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RESEARCH ARTICLE

Suitability Mapping of Solar Energy Potential of Selected Areas in Camarines Sur using ArcGIS

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Abstract

Solar energy, the most common and scalable renewable energy, has a huge potential to supply the increasing electricity demand. Hence, proper site selection for deploying solar PV systems is required. This paper presents the development of a solar suitability map to identify potential sites for solar PV systems in the selected areas in the Rinconada District of the province of Camarines Sur, Philippines. ArcGIS analyzed the annual average solar radiation, weather datasets, and geographical conditions and performed suitability mapping combined with the Analytic Hierarchy Process (AHP) to identify the weights of the nine criteria of suitable site selection. Based on these factors, twenty-seven (27) barangays were found suitable, where the central and eastern parts of Barangay Malawag in Nabua and a massive part of Barangay Causip in Bula are the most suitable locations for large-scale solar PV installation.

KEYWORDS:
Renewable Energy, Solar PV System, Solar Suitability Map, ArcGIS, Analytic Hierarchy Process

1 | INTRODUCTION

Electricity plays a huge part in our daily lives due to its various applications in the residential and industrial sectors. As electricity demand continues to escalate, suppliers need to generate more electricity to meet the needs of consumers. The generation of electricity can be either renewable or non-renewable. Non-renewable energy harnessed from coal, oil, natural gas, and nuclear power comprises 80 percent of worldwide energy [1]. It takes millions of years to produce fossil fuels, and the combustion of fossil or mineral fuels releases greenhouse gases such as carbon dioxide and methane that harm the environment. The massive demand for energy resources over the limited supply of non-renewable resources requires looking for alternatives.

In the Philippines, Republic Act No. 9153, which supports using renewable energy while limiting harmful emissions, achieving economic development, and safeguarding human health and the environment, affirms the government's commitment to accelerating the country's use of renewable energy resources. Under this legislation, the Philippines installed 903 megawatts [2] of solar power in 2016, and more photovoltaic facilities are planned to be launched in the country. In order to lessen the existing dependence on imported fuel and the strain on natural gas, the current power generation must be diversified, and indigenous resources must be investigated and developed simultaneously. Solar energy is a versatile renewable resource that serves both thermal and electrical energy demands. It does not pollute the environment. However, the two fundamental issues involved in solar energy deployment are how to harness this energy for public consumption and how to enhance the efficiency of producing solar energy.

The country's geographic location is regarded as a prime location for the development of solar energy projects. According to data available [3], the average daily solar radiation in the Philippines is 161.7 watts per square meter, with daily fluctuations between 128 and 203 watts. This amounts to 4.5–5.5 kWh of daily potential electricity output per square meter. The southern regions of the country can produce an average of 5-5.5 kWh per square meter per day, whereas the northern half of the country receives enough sunlight to produce an average of 4.5–5 kWh per square meter per day. Therefore, the country's northern and southern regions are both great locations for the deployment of solar energy, raising concerns about the solar energy potential in the center regions, particularly Camarines Sur.

Site selection or identification of potential areas is the starting point in solar energy facility installations. Solar mapping is one of the best methods of analyzing solar energy potential. An online tool called a solar map calculates the solar energy potential of possible building sites or open areas and informs people about solar technology. The objectives of solar maps [4] are to increase public knowledge of solar energy, enable consumers to understand the solar potential of their homes, and motivate property owners to make significant use of solar energy. The solar maps that are available online [5], [6] provide information on the different parameters such as photovoltaic power potential, global horizontal irradiation (GHI), and direct normal irradiation (DNI). The accuracy of the available irradiation data varies greatly across the region, and irradiance conditions are more variable in nations with complicated topographies [3] like the Philippines. Additionally, these available solar maps did not take the local weather into account.

TABLE 1 Criteria For Solar Potential Area Selection

Criteria	Requirement	Weight
1. Solar Irradiance (GHI)	Minimum is 1300 kWh/m^2/year or 3.56 $kWh/m^2/day$	0.30
2. Temperature	15 - 45°C	0.12
3. Precipitation	< 15mm	0.12
4. Cloud Cover	< 50%	0.12
5. Slope	5 - 15°	0.10
6. Proximity to Road Network	< 1000m	0.07
7. Aspect	112.5 - 247.5° (southeast, south, southwest)	0.06
8. Elevation	10 - 50m	0.06
9. Land Cover and Land Use	free from mountains, forests, water bodies, buildings, wetlands, floodplains, preferably low and medium grassy vegetation, shrublands, and barren lands	0.05

In determining viable locations for solar energy projects, the analytic hierarchy process (AHP) [7], [8] is the multi-criteria decision-making method utilized. The analytic hierarchy process (AHP) was utilized to evaluate the suitability of the sites because there were nine criteria in this study. These criteria were adapted from previous studies conducted. Weights of the criterion were used to calculate how much the supplied criteria influenced the selection of the appropriate places, as indicated in Table I. To determine the degree of influence of the criteria, subjective opinions such as satisfaction, feelings, and preferences were used. The table shows the weights of the nine suitability criteria for site selection that depends on many factors, including the level of solar irradiance, geographical location, and weather conditions for sunlight availability. The use of Geographic Information System (GIS) [6], [7], [8], [9] to analyze and identify potential solar power plant sites considered some suitability requirements that include solar irradiance, weather data, and geographical features.

This paper presents the results of the study conducted in the province of Camarines Sur, Philippines that made use of the criteria listed in Table I. The parameter values were obtained from relevant sources [4], [5], [10], [11] in the open literature on solar suitability mapping. The assessment of solar energy potential in the selected locations made use of weather data and Geographic Information System (GIS).

2 | METHODOLOGY

2.1 | Study Locale

The municipalities of Nabua, Baao, and Bula, as well as the city of Iriga, all within the 5th Congressional District of Camarines Sur, have been chosen as the study area. The selected locations are situated in the northwestern part of Rinconada between 13°20'0" and 13°30'0" north latitude and 123°11'0" and 123°29'0" east longitude. Its estimated area is about 507.85 km^2 with Bula having the largest land area and Nabua having the smallest land area. There are a total of 141 barangays included in the study: 42 from Nabua, 30 from Baao, 33 from Bula, and 36 from Iriga City. The selected locations are bounded on the north by the municipalities of Pili and Ocampo, on the east by the town of Buhi, on the west by the municipality of Minalabac and Ragay Gulf (southwest), and on the south by the municipalities of Balatan and Bato.

2.2 | Data Gathering and Analysis Tools

The selected areas were researched using Google Earth Pro, and NASA POWER Data Access Viewer [10] was used to acquire annual weather data from January 2020 to December 2020 for the indicated sites. The study employed vector and raster data formats, and the Philippine GIS website [11] provided the administrative borders. The road network data was collected from DIVA-GIS, a service with accessible global geographic data [12]. The Global Solar Atlas [13] provided GHI data in raster format with a 250-meter national spatial resolution. The USGS Earth Explorer provided a 30 m DEM. DEMs are used in GIS to map slope, elevation, and aspect. The ESRI-ArcGIS Living Atlas of the World [14] presents a worldwide map of land use and land cover (LULC) taken from ESA Sentinel-2 imagery at a resolution of 10 meters. It is composed of LULC features for 9 classes throughout the year in order to generate a representative snapshot of 2020. GIS was utilized to predict and map the solar-potential areas using the collected data. ArcGIS was used to evaluate and interpret suitability data.

The study employed ESRI's ArcGIS Desktop 10.5 [15]. It is a scalable server architecture with a complete mapping and GIS system. This software converts 2D data to 3D for viewing and produces high-quality maps. It includes ArcReader, ArcEditor, ArcInfo, and ArcMap in the ArcGIS Desktop Suite. It can display and study GIS datasets, assign symbols, and build map layouts. This study utilized ArcMap to create the map's GIS layers. Data reclassification utilized ArcGIS Spatial Analyst Tool. Reclassifying modifies an input raster's values into a new output raster. ArcGIS reclassifies data for numerous reasons. This study employed it to reclassify values for appropriateness analysis. Each parameter criterion was grouped into three suitability rankings: inappropriate, less suitable, and suitable, with new reclassified values of 1, 2, and 3 correspondingly. Table 2 shows the site-selection parameter appropriateness levels.

The suitability map was created using ArcGIS. The weighted overlay tool integrated solar radiation, weather, and suitable land characteristics. Modeling suitability uses weighted overlay. It analyzes rasters using multiple criteria. Each raster layer is weighted for appropriateness. A standard suitability scale classifies raster values. Overlapping raster layers multiply each raster cell's suitability value by its layer weight. Results are written to output layer cells. In this study, the result was layered in order to gather the result in solar irradiance, temperature, precipitation, cloud cover, slope, aspect, closeness to the road network, elevation, and LULC. The places' land areas were also determined. Multiplying each categorization value by its weight produced the final solar suitability map. This study should help energy planners and policymakers build solar energy solutions for the Rinconada district.

TABLE 2 Suitability Levels Of Parameter Criteria For Site Selection

Criteria	Unit of Measure	Suitability Level Ranking		
		Unsuitable	**Less Suitable**	**Suitable**
		1	**2**	**3**
Solar Irradiance (GHI)	kWh/m^2/year		1,583.723 - 1,695.492	1,695.493 - 1,807.260
Temperature	°C		27.25	27.48
Precipitation	mm		12.21	11.33
Cloud Cover	percent		63.1	50
Slope	degree	<5, >20	15 - 20	5 - 15
Proximity to Road Network	m	>4000	1000 - 4000	<1000
Aspect	direction	Flat, N, NW	NE, W, E	SE, S, SW
Elevation	m	<10, >150	50 - 150	10 - 50
Land Cover and Land Use		Water, Flooded Vegetation, Trees, Clouds, and Built Areas	Scrub/Shrub and Bare Ground	Grass and Crops

3 | RESULTS AND DISCUSSIONS

The study focuses on the development of a suitability map for solar energy potential in selected locations in the 5th Congressional District of Camarines Sur.

3.1 | Average Annual Solar Irradiance

The primary criteria in determining the best location for solar power facilities was sun irradiance. A region can be economically viable with solar irradiation of 3.56 kWh/m^2 per day or 1300 kWh/m^2 per year, according to a report from the National Renewable Energy Laboratory. The spatial variation in annual solar irradiance (GHI) at the chosen areas in the Rinconada District is shown in Figure 1. The parts with red color indicate areas with a high amount of solar radiation.

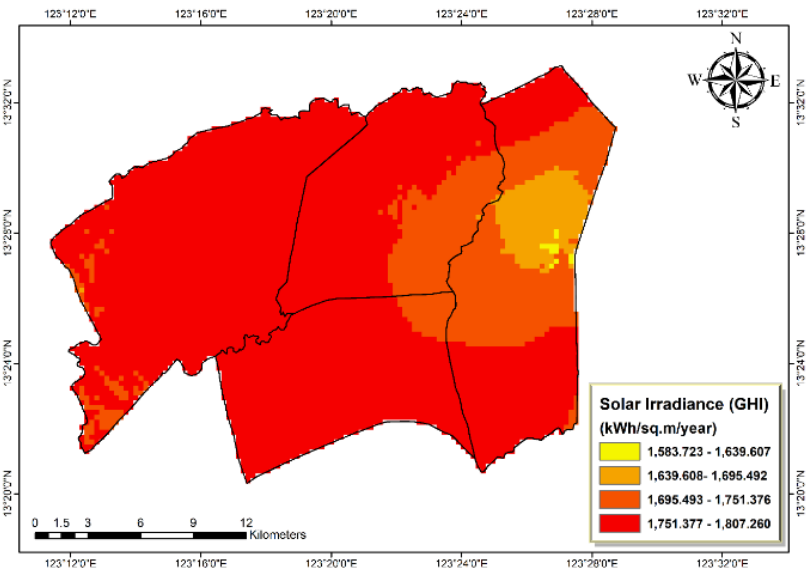

FIGURE 1 Solar Irradiance Map

The maximum range of annual solar irradiance was found to be 1,751.377 to 1,807.260 kWh/m^2 per year which is mostly located in the western portion of the study area including the municipalities of Nabua, Baao, and Bula. The minimum range was 1,583.723 to 1,639.607 kWh/m^2 per year in barangays mostly located in Iriga City. The values satisfy the requirements for solar irradiance levels. The majority of the selected areas in the municipalities of Nabua, Baao, Bula, and Iriga City had shown an abundance of solar radiation which is considered highly suitable and favorable for solar PV installations except for areas in some areas in Iriga City where the mountain is situated.

3.2 | Weather Data

For the weather data analysis, three contributing factors were considered: temperature, precipitation, and cloud cover.

3.2.1 | Temperature

The efficiency of solar power plants and the time they are in operation are directly impacted by temperature. Any solar cell's electrical characteristics are established under what are known as standard testing conditions, such as when solar radiation intensity is high and the panel's working temperature is 25 °C. Consequently, a temperature range of 15 to 40 degrees Celsius is ideal. Figure 2 shows the high and low-temperature values in degrees Celsius for the selected areas. The western part of the map which comprises the municipalities of Nabua, Baao, and Bula, and some parts of Iriga City has the highest temperature value of 27.48°C. On the other hand, the barangays located in the Eastern portion of Iriga City had recorded the lowest temperature value of 27.25°C. All the values obtained fall under the classification of suitable areas for solar energy potential. It indicates that the atmospheric temperature in the Rinconada area can supply the optimum requirement for the solar panels to operate.

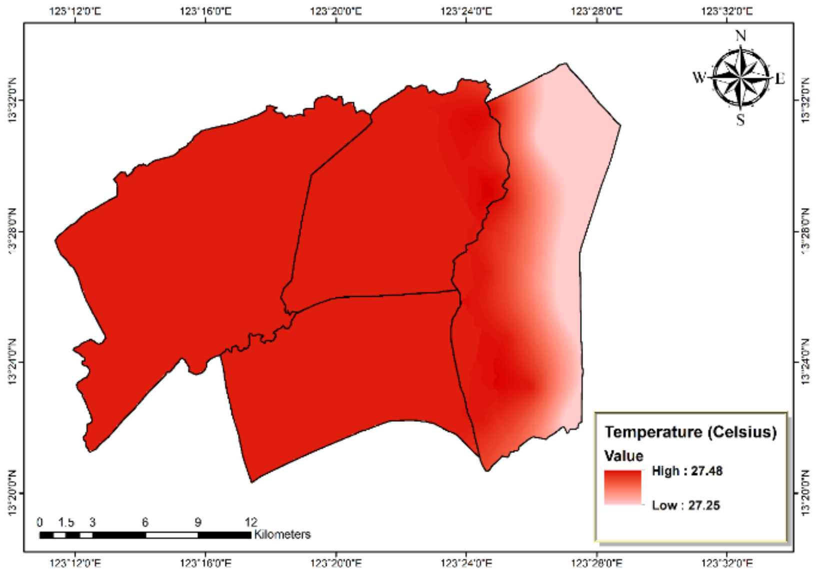

FIGURE 2 Temperature Map

3.2.2 | Precipitation

For the precipitation, the required value was set to <15mm. The values were set by the researchers based on the related literature reviewed for the study. Figure 3 the precipitation value for the study area. The highest precipitation value measured was 12.21mm in the areas found in the western portion of the map specifically in Nabua, Baao, Bula, and other parts of Iriga City. The eastern portion of the map, mostly the terrains and highlands in Iriga City, has the lowest precipitation value of 11.33mm. The rainfall amount per year that governs the majority of the selected areas in the municipalities of Nabua, Baao, and Bula makes them less suitable for solar energy applications. However, the eastern part of Iriga City had seen to be most suitable.

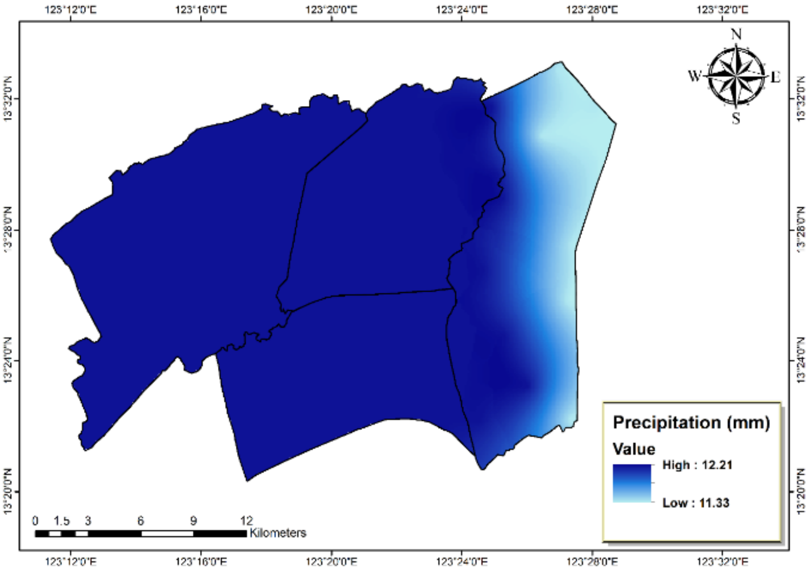

FIGURE 3 Precipitation Map

3.2.3 | Cloud Cover

The suitable value for cloud cover per year was set to <50%. Figure 4 illustrates the cloud cover percentage of the selected locations. Most of the places situated in Nabua, Baao, Bula, and Iriga City have the highest cloud coverage of 63.1 percent, while places in the outskirts of the municipalities have seen the lowest cloud coverage of 50 percent. The values acquired imply that the Rinconada area is mostly covered with clouds which reduces the sunlight duration. Thus, the majority of the locations were categorized as less suitable.

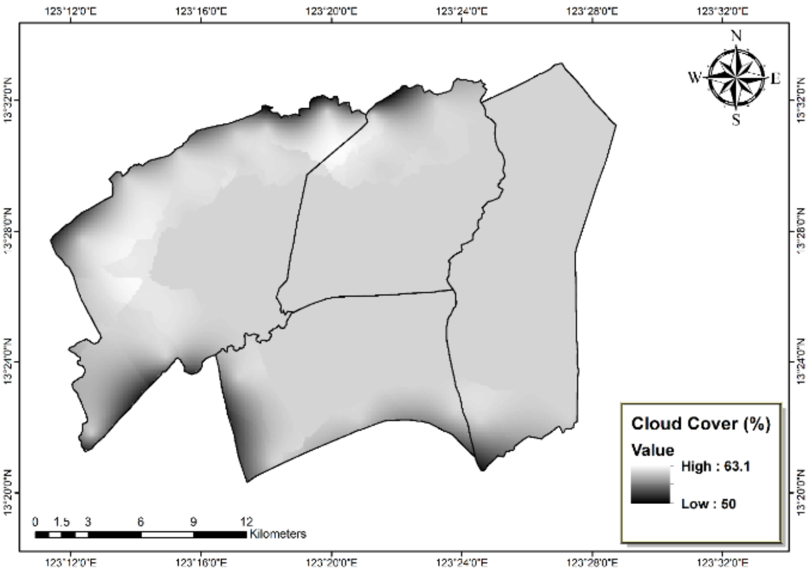

FIGURE 4 Cloud Cover Map

3.3 | Suitable Land Area

Studies that use GIS technology to investigate the optimal placement for solar power plants take into account a wide range of criteria, including the slope of the land, its height, its orientation toward the sun, its accessibility to roadways, and its land use and land cover.

3.3.1 | Slope

One of the equally significant aspects in choosing a place for solar plants is the slope. When solar facilities are installed on steep slopes, drainage issues, erosion, and foundation stability may arise. Figure 5 illustrates the corresponding values of slope in degrees. In the slope gradient map, areas indicated in yellow-green color have slopes of 5-10°, these are very gentle slopes and are considered highly appropriate for solar PV installation sites. Moreover, areas with yellow color have slopes ranging from 10-15°, which are also considered suitable. On the other hand, the places indicated in dark green are flat, have a slope of less than 5°, and are less suitable. The areas that are highlighted with orange and red colors have steeper slopes, which make them less desirable for the installation of solar power plants. The municipality of Nabua has a greater number of suitable locations compared to Baao, Bula, and Iriga City which can accommodate solar PV in terms of the criteria for the steepness of slopes.

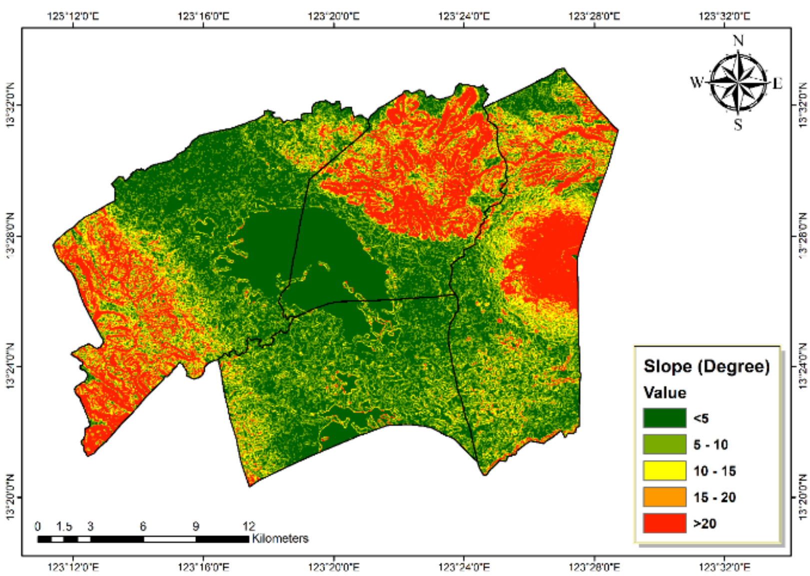

FIGURE 5 Slope Map

3.3.2 | Proximity to Road Network

Road accessibility is crucial in solar power plant installation, construction, maintenance, and dismantling. Because the transportation of materials required for building a solar power plant is expensive, the potential sites must be close to roadways. As a result, solar PV sites close to an existing road network will be advantageous, potentially lowering project costs. The proximity to road values in meters is shown in Figure 6. Locations with a proximity value of fewer than 1000 meters are suitable for the installation of solar power plants, whereas areas with a distance of more than 4000 meters are unsuitable.

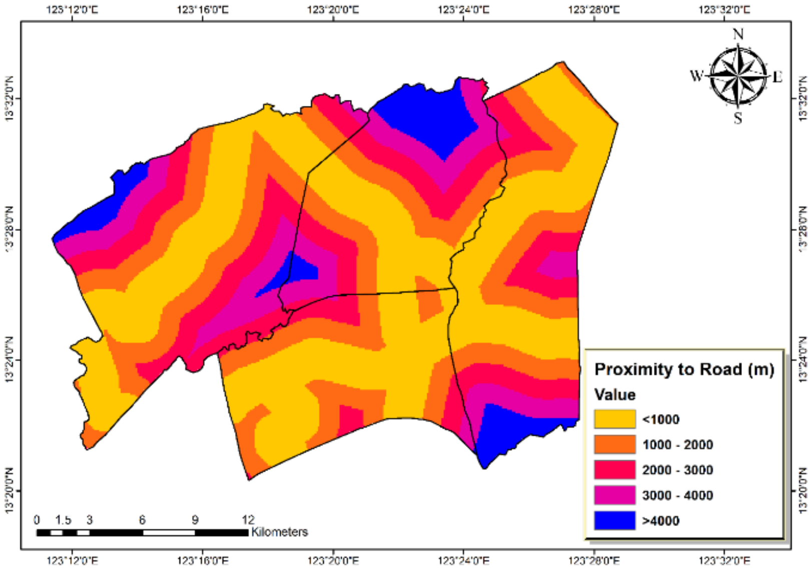

FIGURE 6 Proximity to Road Network Map

3.3.3 | Aspect

The slope direction classes produced by an output aspect raster are typically south, southeast, southwest, east, west, northeast, northwest, north, and flat. If there is no slope, the cell value will be -1. When there is a slope, the aspect is measured clockwise from 0° north. Then it returns to its original position of 360° north. Southern direction areas generate the greatest electricity on a solar panels. Shown in Figure 7 is the map in which the slopes inclined were considered. The high-suitability aspect areas were oriented south, southeast, and southwest. Slopes that were sloped toward the north and flat slopes were not suitable. These are based on the length of time that the slopes are exposed to solar radiation.

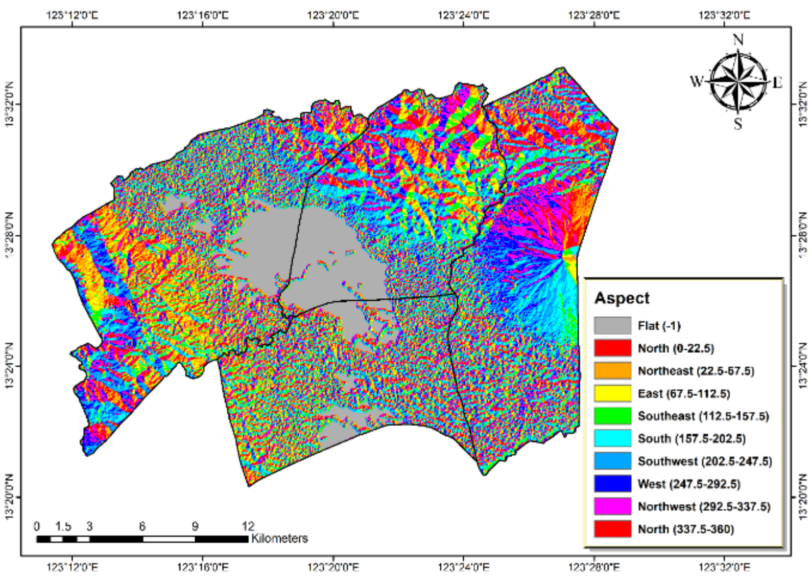

FIGURE 7 Aspect Map

3.3.4 | Elevation

Elevated places receive more sun irradiation than lower regions, but higher elevations require higher installation, transportation, and maintenance costs than areas in lower elevations. The researchers set the acceptable elevation level to 10-50m. Figure 8 shows that the suitable areas in terms of elevation were marked with orange color. Several barangays in Nabua have been seen as highly suitable for solar PV potential. Other highly suitable areas were found in the central part of Baao, the northern part of Bula, and the southwestern part of Iriga City. Mountain, terrains, and hills which are >150m elevated were considered unsuitable. As the elevation value of the place increases, its suitability decreases.

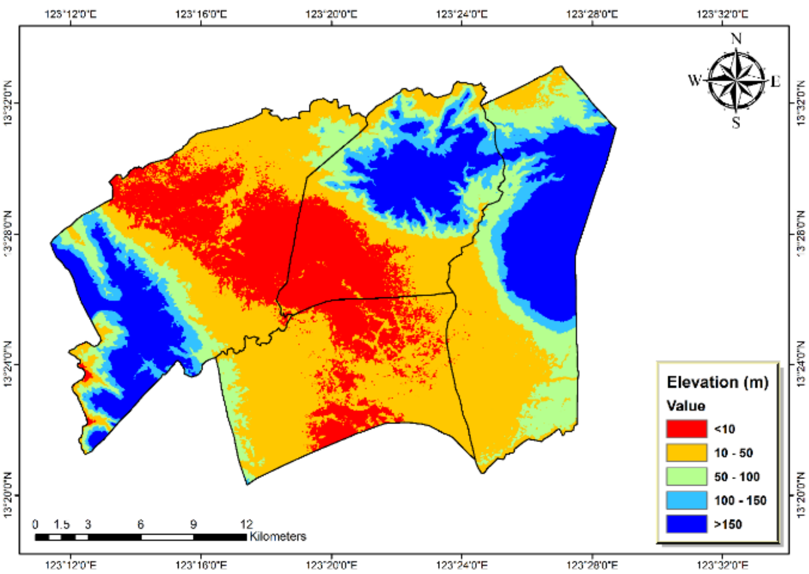

FIGURE 8 Elevation Map

3.3.5 | Land Use and Land Cover

The best place for solar generating facilities was determined in part by land use and land cover. The retrieved LULC map is composed of 9 class definitions namely water, trees, grass, flooded/vegetation, crops, scrub/shrub, built area, bare ground, and clouds. In Figure 9, the distribution of the class definition was shown. Crops occupies the largest area on the map. Open spaces, meadows, and agricultural fields were thought to be excellent locations for solar power plant sites. On the contrary, built areas, trees, clouds, water and flooded vegetation were considered unsuitable. The municipalities of Nabua, Baao, and Bula have large areas covered with crops which are suitable for solar PV installations. Iriga City is mostly covered with trees which are considered unsuitable areas.

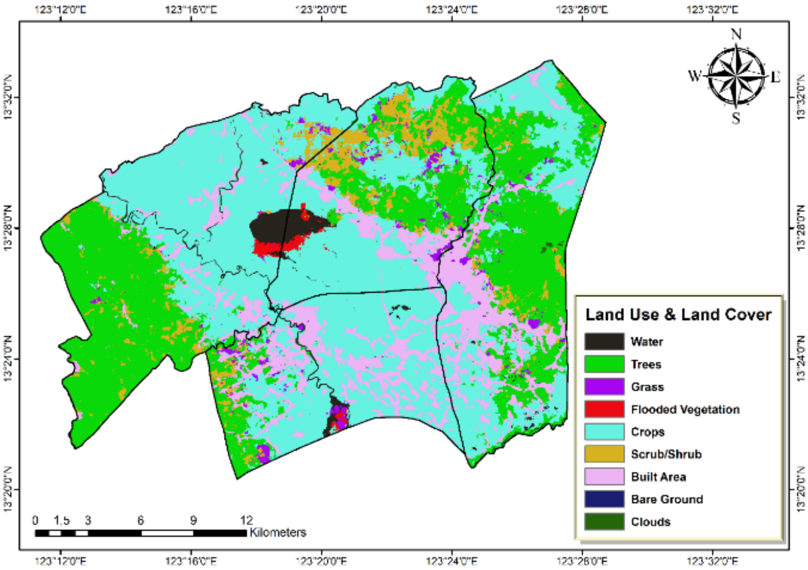

FIGURE 9 Land Use and Land Cover Map

3.4 | Solar Suitability Map

In order to generate the final suitability map, the researchers overlaid the layers from all the figures in ArcGIS software to identify the suitable land area that satisfy the criteria. Weighted overlay tool, a feature in ArcMap used for overlaying map layers to come up with the final solar suitability map. The overlaid maps resulted into two suitability criteria levels: SUITABLE and UNSUITABLE.

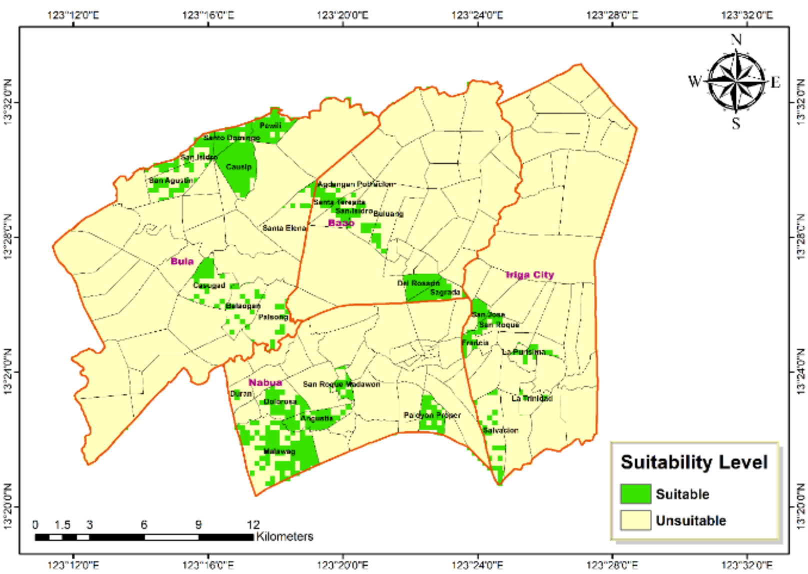

FIGURE 10 Suitability Map for Solar Energy Application

Figure 10 shows the suitable and unsuitable locations within the study area based on the identified suitability factors. In the municipality of Nabua, 6 barangays were classified as suitable areas. These are Malawag, Angustia, Dolorosa, Duran, San Roque

Madawon, and Paloyon Proper. Likewise, 6 barangays from Baao were identified as suitable areas namely Agdangan Poblacion, San Isidro, Santa Teresita, Buluang, Del Rosario and Sagrada. In the city of Iriga, there were also 6 suitable areas which include San Jose, San Roque, Francia, La Purisima, La Trinidad and Salvacion. In the municipality of Bula, 9 locations were found suitable. The barangays are Pawili, Santo Domingo, Causip, San Isidro, San Agustin, Balaogan, Casugad, Palsong and Santa Elena. The said locations satisfy the requirements for solar power plant installations.

The solar suitability map that was developed using ArcMap was converted into Keyhole Markup Language (KML) file and viewed as a satellite image in Google Earth Pro. Figure 11 shows the suitability map displayed in Google Earth Pro for the municipalities of Nabua, Baao, Bula, and for the city of Iriga. The orange lines indicate the administrative boundary of the municipalities and city. On the other hand, the blue lines depict the administrative boundary for the barangays. Areas highlighted with color green are the suitable areas for solar energy siting.

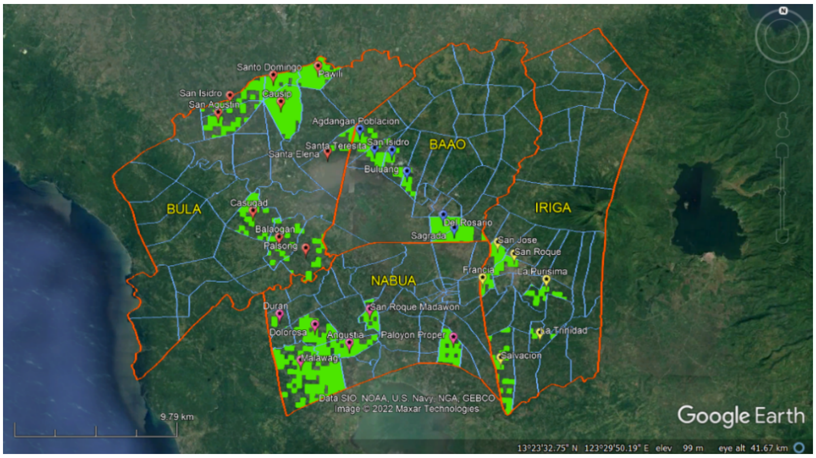

FIGURE 11 Solar Suitability Map in Google Earth Pro

This study had found 128 feasible locations for the deployment of solar energy facilities with a total land area of 42,553,333 m^2. The land area for each location was determined using the PRS 1992 Philippine Zone IV Projected Coordinate System in ArcMap. As a rule of thumb, a 10 sq. meter area is required for a 1 kW solar system capacity [16]. Additionally, the amount of solar energy produced annually is determined by the total area of available sites, the expected area factor of panel coverage, the kind of solar PV technology, and the module efficiency [6]. After identifying the suitable locations, it is necessary to measure the total land area that will be used as a reference in installing solar energy facilities. Table 3 shows the land area ranges of the identified suitable locations. The central and eastern part of Malawag, Nabua has the largest area of 4,896,838 m^2. The location with the second largest area of 4,622,096 m^2 was situated at Causip, Bula.

TABLE 3 Land Area of the Suitable Locations

Land Area (in sq. m.)	Location
4,000,000 – 5,000,000	Central and Eastern parts of Malawag, Nabua
	Causip, Bula
2,000,000 – 3,000,000	Pawili, Bula
	Del Rosario Baao
	Paloyon Proper, Nabua
	Sagrada, Baao
1,000,000 – 2,000,000	Sto. Domingo, Bula
	Central part of Dolorosa, Nabua
	Central part of Angustia, Nabua
	Northern part of Casugad, Bula

	Western part of Agdangan Poblacion, Baao
	Central part of Sta. Teresita, Baao
	San Jose, Iriga City
	San Roque Madawon, Nabua
	San Roque, Iriga City
	Eastern part of San Isidro, Bula
500,000 – 1,000,000	Francia, Iriga City
	Eastern part of Malawag, Nabua
	Western part of San Agustin, Bula
	Central part of San Isidro, Bula
	Western part of Angustia, Nabua
	Western part of San Isidro, Baao
	Southern part of San Agustin, Bula
< 500,000	105 remaining suitable areas

4 | CONCLUSIONS

The study used GIS-based average annual solar irradiation, weather data, and suitable terrain to estimate solar energy potential in the Rinconada District. The highest yearly sun irradiation occurs in Nabua, Baao, and Bula. In the western part, 12.21mm of rain fell, while the east had 11.33mm less. Cloud cover was 63.1% of the research area and 50% of Iriga City. The choice of solar plant sites incorporates slope, road proximity, height, aspect, land cover, and usage. Elevation must be 10–50 m high; any higher is undesirable. Solar power plant sites with a 5-10 degree slope are appropriate. Suitable territory for solar energy deployment is available in the southwestern part of Nabua, the western and southern portions of Baao, the northern and eastern parts of Bula, and the southwestern part of Iriga City. Twenty-seven barangays were found to be suitable. Barangay Malawag in Nabua and Barangay Causip in Bula have the most land for large-scale solar PV installations. Future researchers can use different websites to gather weather datasets for more accurate results without weather monitoring stations. Additional land suitability factors that need to be considered are water bodies, flood-prone locations, and residential areas. Expert information and views can be used further to determine the influence and weight of different factors and validate study results, including ocular site surveys. The results of this research may help energy planners, developers, and policymakers promote solar energy solutions for Rinconada's sustainable development.

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