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Suitability Map of Potential Solar-Powered Irrigation Systems through GIS and Remote Sensing Techniques

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***Abstract*— In the Philippines, a significant portion of agricultural land, spanning 2.7 million hectares, lacks irrigation facilities, relying on deep well pumps and rainfall. To address this issue, the Department of Agriculture of the Philippines has advocated for the widespread adoption of solar-powered irrigation systems (SPIS), emphasizing the need for technical and financial feasibility. This study aimed to identify and map potential locations for SPIS in the barangay of San Esteban, Alcala, and Cagayan, utilizing Remote Sensing and GIS techniques. The resulting suitability map was generated using the Analytical Hierarchy Process (AHP), in combination with GIS and Remote Sensing, considering various criteria for selecting suitable SPIS areas. Analysis of the data revealed that out of the total 743 hectares of land area in Barangay San Esteban, 286 hectares (38.42%) were found to be unsuitable, 404 hectares (54.37%) exhibited moderate suitability, and 53 hectares (7.13%) were deemed highly suitable for implementing SPIS.**

Keywords*— *solar-powered irrigation system, GIS, remote sensing

I. Introduction

Drought, characterized by insufficient water leading to reduced soil moisture or groundwater levels [1], poses a significant challenge, particularly in agricultural regions of the Philippines. As the country encompasses 32% of agricultural land [2], it becomes crucial to identify early indications of drought, considering the vital role of agriculture in the Philippine economy. By providing timely information, farmers can take preemptive measures to secure adequate water supply and safeguard their crops against the detrimental impacts of drought.

Studies emphasize the importance of affordable and reliable irrigation systems to enhance agricultural productivity [3]. In line with this notion, the installation of solar-powered irrigation systems (SPIS) gains prominence as an environmentally friendly approach and a key aspect of conservation agriculture [3]. SPIS harnesses solar energy to generate electricity, offering an efficient and sustainable means of irrigation. Previous research conducted in Davao Del Norte explored land suitability analysis for SPIS in non-irrigated rice production, resulting in a provincial suitability map of SPIS. This study utilized the Analytical Hierarchy Process (AHP) in conjunction with a Geographic Information System (GIS) to assess various criteria and assign weights to generate the suitability map. While this existing study provides valuable insights into potential SPIS locations at a provincial level, there is a need to extend this research to a smaller scope, specifically focusing on a barangay, and considering essential criteria to develop a potential SPIS location map.

The study focuses on San Esteban, a barangay situated in the Municipality of Alcala, Cagayan, covering an area of 7.79 square kilometers, accounting for 4.62% of the total municipal area. This barangay faces aridity issues, leading to inadequate water supply for crops [4]. Moreover, a reliable source indicated that Cagayan Valley, the province encompassing the study area, classified its water scarcity as low, projecting only a 1% probability of drought occurrence within the next decade [5].

Within the study area, farmers primarily rely on expensive deep wells powered by gasoline and diesel engines, which incur rising operating costs due to global crises. In addition, two existing SPIS projects implemented by the Department of Agriculture (DA) operate within the barangay. The absence of irrigation canals further exacerbates the challenges faced by farmers, rendering the SPIS the most suitable water system for agricultural purposes. Previous studies have shown that SPIS adoption can mitigate the effects of drought, provided there is an accessible water source such as groundwater, rivers, or other surface water bodies [6]. SPIS offers operational cost benefits, as solar energy serves as a constant and readily available source of power, replacing the reliance on gasoline-based deep wells. This system efficiently supplies water to crops while reducing farmers' workload, allowing them to invest more time in productive activities [6].

Therefore, this research endeavors to address the gap in knowledge by generating a GIS and Remote Sensing-based map indicating potential locations for SPIS installation within the barangay of San Esteban, Alcala. Currently, no existing map specifically designed for SPIS installation is available for this barangay, underscoring the significance and novelty of this study.

II. Related Works

Water availability is a critical factor in agricultural production, particularly for rice crops. However, the

Philippines, being located in the equatorial region and affected by climate change, is currently facing extreme heat, leading to significant damage to crops [7]. Agricultural areas without access to irrigation systems are especially vulnerable to the impacts of El Niño, as highlighted by the Agricultural Assistant Secretary and deputy spokesman Rex Estoperez [7].

Irrigation systems play a crucial role in enhancing agricultural productivity by providing a sufficient water supply and ensuring production stability, even under extreme weather conditions [8]. In 2019, Agricultural Secretary Emmanuel Piñol revealed that out of the total 3.9 million hectares of rice farms in the country, only 1.2 million hectares were irrigated, leaving the remaining 2.7 million hectares reliant on rainfall [9]. To compensate, farmers have resorted to using expensive deep wells powered by gasoline and diesel engines, but the reliance on crude oils for operating deep wells has negative implications for agricultural production due to fluctuating prices [10]. The Philippines is significantly affected by crude oil price fluctuations in the global market, further highlighting the need for alternative irrigation solutions [11].

Given the limitations of conventional irrigation systems, such as the cost of crude oils and the lengthy construction process for irrigation infrastructure and dams, Agricultural Secretary Emmanuel Piñol has advocated for the widespread adoption of solar-powered irrigation systems (SPIS) in the country [12]. SPIS utilizes solar energy to pump water, providing a sustainable and cost-effective alternative to deep wells and fuel-powered pumps [13][14]. Moreover, the shift from fossil fuels to renewable energy sources, such as solar energy, contributes to greenhouse gas emissions reduction in irrigated agriculture [6]. SPIS has demonstrated technical viability and competitiveness, offering attractive returns on investment [6]. However, for widespread adoption, SPIS must be both technically and financially feasible [15].

Literature reviews emphasize the importance of considering various technical, social, and environmental factors when selecting suitable SPIS locations [16]. Studies highlight categories of criteria, including climatology, environment, and location, influencing the site selection process. Analytical Hierarchy Process (AHP) and GIS Weighted Overlay Technique have been utilized for complex decision-making and map generation [17]. Studies in different regions, such as Ghana and the Hindu Kush-Karakoram-Himalaya (HKH) ranges, have identified key variables like solar irradiation, slope, subsurface water levels, proximity to rivers or small dams, terrain suitability for crops, aquifer productivity, population, road accessibility, and travel time to markets as essential factors in determining suitable SPIS sites [18][19]. Notably, solar insolation and groundwater availability have been prioritized in determining suitable SPIS sites, as demonstrated in a study conducted in Davao Del Norte [17].

GIS and Remote Sensing have played a pivotal role in generating maps for these studies. GIS provides spatial data management and manipulation capabilities, making it a valuable tool for map production [20]. The practicality and efficiency of GIS and Remote Sensing have been recognized, particularly for covering large areas [21]. These technologies have been extensively employed to analyze and visualize geographic data, contributing to the identification of suitable SPIS locations.

III. Methods

San Esteban is a barangay located in the municipality of Alcala, Cagayan, with geographical coordinates of approximately 17°55' North latitude and 121°43' East longitude. Covering an area of 779 hectares, San Esteban represents 4.62% of the total municipal area in Alcala, Cagayan. According to the 2020 Census conducted by the Philippine Statistics Authority, the barangay has a population of 1,311, accounting for 3.17% of the total population of Alcala. This particular barangay shown in Fig. 1 is known for its arid conditions, characterized by excessively dry and barren areas that are unsuitable for vegetation [4].

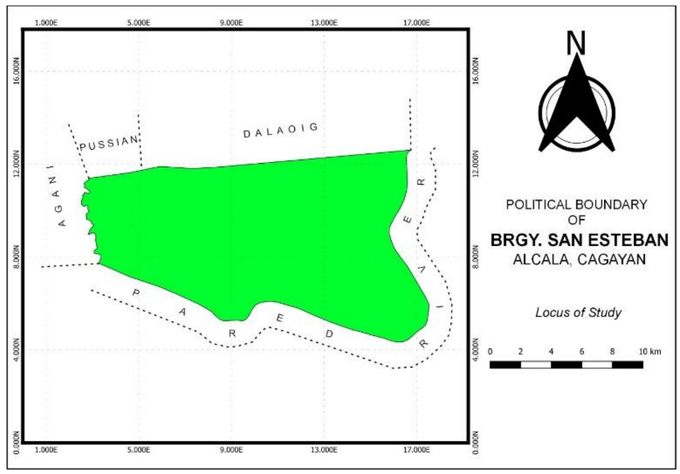

Fig. 1. Locale of the Study

For the analysis of solar source viability and availability in the area, the study utilized a Digital Elevation Model (DEM). Additionally, digital datasets containing information on roads, political boundaries, and land cover were incorporated. Using QGIS, the researchers generated maps for each criterion and performed a multi-criteria analysis through the raster calculator using the Analytical Hierarchy Process. This analysis ultimately resulted in the production of a suitability map highlighting potential locations for solar-powered irrigation systems (SPIS).

The researchers obtained the necessary datasets from Engr. John Mark C. Contillo, the Agricultural Technologist of LGU Alcala, Cagayan, acquired the DEM data from a government agency. These datasets underwent further processing using QGIS, ensuring that each criterion was projected using the common WGS84 projection. Field data, including the locations of existing deep wells and two SPIS, were collected using Real-Time Kinematic (RTK) techniques. The gathered data were then plotted on AutoCAD, projected using BLLM 1 as the tie line, and saved as a drawing exchange format (dxf) file to generate the map in QGIS.

Fig. 2 displays the solar energy received by the study area, ranging from 1,755.7570 to 1,771.0970 kWh/m2. Solar panels typically operate within an effectiveness range of 1,300 kWh/m2 to 2,000 kWh/m2 [16]. Based on this range, the study area is deemed suitable for installing solar panels.

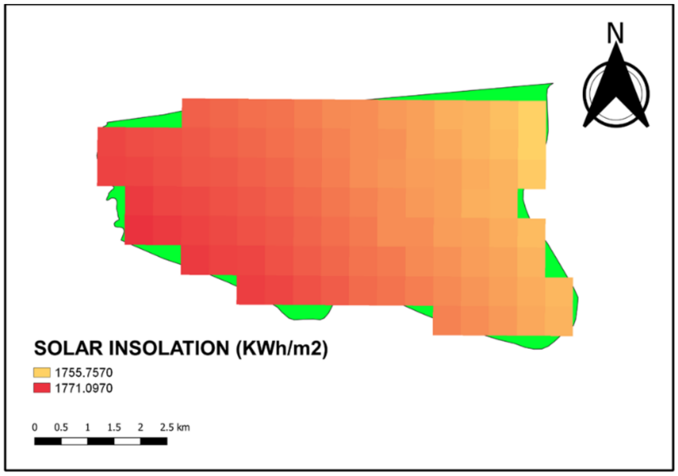

Fig. 2. Solar Insolation

Solar irradiance refers to the amount of solar power projected onto or received by a surface, typically measured in Watts per square meter (W/m2) [28]. Previous studies have highlighted that countries situated in the equatorial region of the globe experience the highest annual average solar insolation, making them ideal locations for solar panel installation [15].

Determining suitable sites for solar-powered irrigation systems (SPIS) typically involves considering various factors, including environmental, land-use, hydrological, economic, geographical, demographic, security, and technical aspects [17]. In this study, the researchers reviewed different studies and articles to develop a map of potential SPIS locations based on the present conditions and problems in the area. The integration of literature reviews helped determine the criteria to be considered in the study.

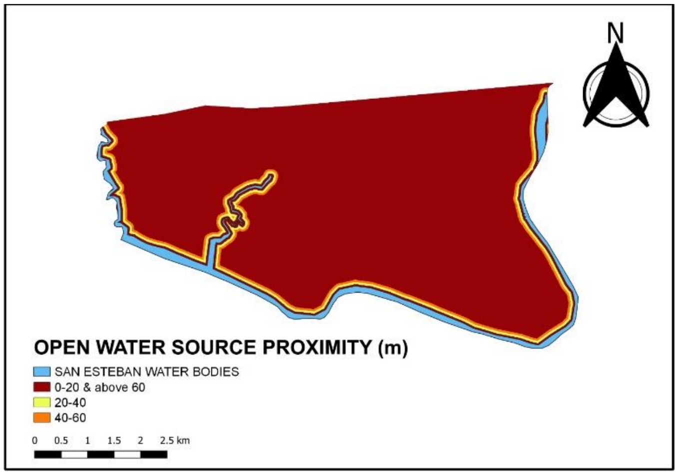

Fig. 3. Proximity to Open Water Source

Fig. 3 presents a classification of suitability for SPIS installation based on distance from the river. Areas within 0 to 20 meters and 60 meters above distance are classified as not suitable, 40 to 60 meters as moderately suitable, and 20 to 40 meters as highly suitable. DENR Administrative Order (DAO) No. 97-05 specifies that riverbanks should have a minimum of twenty (20) meters of easement from their margin. The presence of the Pared River and its tributaries surrounding the barangay makes it a viable location for SPIS installation.

Water availability is crucial for agricultural production, particularly for rice crops. Irrigation water sources are categorized into rivers, large reservoirs, medium-size reservoirs, and non-local non-renewable blue water [22]. Better access to surface water resources improves the economic feasibility of expanding the irrigation system [23].

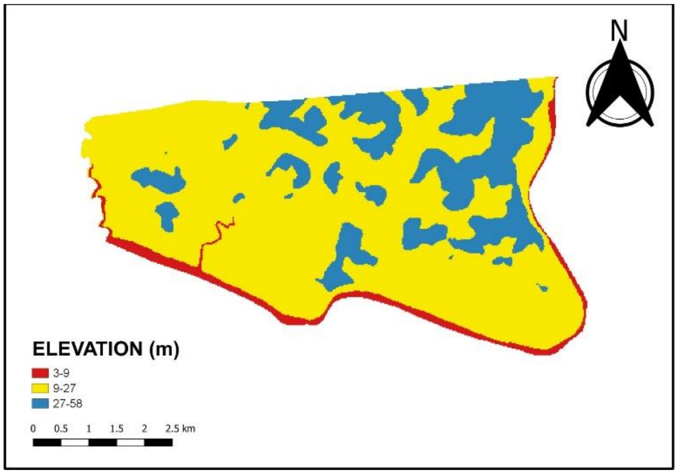

Fig. 4. Digital Elevation Model

Fig. 4 displays the elevation map of Barangay San Esteban, generated using the Digital Elevation Model (DEM). The map classifies areas into three categories: not suitable (3 to 9 meters), moderately suitable (9 to 27 meters), and highly suitable (27 to 58 meters) for SPIS installation. The majority of the area falls under the moderately suitable and highly suitable categories due to the moderate elevation and the presence of hills. The relief of an area, determined from the DEM, plays a significant role in determining the amount of solar radiation received at a given location [24]. Solar panels are more efficient at higher altitudes due to the increase in solar UV rays with altitude in the atmosphere. Consequently, installations at high altitudes can generate more power than those at sea level [25].

Fig. 5 illustrates the slope percentage of the area, indicating suitable and unsuitable locations for SPIS installation. The classifications are as follows: not suitable (18% and above), moderately suitable (8 to 18 percent), and highly suitable (0 to 8 percent). Lands with a slope of 18 percent or more are classified as forest areas based on section 15 of PD 705. Additionally, slopes higher than 8 percent are not acceptable in irrigated agriculture due to soil erosion concerns [17].

Fig. 6 presents a buffered road map of Barangay San Esteban. The road proximity classifications are as follows: not suitable (0 to 2 and above 600 meters) to maintain a 2-meter setback from the road following BP 220, moderately suitable (300 to 600 meters), and highly suitable (2 to 300 meters). The road network is crucial for connectivity and transportation, making it an important factor in determining potential SPIS sites [26]. SPIS installations should avoid areas with difficult access [27]. Additionally, proximity to roads reduces the cost of transporting materials during SPIS installation.

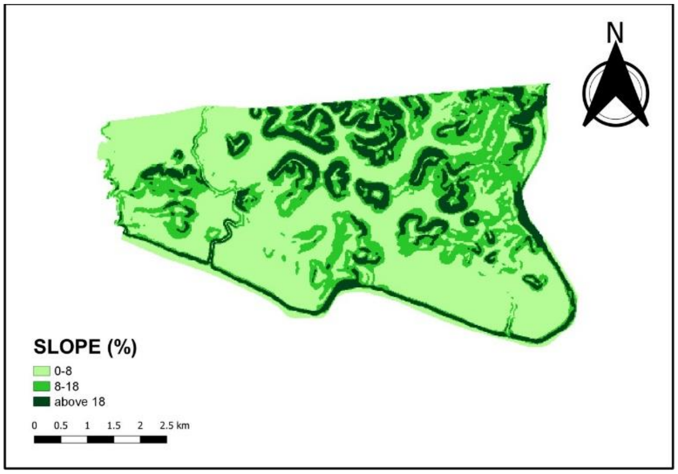

Fig. 5. Slope Percentage

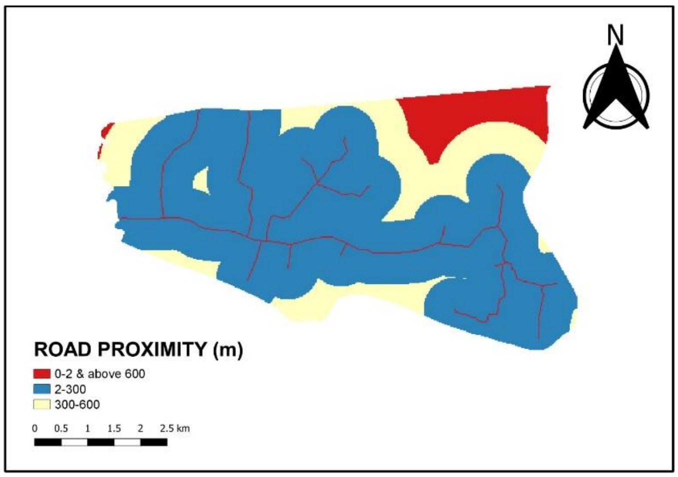

Fig. 6. Road Proximity

Table I presents the reclassification of each criterion along with its parameters, indicating the suitability levels of the factors considered in the study. The "Open Water Source" criterion assesses the suitability of distances from water sources. Areas within 0–20 meters and above 60 meters are classified as not suitable, while those within 40–60 meters are moderately suitable, and areas within 20–40 meters are highly suitable. The source of this information is the Municipal Agricultural Office (MAO) in Alcala, Cagayan. The "Elevation" criterion considers the elevation range for suitability. Areas within 3–9 meters are classified as not suitable, those within 9–27 meters are moderately suitable, and areas within 27–58 meters are highly suitable. The Digital Elevation Model (DEM) provided by the Department of Environment and Natural Resources (DENR) was used as the data source. For the "Slope" criterion, areas with a slope of 18% and above are categorized as not suitable, slopes between 8% and 18% are considered moderately suitable, and slopes ranging from 0% to 8% are highly suitable. The DEM from DENR was used to determine the slope information. The "Road Proximity" criterion examines the distance from roads. Areas within 0–2 meters and above 600 meters are classified as not suitable, those within 300–600 meters are moderately suitable, and areas within 2–300 meters are highly suitable. The source of this data is the Municipal Agricultural Office (MAO) in Alcala, Cagayan. These reclassifications provide a clear understanding of the suitability levels for each criterion, aiding in the identification of potential locations for solar-powered irrigation systems (SPIS).

TABLE I. RECLASSIFICATION OF CRITERIA

Criteria	Not Suitable	Moderately Suitable	Highly Suitable	Source
Open Water Source	0 – 20 meters, and above 60 meters	40 – 60 meters	20 – 40 meters	MAO, Alcala, Cagayan
Elevation	3 – 9 meters	9 – 27 meters	27 – 58 meters	DEM,DENR
Slope	18% and above	8% – 18%	0% - 8%	DEM,DENR
Road Proximity	0 – 2 meters, and above 600 meters	300 – 600 meters	2 – 300 meters	MAO, Alcala, Cagayan

AHP (Analytical Hierarchy Process) is a widely utilized tool in multi-criteria decision-making, originally proposed by Thomas Saaty in 1977. Since its inception, AHP has undergone further development and has found application in various fields [29]. In this study, AHP was employed to determine the suitable sites for the installation of solar-powered irrigation systems (SPIS). An AHP automatic Excel sheet was utilized by the researchers to calculate the weights of the individual criteria. These criteria layers were then overlaid, taking into consideration their respective weights, in QGIS using the raster calculator.

The AHP template utilized in this study was developed by Dr. Klaus D. Goepel. It includes several worksheets designed for pair-wise comparison, consolidation of all judgments, a summary sheet for displaying the results, and reference tables such as the random index and limits for the geometric consistency index (GCI). Additionally, the template provides judgment scales and a sheet for solving the eigenvalue problem when using the eigenvector method (EVM) [30]. By utilizing the AHP methodology and the provided template, the researchers were able to systematically evaluate and prioritize the criteria, enabling them to make informed decisions regarding the selection of suitable sites for SPIS installation.

TABLE II. CRITERIA AND WEIGHTS FOR POTENTIAL SPIS

Criterion	Weights
Elevation	0.205
Road Proximity	0.112
Open Water Source	0.478
Slope	0.204

Table II presents the criteria considered in determining the potential locations of solar-powered irrigation systems (SPIS) in Barangay San Esteban, along with their corresponding weights. The criteria included in the analysis are Elevation, Road Proximity, Open Water Source, and Slope. The table indicates that Open Water Source and Elevation are the two highest priority criteria, which have a significant impact on determining suitable locations for SPIS in the area.

Traditionally, the selection of optimal SPIS locations involves considering various group categories, such as Environment, Economy, Geography, Demographics, Land-use, Hydrology, Security, and Technology [17]. However, based on the analysis of the gathered data and integration of literature reviews, the chosen criteria for this study are Elevation, Road Proximity, Open Water Source, and Slope, as they are deemed most relevant in determining suitable SPIS sites in Barangay San Esteban.

To determine the suitable location of solar-powered irrigation systems (SPIS) in Barangay San Esteban, the researchers utilized the raster calculator in QGIS to overlay the criteria weights. The formula used to calculate the Suitability Map of SPIS is as follows:

*Suitability Map of SPIS = (0.205 * Elevation) + (0.112 * Road Proximity) + (0.478 * Open Water Source) + (0.204 * Slope)*

The weights assigned to each criterion are as follows: 20.5% for elevation, 11.2% for road proximity, 47.8% for open water sources, and 20.4% for slope. By multiplying each criterion with its corresponding weight and summing up the results, the Suitability Map of SPIS is generated. This map will indicate the areas in Barangay San Esteban that are most suitable for the installation of SPIS based on the integrated criteria.

IV. Results and Discussion

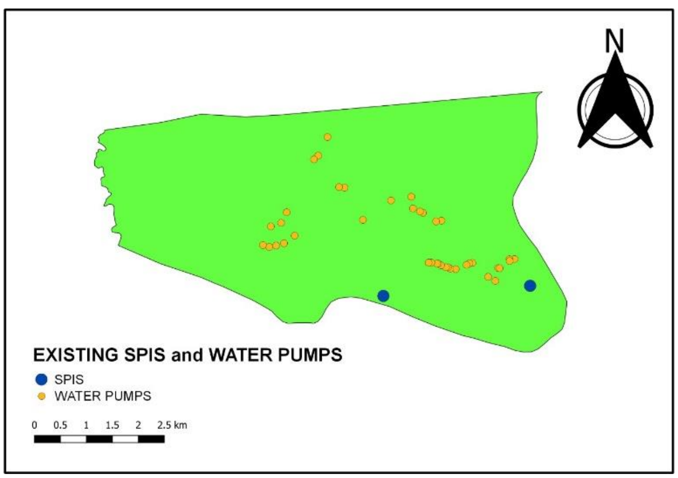

Fig. 7. Map of Existing SPIS and Water Pumps

Fig. 7 presents a map showcasing the existing deep wells and two (2) solar-powered irrigation systems (SPIS) in Barangay San Esteban. Due to the limited feasibility of establishing irrigation canals in the area, local farmers have resorted to using deep wells fueled by crude oils as their water source for crop irrigation. The two (2) existing SPIS were implemented as part of the DAR's Climate Resilient Farm Productivity Support Project (CRFPSP) in collaboration with the DA's Bureau of Soils and Water Management (BSWM). This initiative aims to enhance agricultural productivity and resilience among farmers in the barangay.

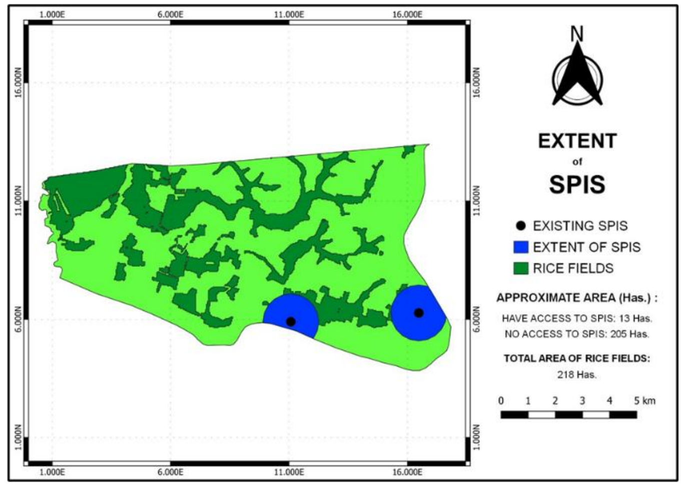

Fig. 8. Coverage of Existing SPIS

Fig. 8 illustrates the extent of agricultural land that can be supplied by the SPIS. As mentioned in Figure 7, the barangay captain stated that the existing SPIS can provide water for 30 hectares of rice land. However, due to its location along the barangay boundary, it currently only covers 13 hectares. Consequently, there are still 205 hectares of rice land in the area without access to SPIS.

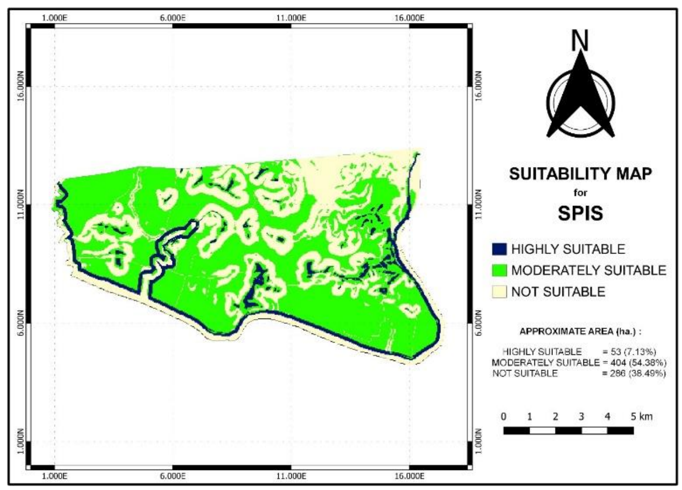

Fig. 9. Suitability Map for Potential SPIS

Taking into account the need to address the remaining uncovered rice land, the proposed map in Fig. 9 highlights suitable locations for the installation of SPIS. Through the integration of criteria and the overlaying of their respective weights, the map indicates that out of the total land area of 743 hectares in Barangay San Esteban, 286 hectares (38.42%) are classified as not suitable, 404 hectares (54.37%) as moderately suitable, and 53 hectares (7.13%) as highly suitable for the establishment of SPIS.

The map reveals that areas near the Pared River and its tributaries are highly suitable for SPIS installation.

Conversely, the upper right region of the map, which lacks road access, is deemed not suitable. It is worth noting that the existing SPIS locations align with the suitability map, confirming their classification as highly suitable sites.

These results provide valuable insights for decision-makers and stakeholders involved in the planning and implementation of SPIS in Barangay San Esteban. By identifying suitable areas and considering the unmet irrigation needs of rice farmers, steps can be taken to enhance agricultural productivity, improve water resource management, and promote sustainable farming practices in the barangay.

V. Conclusion

Determining the suitable location for the installation of solar-powered irrigation systems (SPIS) is crucial for maximizing their utilization. Previous studies have highlighted various criteria for different regions, such as temperature, elevation, solar insolation, and groundwater availability. In this study, the appropriate criteria factors were carefully selected based on the present condition of Barangay San Esteban, resulting in the identification of suitable SPIS locations. By employing GIS and Remote Sensing techniques and utilizing the AHP Excel Template to assign criteria weights, this study successfully generated a suitability map for SPIS installation. The integration of these tools and methods has provided valuable insights for decision-making regarding irrigation system implementation in the agricultural sector, particularly for rice crops.

It is recommended that the local government unit (LGU), agricultural cooperatives, and financially capable farmers consider the installation of SPIS in their respective areas if there is a need for an efficient irrigation system to support agricultural water supply. Given the ever-changing climate conditions, the adoption of SPIS can contribute to the resilience of farming practices. Furthermore, as technology continues to advance, there is room for further improvement in this study. Continued research and development efforts can explore the integration of high-end technologies and software to enhance the precision and effectiveness of SPIS installations. These advancements have the potential to significantly boost farmers' production yields and contribute to the overall sustainability and productivity of the agricultural sector.

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