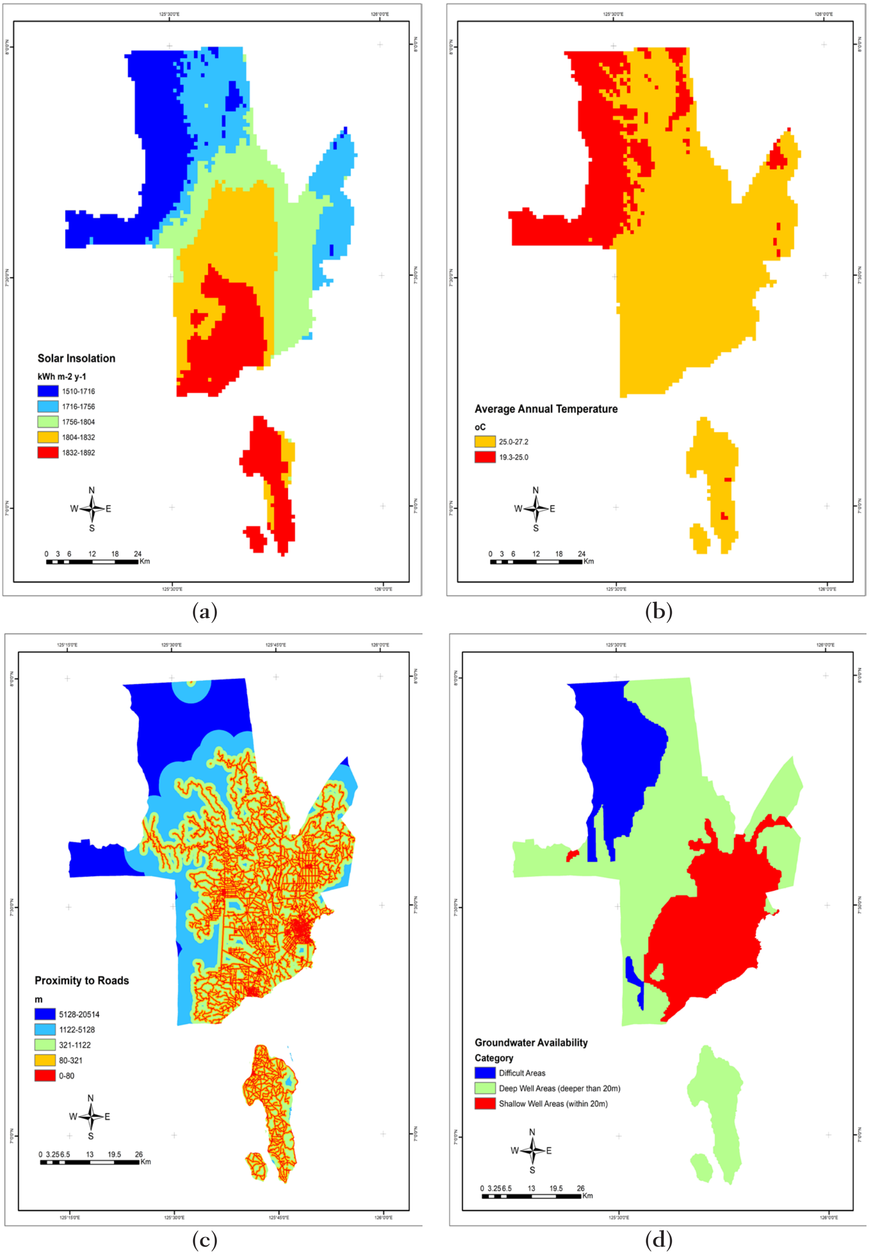

Figure 7. Evaluation Criteria Layers for Land Suitability Analysis:
(a) Solar Irradiation; (b) Average Annual Temperature; (c) Proximity to Roads;
(d) Groundwater Availability

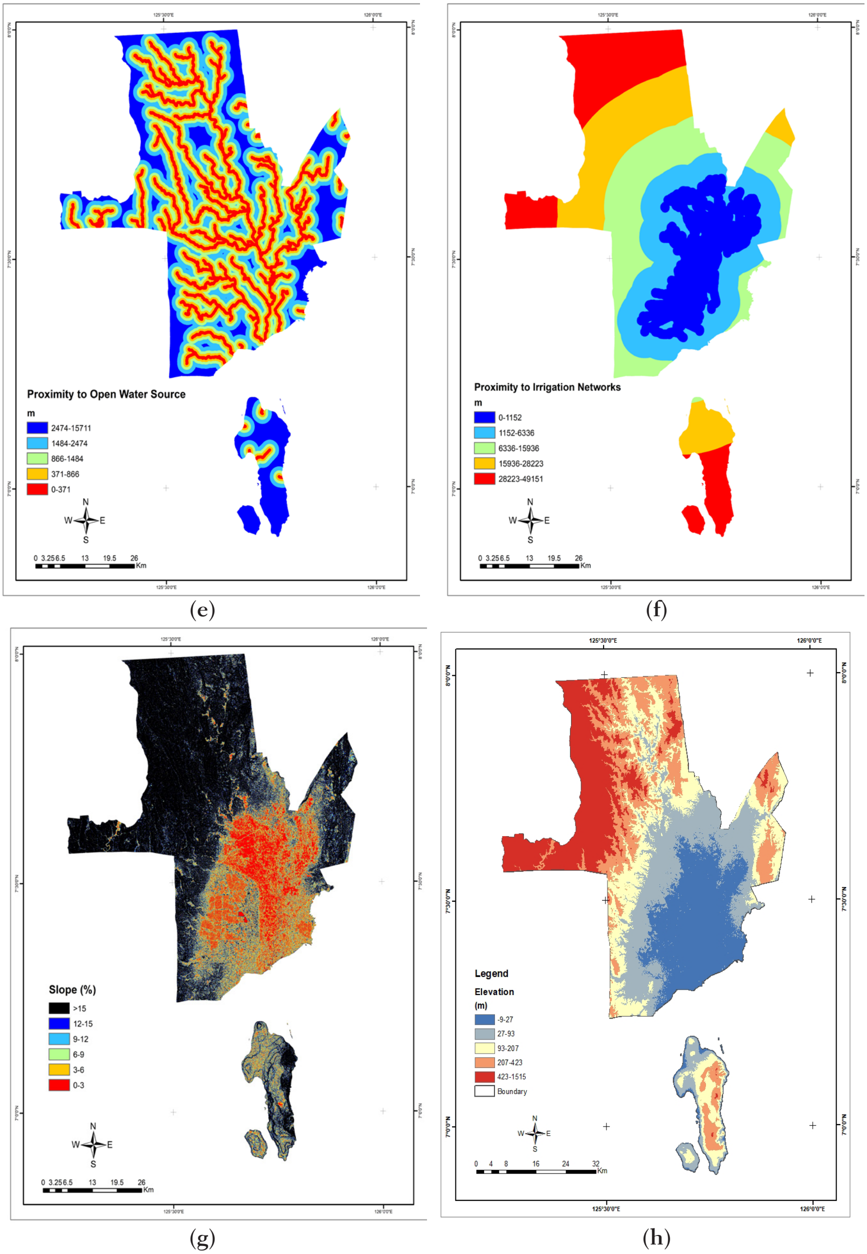

Figure 8 (cont.) Evaluation Criteria Layers for Land Suitability Analysis: (e) Proximity to Open Water Source; (f) Proximity to Irrigation Networks; (g) Slope; and (h) Elevation

For solar insolation, using solar panels to harness the sun's energy is perfectly suited in the whole area of the province, since all areas included in its boundary have a high insolation value ranging between 1,510 and 1,892 kWh/m^2y, making it safe and economical for solar panel operation. The gathered values were calculated to be between the set minimum of 1,300 kWh/m^2y (463 W/m^2 solar irradiance at 7.7 peak sun hours) and the set maximum allowable insolation of 2,000 kWh/m^2y (712 W/m^2 solar irradiance at 7.7 peak sun hours). It is apparent that solar PV is an excellent system for provincial area; however, insolation amounts higher than the threshold are discouraged due to possibly causing poor panel performance, subsequently caused by heating from the increased ambient temperature (Noorollahi et al., 2016).

The average annual temperature ranged from 19.3°C to 27.2°C. Only 10 hectares satisfied the maximum 25°C criteria and were considered extremely suitable. While there is no restriction for temperature, this factor affects solar panel performance because of the consequent heating effect, as affected by the ambient temperature increase. A study of the Department of Energy (DoE) revealed that an increase in panel temperature would result in voltage reduction, and there is a 4% decrease in voltage if the panel temperature increases from 25°C to 35°C. Thus, areas having temperature values higher than 25°C were given smaller score values, but were not eliminated.

Distance to roads, open water sources, and irrigation networks were processed identically. The vector files were first converted to raster using a Euclidean distance tool before it was classified. This process was done using the reclassification tool in GIS. Areas near the roads and open water sources were given higher score values or classified as highly suitable, while those near irrigation networks were given less priority in this land suitability analysis in line with the study's parameters and objectives.

The SPIS is not recommended for areas with an elevation greater than 2.2 kilometers due to difficulty in transportation and installation (Noorollahi et al., 2016). Despite this, higher elevations still allow for greater solar radiation potential (Piazena, 1996), thus high score values are given to higher elevation. Based on the results, around 106 hectares are classified above the standard deviation of the 265-meter elevation, and are more concentrated in the Talaingod and Kapalong areas.

Criteria Weights

The result of land suitability was obtained using a combination of AHP and the Weighted Overlay technique. The summary of the weighted scores used in land suitability analysis is exhibited in Table 5, with the criteria weight scores directly reflecting that solar insolation and groundwater availability are critical. Nearly 50% of the determining factor is composed of combined scores of these two criteria, while the criteria layers were reclassified, as shown in Table 6, in preparation for the overlaying process of each map, along with the obtained criteria weights.

Table 5. The Calculated Weights for the Defined Criteria by AHP

Goal	Criteria	Weight
Land Suitability for SPIS Site selection in rainfed rice production areas	C1. Solar Insolation	0.2649
	C2. Average Annual Temperature	0.1035
	C3. Proximity to Roads	0.0979
	C4. Groundwater Availability	0.1980
	C5. Proximity to Open Water Source	0.1340
	C6. Proximity to Irrigation Networks	0.0720
	C7. Slope	0.0585
	C8. Elevation	0.0711

Table 6. Reclassification Criteria Used for the Various Maps included in the Analysis

Factor	Very highly suitable	Highly suitable	Mode-rately suitable	Less suitable	Least suitable	Cons-traint	Source
	(5)	(4)	(3)	(2)	(1)	(0)	
Solar Insolation (kWh/m^2y^-1)	1,832-1,892	1,804-1,832	1,756-1,804	1,716-1,756	1,510-1,716	<1,300	SolarGIS
Ave Annual Temperature (°C)	19.3-25.0	25.0-27.2	-	-	-	-	USeP PAGASA
Proximity to Road (m)	0-80	80-321	321-1,122	1,122-5,128	5,128-20,514	-	PPDO, Davao del Norte Province
Groundwater Availability	Shallow well areas (within 20m)	-	Deep well areas (deeper than 20m)	-	Difficult areas	-	DA - CIRDUP
Proximity to Open Water Source (m)	0-371	371-866	866-1,484	1,484-2,474	2,474-15,711	-	SAR DEM - Lidar
Proximity to Irrigation lines (m)	28,223-49,151	15,936-28,223	6,336-15,936	1,152-6,336	0-1,152	-	Lidar
Slope (%)	0-3	3-6	6-9	9-12	12-15	>15	Schmitter et al., 2018
Elevation (m)	423-1,515	207-423	93-207	27-93	-9-27	-	SAR DEM - Lidar

Land Suitability Map

Davao del Norte has a total land area of 349,296 hectares, of which 334.93 hectares (0.10%) are considered as *extremely suitable*, 102,696.34 hectares (29.40%) are considered as *highly suitable*, 130,078.61 hectares (37.24%) are *moderately suitable*, 16,746.29 hectares (4.79%) are *less suitable*, and 99,439.60 hectares (28.47%) are areas deemed *unsuitable* for SPIS site installation. The suitable sites' locations are exhibited in Figure 9.

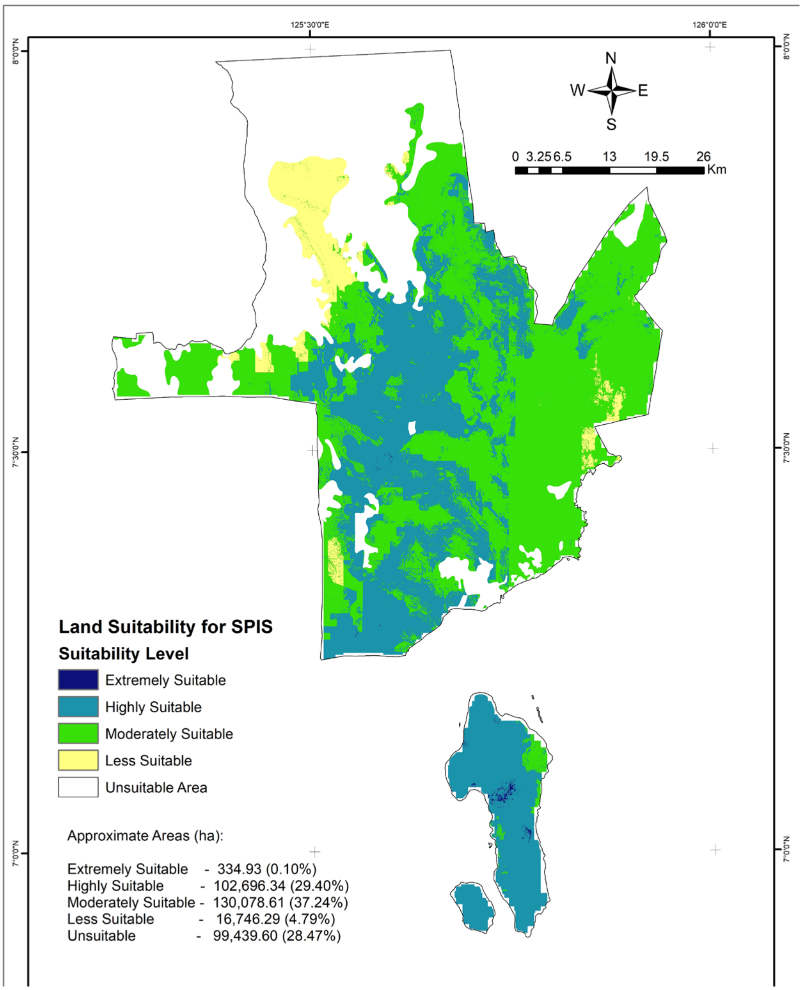

Figure 9. Land Suitability Map of Davao del Norte

Data showed that among all municipalities and cities in the Davao del Norte province, Samal has the *extremely suitable* area coverage, with 314 hectares, for SPIS installation; it is followed by Santo Tomas with 15 hectares, and Panabo with 7 hectares (Table 7). This result is attributable to the top two most relevant criteria obtained in the AHP technique - solar insolation and groundwater availability - which the expert perceived to be vital in the SPIS site selection.

For solar insolation, Samal received a suitability score of 79 percent and groundwater availability of 100 percent. Moreover, *highly suitable* areas can also be found in Samal with 23,024 hectares, Panabo with 16,925 hectares, Santo Tomas with 16,581 hectares, Kapalong with 11,780 hectares, and Talaingod with 11,483 hectares.

In the *moderately suitable* category, New Corella (23,238 ha) was identified as the highest, followed by Asuncion (18,242 ha), Talaingod (17,969 ha), and Tagum City (15,267 ha).

Despite this, the decision of establishing an SPIS in extremely suitable areas still requires careful planning because Samal's rainfed rice production area is only about 67 hectares. This should be considered in the light of other municipalities' having about 700 hectares of rainfed rice area such as Asuncion and Kapalong, which have considerable areas highly suitable for SPIS.

Table 7. SPIS Suitable Areas per Municipality

Municipality? City	Extremely Suitable	Highly Suitable	Moderately Suitable	Less Suitable	Unsuitable	Rainfed Rice Production Areas (ha)
Asuncion		3858	18242	7	2357	739.09
Kapalong		11780	13350	8062	54129	721.40
New Corella		1514	23238	947	533	405.90
Santo Tomas	15	16581	9410		806	288.00
Talaingod		11483	17969	6071	24424	221.00
San Isidro		6949	9235		4785	212.60
Tagum City		54	15267	731	2110	168.60
Carmen		5725	6313		3068	143.47
Panabo City	7	16925	9023	928	3285	124.50
Samal City	314	23024	1584		3262	67.00
Braulio E. Dujali		4805	6437		682	-
	334.93	102,696.34	130,078.61	16,746.29	99,439.20	3,091.56

Summary of Findings

The high investment capital of establishing a solar powered irrigation system necessitates rigorous planning to identify the most appropriate economic and beneficial sites for SPIS installation. This study guides the decision-makers in the selection process using the determined criteria factors that will potentially influence solar panel performance. The criteria considered are the following: solar insolation, annual average temperature, distance to road, groundwater availability, distance to open water source, distance to the irrigation system, slope, and elevation. The land suitability analysis was done using the AHP technique and the geographical information system (GIS).

The results indicated that 0.10% (334.93 ha) of the area under the political boundary of Davao del Norte is extremely suitable; 29.40% (102,696.34 ha) is highly suitable, 37.24% (130,078.61 ha) is moderately suitable, 4.79% (16,746.29 ha) is less suitable, and 28.5% (99,439.60 ha) is unsuitable.

Samal, Sto. Tomas, and Panabo are the only areas with extremely high suitability, while Samal, Panabo, Sto. Tomas, and Kapalong have the most areas under the high suitability category. Meanwhile, New Corella, Asuncion, Talaingod, Tagum, and Kapalong have the most areas that fall under the moderately suitable category.

In terms of rainfed rice production, Asuncion and Kapalong have the highest number of rainfed rice areas of 739 and 721 hectares, respectively; while the summed rating of highly suitable and moderately suitable areas of these municipalities total 90% (22,097.95 ha) and 29% (11,241.40 ha), respectively. When it comes to giving more priority to non-irrigated rice production areas, the municipality of Asuncion should be selected first, followed by Sto Tomas and Talaingod.

Recommendation

In the context of increasing rice production, the government has launched the SPIS installation program in 2018. Considering the limitation of government funds and the fact that SPIS is highly dependent on solar energy, the results of this study are recommended to be used by decision-makers in the DA, LGUs and even financially capable farmers in the selection of the most suitable areas for SPIS installation in order to maximize the technology's performance and benefit.

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