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GIS-based site suitability analysis for biomass power plant in Bohol

Galang, W. N.[*], Tabañag, I. D. F. and Loretero, M. E.

School of Engineering, University of San Carlos, Cebu City, Cebu, Philippines; College of Engineering and Computer Studies, Holy Name University, Tagbilaran City, Bohol, Philippines; Department of Chemical Engineering, University of San Carlos, Cebu City, Cebu, Philippines; Department of Mechanical and Manufacturing Engineering, University of San Carlos, Cebu, Philippines.

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Abstract Site suitability is an essential process in determining potential sites for power plant development with respect to some economic and environmental factors, such as road access, land surface features, crop distribution, and the population's energy demand. In terms of the working population and land usage, agriculture remains to be Bohol's largest sector. Agriculture covers more than half of the province's total land area. It was found that the municipalities of Dagohoy, San Miguel, Talibon, Trinidad and Ubay are abundant in coconuts, accounting for 38% of agricultural land and cultivating rice on about 32% of their agricultural area. The large croplands offer an abundant supply of agricultural residues. Along with an increasing number of people located some distance from croplands, electricity may be used efficiently. Furthermore, the municipality of Ubay was identified as the most suitable site for plant development through the integration of the GIS approach that allowed the analysis of the top rice and coconut areas in the province to determine the most suitable location that balanced economic and environmental criteria within the biomass supply.

Keywords: Biomass, Energy potential, GIS-MCDA, Site suitability, Waste to energy

Introduction

Globally, the use of renewable energy as an alternative to fossil fuel is highly considered to counter the increasing fuel cost and environmental concerns. Biomass is considered as one of the main option for renewable energy sources given its abundance to nature (Woo *et al.*, 2018).The term biomass refers to any organic material that comes from plants. Biomass is produced by green plants that convert sunlight into plant material through photosynthesis as discussed by (McKendry, 2002). The solar energy stored in chemical bonds makes the biomass resource an organic material. The stored

[*]**Corresponding Author**: Galang, W. N.; **Email**:naborgalang@gmail.com

chemical energy is released when the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion, combustion, or decomposition. Basically, biomass can be divided into three major groups: wood biomass, non-wood biomass and secondary fuels (Rosillo-Calle and Woods, 2012).

The Philippines being an agricultural country has the opportunity to effectively and efficiently explore biomass as a renewable energy resource considering its abundance in the surroundings. Biomass represents 25.5% of the indigenous energy supply as of 2016 with the bulk of demand consumed by the household sector. It is the most preferred fuel among households because of its abundance, accessibility and affordability, particularly in the rural areas (Energy, 2018). The province of Bohol in Central Visayas is a main producer of agricultural products in the region. It is called the “Rice Granary of Central Visayas” after it was cited for surpassing other provinces in the region in terms of rice output (Bohol, 2006). According to the Department of Agriculture(PSA, 2018), the rice production in the province raised by 54.2% from 161,003 metric tons in 2016 to 248,314 metric tons in 2017, representing the bulk of the rice produced in Central Visayas region. The province had a higher contribution of the rice production in the region by improvement of 45% from 231,982 metric tons in 2016 to 335,420 metric tons in 2017. In addition, the province has abundance in coconut plantation. Bohol Island has around 4,679,329 coconut trees with production of 170,293 MT in an area of 35,338.00 hectares(Philippine Coconut Authority, 2018).

The power plants located in Leyte and Cebu through Leyte-Bohol Transmission Interconnection is the prime power supplier of Bohol. In 2015, about 68.86 MW or 89% of the peak demand of the province were supplied by power plants outside Bohol through the Leyte-Bohol Interconnection, while the remaining 8.4 MW or 11% is collectively supplied by the three mini-hydro plants inside Bohol(Provincial Planning and Development Office, 2018). The vulnerability of its electric power system and the need to make it resilient to the effects of natural disasters lead to recognize the need to put in place measures that can ensure sufficient power is supplied to the whole island province. Such readiness is in response to the event that it is disconnected from the rest of the Visayas Grid or to the interconnected island grids of Cebu, Negros, Panay, Leyte and Samar.

Given the abundance of agricultural sources, the province has the means of potential energy from agricultural products waste such as rice and coconut, respectively.The meaning of potential is not just defined by energy transfer, but defined by economic and environmental factors as well. To promote energy from agricultural waste or residues corresponds to identifying the feasible location of a biomass energy plant. A bioenergy plant is affected by a wide variety of factors and criteria. The Geographical Informational System (GIS) with multiple criteria decision analysis (MCDA) is a practical approach that considers various limiting factors in order to identify the most suitable locations for a renewable energy plant. GIS is a collection of technologies used to input, save, and retrieve spatial data, as well as manipulate and analyze it and process its results (Malczewski, 1999). The GIS provides the decision-maker with a flexible environment in the process of the decision research and in the solution of the problem that aids the solution of complex spatial problems. MCDA supports analyzing situation when priorities must be identified according to multiple criteria especially when conflicting interest coexist (Gomes and Lins, 2002). MCDA can convert both geographical data and stakeholder preferences into quantifiable values for assessment and subsequent decision-making (Malczewski, 2004). The integration of GIS and MCDA has been widely promoted for solving spatial problems in urban assessment and planning to create visualized suitability map for users and decision makers (Phua and Minowa, 2005).

There have been several studies conducted to introduce multi-criteria decision analysis into land use suitability analysis along with the existing perspective evolving the role of GIS (Chen, 2014). Some case studies were performed using the method of integrating GIS and multi-criteria analysis to create an output with a set of land use suitability maps incorporating complex criteria integrating several stake-holders' points of view. In the Philippine setting, a study using Multi Criteria Decision Analysis and GIS processes were employed in the province of Nueva Ecija. The land cover was classified from LandSAT 8 image using Support Vector Machine classification technique. The classified map was used to generate the biomass resource map in addition to expert consultation for a three level hierarchy of factors used in the site suitability analysis (Sevilla *et al.*, 2015). However, in the region of Visayas, there is limited study done for site suitability particularly in the province of Bohol utilizing the GIS-MCDA approach given its biomass potential for renewable energy sources.

The overall goal of this study was to develop geospatial site suitability analyses for use in Bohol province. The locations suitable for agricultural waste and energy use respectively were classified through land suitability analysis. Specifically, the objectives were to identify appropriate land based on environmental and economic criteria in order to develop suitability map layouts for the adaptation of the biomass plant site facility for power generation. For that purpose this study utilizes the integration of GIS-MCDA to support decision-makers in the province by providing them with ways to evaluate several alternatives by linking data on environmental factors and economic conditions of the study area for decision making in identifying potential sites using geospatial techniques. In site suitability modeling, the limiting factors are weighted to their level of influence using multi-criteria evaluation to produce a site suitability map. Mapping potential sites is vital to locate and rank which areas are highly suitable and less suitable, so that coherent management measures can be suggested and applied to the site specific management interventions.

Materials and methods

The study was conducted within the scope of Bohol province in the country's Central Visayas region. Bohol is composed by three districts with a total of 47 municipalities and a city, possessing a total land area of 411,726 ha and arable area of 256,400 ha.

Study area

The municipalities of Alburquerque, Antequera, Baclayon,Balilihan, Calape, Catigbian, Corella, Cortes, Dauis, Loon, Maribojoc, Panglao, Sikatuna, Tagbilaran and Tubigon composed the first district; the second district are municipalities of Bien Unido, Buenavista, Clarin, Dagohoy, Danao, Getafe, Inabanga, Pres. Carlos P. Garcia, Sagbayan, San Isidro, San Miguel, Talibon, Trinidad and Ubay; and the rest of the municipalities particularly Alicia, Anda, Batuan, Bilar, Candijay, Carmen, Dimiao, Duero, Garcia Hernandez, Guidulman, Jagna, Lila, Loboc, Mabini, Pilar, Sevilla, Sierra Bullones and Valencia belong to the third district (Figure1).

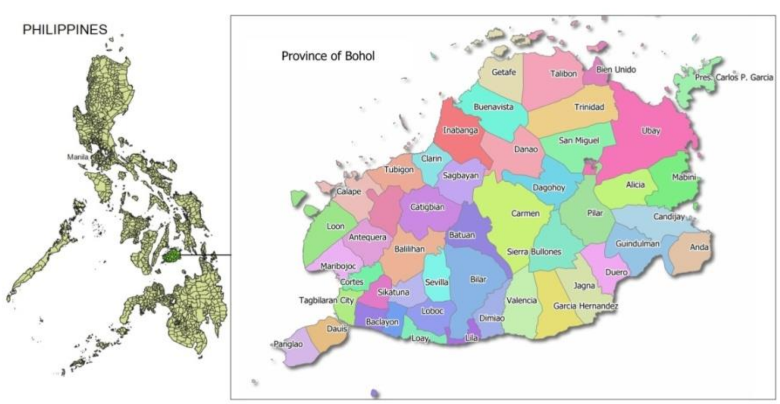

Figure1. Area of study, the Province of Bohol

The availability of biomass residues varies spatially in the province of Bohol, mostly due to land cultivation area and land topography. The first district of Bohol has fifteen municipalities, including the city of Tagbilaran. The second district, particularly the municipalities of Dagohoy, San Miguel, Talibon, Trinidad, and Ubay, were considered to be the top rice and coconut producers in the province, as shown in Figure2. The rest of the nineteen municipalities belong to the third district, which is abundant in corn production.

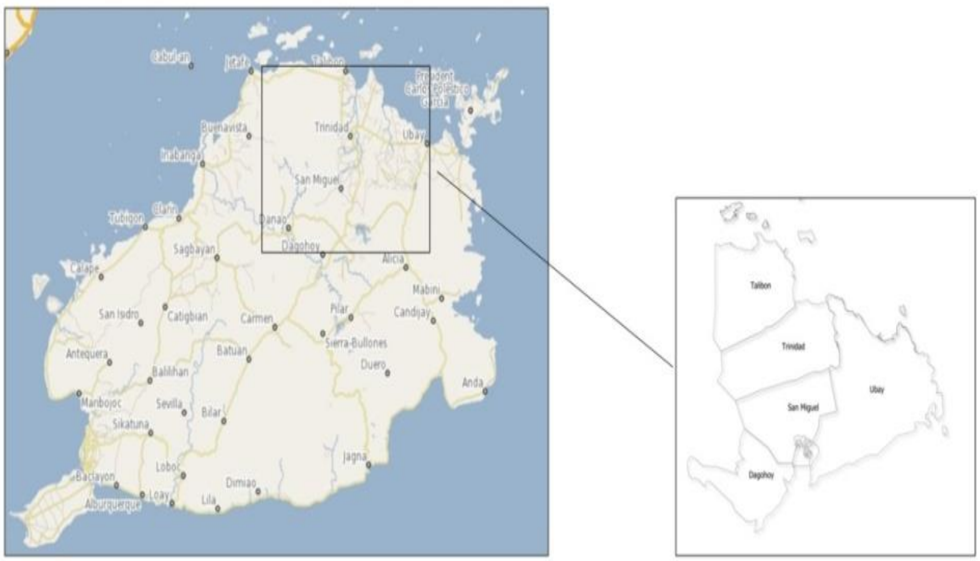

Figure2. The municipalities with highest in rice and coconut production

Data collection

Data were collected from PhilGIS free data source for Philippines(Philippine GIS Data Clearinghouse, 2020). Available data on population, administrative boundaries, roads, and slope were acquired. The digital analysis was carried out using the Geographical Information System (QGIS version 3.4.11)(QGIS Official Website, 2020).

A suitable land for a new plant was determined, and the following major approach was developed and illustrated as seen in Figure3. The input data from the case study was collected: population distribution; identification of rice and coconut cultivation areas; and road and slope maps. The process calculated the composite scores and the output was a map identifying locations that were suitable for the selected plant facility.

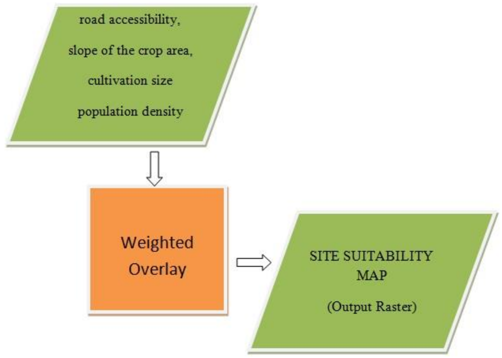

Figure3. Weighted overlay model

Data and criteria of analysis

The basic key to the GIS plan was the model of the database. The basic database consisted of current data for road accessibility, slope of the crop area, cultivation size and population density. Raster maps were used for weight overlay analysis. Multi-criteria weighted-overlay analysis is done in the process of allocating areas on the basis of a variety of attributes that the selected areas should possess. Working in the raster space provided a ranking of suitability. It allowed for combining any number of input layers easily and assigning different weights to each criterion, making it the preferred approach for site suitability.

The typical workflow for performing a site-suitability analysis involves converting source vector data to appropriate rasters, re-classifying them and performing the mathematical operations. Specifically, input criteria in raster form (road accessibility, slope of the crop area, cultivation size, and population density) were multiplied by the assigned weights and then added together in the Raster Calculator tool of the QGIS environment.

Raster and reclassify

In this study, a location for a biomass plant facility is chosen. Four factors are considered as road accessibility, slope of the crop area, cultivation size and population density. The input rasters to the weighted overlay are displayed in Figure 4 - 7. They are done the population map for 2015, land area and respective villages for each municipality, road map, and slope map for rice and coconut producer municipalities of Bohol province.

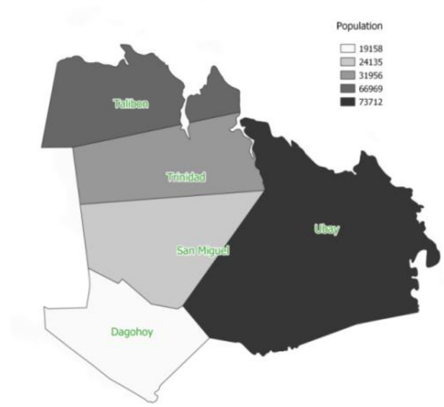

Figure4. Population map for 2015

Figure5. Land area and respective villages for each municipalit

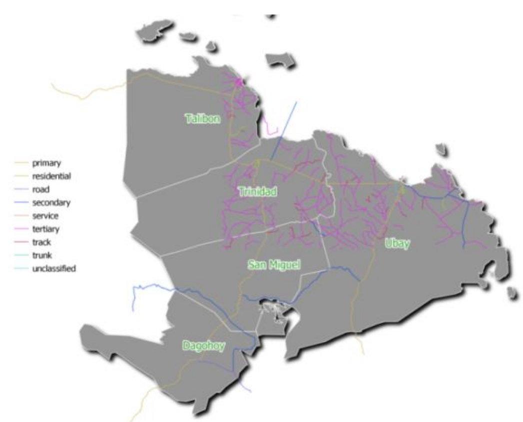

Figure6. Road map for rice and coconut producer municipalities

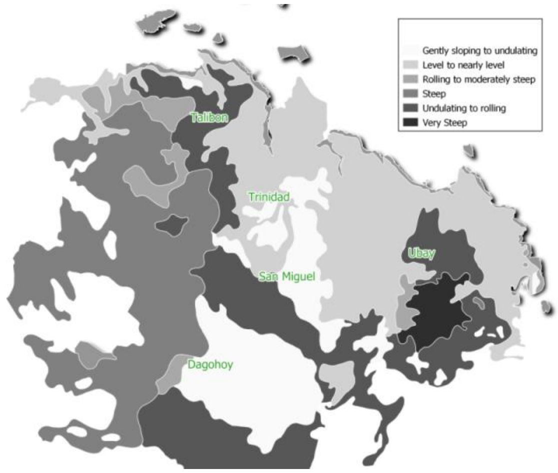

Figure7. Slope map for rice and coconut producer municipalities

Suitability scores and weighted overlay

The input data were the vectors in shape file processed using QuantumGIS, a free and open-source cross-platform desktop application that supported viewing, editing, and analysis of geospatial data from QGIS Official Website. Using QGIS a new field was created in the attribute table of each input layer and classified them according to importance. The classification field was used to rasterize the respective layers for major road, slope, land area and population.

Each value class in each input raster is assigned a new, reclassified value on an evaluation scale of 1 and 0, where 0 represents the lowest suitability and 1 the highest. The site selection was based on multiple criteria. First, they must be approached near major roads and easily accessible. The primary road in the identified area of study was given the top priority. Secondly, the slopes of the land must be near the cropland. A higher slope increases the difficulty of construction, so a lower slope area is considered more suitable for the new plant. Furthermore, the croplands must be large enough to provide a plentiful supply of agricultural residues. Lastly, there is a large population at some distance from the croplands, so the power can be used efficiently.

Each of the four input rasters is weighted. In this weighted overlay, road access had influenced a slope, cultivation area and population of 20 percent. The particular location of the land which satisfied these multiple criteria is appropriated to the suitable area to put up a biomass power plant.

Results

The weighted overlay tool allowed the calculation of a multiple-criteria analysis between several rasters. The applied methodology of overlay analysis enabled to the optimal site selection or suitability modeling. It applied a common scale of values to diverse and dissimilar inputs to create an integrated analysis.The overview of weighted overlay approach included scaling the input data on a defined scale (in this study being 0 to 1), weighted the input rasters, and added them together. The more suitable locations for each input criterion isreclassed to the higher values. In this study, the four input rastersare reclassified to a common measurement scale of 0 to 1. Each raster is assigned a percentage of influence, 20% for road access, 20% for slope, 40% for cultivation and 20% for population. The cell values are multiplied by their percentage influence, and the results are added together to create the output raster.

The weighted overlay assumed that more favorable factors resulted in the higher values in the output raster and leaded to identify the specific locations for the best. The result of the reclassifying raster based on attributes ranked of 0 to 1 with 1(in black color) in the unrestricted area for development. The assignment of influence considered cultivation area as the most valued layer because of having the most abundance of agricultural residue guaranties a sufficient energy source for biomass plant development. The areas with slopes from 0% to 3% are given its description as level to nearly level land surface as shown in Figure9. They were the most suitable areas in order to place a biomass plant due to ease of construction. As a result of raster and reclassify process, the municipality of Ubay possessed 50% larger area and level slopes were compared to the rest of the other rice and coconut producing municipalities of the province as reflected in Figure8.

Figure8. The rasterized cultivation land area with site suitability identification

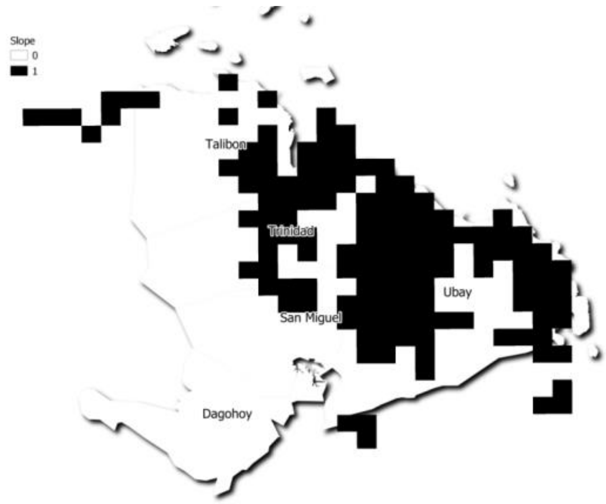

Figure 9. The rasterized slope map with site suitability identification

With regards to the accessibility of roads, the primary road was the most valued. These primary roads are concerned the ones that directly connect to major cities as shown in Figure10. In the case of energy demand, the population layer of high numbered household was most valued as reflected in Figure 11.

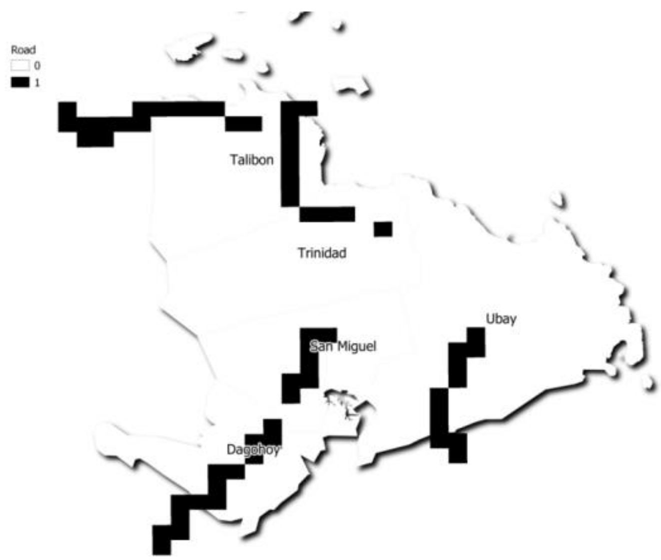

Figure 10.The major roads map with site suitability identification

Figure11. The population map with site suitability identification

The combined layers for road, slope, land area and population lead to the identification of exact location were found to be the best station a biomass power plant as reflected in Figures 12 and 13. The spatial distribution of various criteria influencing the site analysis is recorded.

In rasterized suitability map layer, it is in the municipality of Ubay that serve as best location for biomass plant. The suitability map was calculated using raster calculator feature in QGIS following the weightage given for each criterion.

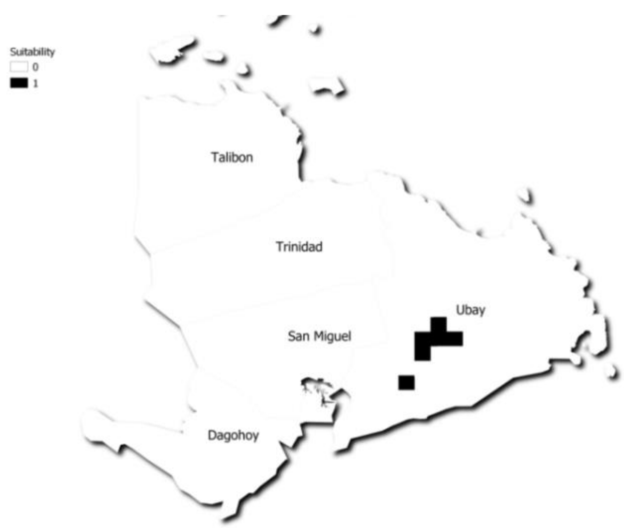

Figure12. Suitability Map

Ubay is the largest and most populated locationamong the rice and coconut producer municipality in Bohol. The Department of Energy estimated around 34.97 percent of the total households in the municipality had electricity as compared to the province, which were 58.3 percent energized in 2000(Reyes, 2018). The percentage indicated a need for an increase of electrification ratio given the number of population in the area which described the bulk of demand.

Figure13. Biomass plant suitability map in satellite view with OpenStreet map

The municipality of Ubay is one of the largest rice and coconut growing areas in the province, making it an ideal location for a biomass power plant. The integration of the GIS technique enabled the linkage of data on environmental factors (cultivation area and slope) and economic conditions (population distribution and road network) in the study region required for the identification and analysis of optimal appropriate locations that balanced economic and environmental requirements within the biomass supply. The generated suitability map is critical for establishing consistent management measures that may be applied to site-specific management interventions.

In the study, the emphasis was on the criteria selection and determination of potential sites for biomass facilities where the resources are widely available and electricity generation is highly needed. The research considered only limited economic and environmental factors as an initial phase to assess site suitability with its straight-forward approach. In this research, the weight was determined by the judgement of municipal land use evaluators, leading to a simplified simulation of the suitable level. The technique assisted decision-makers in evaluating numerous possibilities in the Visayas area, where there has been minimal study for site suitability, notably in the province of Bohol, using the GIS-MCDA. The approach was streamlined, so that local government entities may simply use it in order to efficiently and effectively use agricultural residues for energy generation.

Discussion

Soil quality is an essential factor in evaluating an area's viability for agriculture. The identified soil types are agriculturally viable due to their high fertility, nutrient deficit, and high water holding capacity(Joshua*et al.*, 2013). The kind of soil in the case study area isclay soils with fine textures predominate throughout the province. The major soil type is Ubay Clay, which covers 19.53% of Bohol's land area, or 79,644 hectares. Clay loam to clay soils are found on steep to extremely steep slopes (18-50%). Clay is found on gently sloping to undulating terrain (3-8%), whereas silty clay to clay is found in narrow alluvial valleys (Bohol, 2006). The province's soils are generally brown, with moderate to high intrinsic fertility making the selected site suitable for agricultural cultivation as accounted by its physical, chemical and morphological characteristics. Furthermore, the amount of solar radiation intercepted by a vegetated surface is greatly influenced by its slope. Solar radiation dominates the surface energy balance and impacts biologically important microclimate variables such as nearsurface temperatures, evaporative demand, and soil moisture content(Bennie *et al.*, 2008). Bohol's topography ranges from practically level in the middle plains to low rolling, moderate to steep slope with 5 to 50 meter high cliffs in the Sierra-Bullones limestone formation (Bohol, 2006). The province's most difficult topography is situated in the south, however the Ubay volcanic rocks and Boctolserpentinite in the north and northeast have moderate to rugged slopes in most of their outcrop regions. The center valley ranges from almost flat to moderately hilly. In addition, during agricultural site selection processes, proximity to highways is one of the economic and social variables evaluated. Due to the high cost of transportation, cultivation areas should be located near a road network. The plant-suitable area was chosen for its proximity to key highways. In the same manner, nearness to a community with a high demand for power due to high population density is a priority for potential site selection.

The studies on site suitability provided a broader context of inquiry as it recognized a wide variety of environmental, ecological, social and economic parameters(Jeong and Ramírez-Gómez, 2017a, 2017b; Quinta-Nova *et al.*, 2017; Woo *et al.*, 2018).However, this study on its residue evaluation for site suitability took into account restricted environmental and economic factors due to challenges in data availability. Furthermore, this evaluation can be considered as a starting stage for the complex land use plan method for the study area.

The generated suitability map reflects the limits of data resources when the site suitability study is performed. The selection of criteria and the assignment of weight should be widely debated and investigated to promote an increase in the reliability and accuracy of site suitability assessments. The weight of the criterion should be decided by experts and stakeholders. The literal assessment of the land use plan determined the weight in this study. However, it is worth emphasizing that the credibility of the assessment results depends on several circumstances. The results are the possibility of an evaluation based on GIS for site adaptability purposes.GIS facilitates the solution of complicated geographical problems by providing the decision-maker with a flexible environment during the decision-making and problem-solving processes. One of the most powerful components of a decision support system is the visualization of the context, structure of the problem, and its possible solutions (Gomes and Lins, 2002).

The combination of GIS with MCDA assists decision-makers through a method for assessing possible sites based on environmental factors (cultivation area and slope) and economic conditions (population distribution and road network). In the case of Bohol’s agricultural areas, where potential sites have to be identified according to several criteria, MCDA supports decision makers. It is where geographical data and the preferences of stakeholders can be combined into both quantifiable evaluation and decision making values. The GIS solution provides a flexible environment for policy-makers to deal with complicated spatial concerns.

The computer-assisted overlay approaches were created in response to the manual method's limitations in mapping and merging big datasets. Individual suitability maps can be examined and merged to create an overall suitability map. The advancement of computer-assisted mapping techniques was critical in enhancing land-use suitability assessments (Malczewski, 2004). The incorporation of MCDA methodologies with GIS has significantly enhanced the traditional map overlay approaches to land-use appropriateness analysis. GIS-based MCDA may be conceptualized as a process that integrates and transforms geographic and a spatial data as input into a decision as output. The technique established a connection between the input and output maps. The methods entailed the use of geographical data, the decision maker's preferences, and the modification of the data and preferences in accordance with predefined decision criteria (Malczewski, 2004).

The site suitability assessment is a useful tool for making plant development decisions. The method in this study resulted in the identification of the most suitable site for the biomass plant siting among areas of higher value in terms of evaluation criteria (weighted criteria). The use of overlays of different rasters utilizing a common measuring scale and weighting each element according to its value is a simple strategy that can be easily adopted by local government entities to promote biomass, notably agricultural residues, for energy generation. Hence, suitability analysis is a powerful tool of solving energy planning issues as a means to see the problem through a combination of MCDA and GIS methodologies.

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