LOCATING POTENTIAL SITE FOR BIOMASS POWER PLANT DEVELOPMENT IN CENTRAL LUZON, PHILIPPINES USING LANDSAT-BASED SUITABILITY MAP

Bryan M. Baltazar[1], Marjorie Remolador[1], Klathea H. Sevilla[1], Imee Saladaga[1], Ma. Rosario Concepcion O. Ang[1], Loureal Camille V. Inocencio[1]
[1]Training Center for Applied Geodesy and Photogrammetry, University of the Philippines, Diliman, Quezon City, Metro Manila, Philippines
Email: brybaltazar@gmail.com, mvremolador@gmail.com, klathea.sevilla1@gmail.com, saladaga_imee@yahoo.com, lcvinocencio@gmail.com, moang@up.edu.ph

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ABSTRACT: Philippines, as an agricultural country, has an abundant source of biomass that can be used for power production. However, lack of research on biomass resources impedes development of bioenergy facilities. Conducting biomass resource assessment is important in determining bioenergy of an area. Resource assessment combined with the analysis of physical, environmental, and socio-economic aspects will helps investors in developing strategies for potential power plant facilities in the country. Thus, this study develops an integrated method combining biomass resource assessment of rice hull and energy planning methods for locating suitable site for biomass power plant development in Central Luzon, Philippines using remote sensing technologies, mathematical models, and Geographic Information Systems (GIS). Biomass resource assessment was done by utilizing LANDSAT-based land cover map and two mathematical models, whereas, theoretical biomass potential (B_n) and available biomass potential (B_{av}) maps were derived. On the other hand, site suitability analysis was conducted using results of biomass resource assessment, Multi-Criteria Decision Analysis (MCDA), and Analytical Hierarchy Process (AHP) processed in GIS platform. After the analysis, it was determined that the most suitable area to develop a biomass power plant is within the municipality of Talavera, Nueva Ecija; with an estimated total area of 388.44 hectares; that can generate available power of 2.85 MW. Further analysis can be conducted accounting transport cost of rice hull to determine the optimal site for the power plant.

1. INTRODUCTION

1.1 Background

Biomass energy is the energy from the sun stored in materials such as agricultural crop residues, forest residues, animal wastes, agro-industrial wastes, municipal solid wastes and aquatic biomass (Dong, 2008) It is a traditional source of sustainable energy, which has been widely used in developing countries because of high availability of biomass and environmental friendliness of the byproduct (Hiloidhari, 2011).

The Philippines, being considered as an agricultural country, is a rich source of biomass resources, which comes as a cheap feedstock to generate power. One of its main agricultural product is rice, which is comprised of 22% of the country's crop production. The biomass residues that can be derived from rice are rice hull and rice straw. Rice straw are left in the field during harvesting while rice hull are collected after milling (IRRI, 2015). The ease of collection, widespread availability and no further processing required for burning of rice hulls makes it an interesting source of feedstock for biomass power plant (Mendoza and Samson, 2006). However, lack of research on biomass resources impedes development of bioenergy facilities.

Effective utilization of surplus biomass for energy production can be done by conducting biomass resource assessment. Biomass resource assessments quantify the existing or potential biomass material in a given area. The purpose of an assessment is to identify resource potential within a given area for a particular end use (NREL, 2008). The Theoretical (B_n) and Available (B_{av}) potential are the two types of biomass potential evaluated to know the resource capacity of a specific area. The theoretical potential is the total annual production of residue in a region while available potential shows the actual amount of energy that can be derived from the residue.

However, aside from resource availability, other factors such as physical, environmental, and socio-economic aspects must be taken into consideration. These factors are interdependent, wherein failure in one can lead to failure of the entire project. Hence, these gives rise to a method that should account for multiple biomass stakeholder's objectives and interests which are normally diverse and conflicting.

Multi-criteria decision analysis (MCDA) is a widely used method in energy planning. It facilitates the participation of stakeholders and has an important role in policy and management strategies and long-term planning. Combining it with Geographical Information System (GIS) provides a powerful tool in site selection and optimization. GIS offers geospatial tools for easier analysis whereas MCDA accounts economic, social and environmental aspects of the problem. It has been extensively used in site suitability analysis as it serves as an important decision-making tool for planning and has been employed to assess physical, environmental, and socio-economic constraint (Hohn et al., 2013). Selection of criteria (factors and constraints) is the most important phase and the one with a strong influence in the evaluation of potential sites for development. This will depend on the required objectives, the information available, planner's experience, etc. This can be obtained from literature and consultation with experts (Dael et al., 2012).

Assigning weights to criteria is also an important process. The most applied method in determining weights for each criterion is the Analytic Hierarchy Process. It is simple in structure and allows the analyst to negotiate results until consistency is reached nearing almost consensus (Taba et al. 2013). It assumes that all factors do not have equal influences in the selection of suitable sites and measures through pair-wise comparisons wherein the key role to derive the priority scale is the experts' judgements (Sultana et al., 2012).

Furthermore, biomass distribution is highly dispersed geographically, thus, this study focuses on the regional energy systems planning for power generation. Resource assessment combined with the analysis of physical, environmental, and socio-economic aspects will helps investors in developing strategies for siting potential power plant facilities in the country. Thus, this study develops an integrated method combining biomass resource assessment of rice hull and energy planning methods for locating suitable site for biomass power plant development in Central Luzon, Philippines using remote sensing technologies, mathematical models, and Geographic Information Systems (GIS).

1.2 Study Area

Though rice is produced throughout the country, Central Luzon (Figure 1) is the major rice growing region that produced around 3.3 million tons of rice in 2015 (PSA, 2015). It is composed of seven provinces, twelve cities, and 118 municipalities. Its 7 provinces are Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac and Zambales. Central Luzon remains as the Rice Granary of the Philippines to comply with the nation's huge demand in rice production, consequently, it produces the largest amount of rice hull wastes, about 700,000 MT, among other regions. Despite the many known benefits, bulk of rice hull in the region is still being disposed indiscriminately.

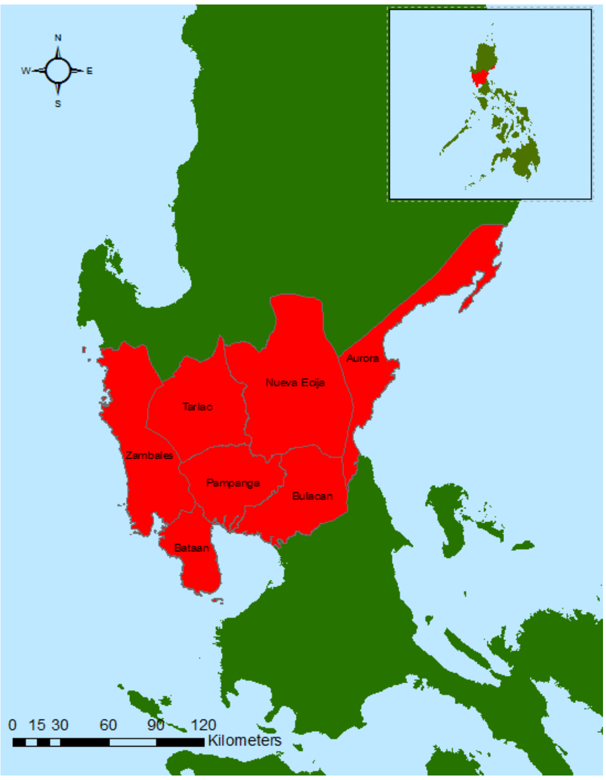

Figure 1. Central Luzon, Philippines

2. METHODOLOGY

2.1 Biomass Resource Assessment

Biomass resource map of Central Luzon (Figure 2) was produced by classifying LANDSAT Image using pixel-based classification technique. Afterwards, the theoretical (B_n) and available (B_{av}) potential in the region were computed using Equation 1 and Equation 2, respectively; which are mathematical models developed by Voivontas et al.

$$B_n = \sum_n A_n Y_n \qquad (1)$$

Where:
- A_n = cultivated area for crop *n* (Ha)
- B_n = biomass theoretical potential for crop *n* (MT of residue/year)
- Y_n = residue yield for crop *n* (MT/Ha/year)

$$B_{av} = \frac{fg \sum n\ B_n\ a_n\ LHV}{A_r} \qquad (2)$$

Where:
- a_n= biomass available for energy production from crop *n*
- A_r = area of the region under consideration (Ha)
- B_n = biomass theoretical potential for crop *n* (MT of residue/year)
- B_{av}= biomass available potential (kJ/Ha/year)
- f_g = efficiency of the biomass collection procedure
- LHV = lower heating value of the residue from crop *n* (kJ/kg)

Parameters in the equation were gathered from literature and the LANDSAT-based agricultural resource map, and were summarized in Table 1 and Table 2. Then, the mathematical models were employed in a GIS platform to produce Theoretical and Available Biomass Potential Maps of Central Luzon.

Table 1. Parameters for Theoretical Potential and Available Potential

Parameter	Source
Crop area	Agricultural Resource Map
Crop yield	Bureau of Agricultural Statistics, 2015
CTRP	Biomass Atlas of the Philippines in 2000
Efficiency of collection	Samson and Mendoza, 2006
Availability for energy production	Samson and Mendoza, 2006
Lower heating value	Biomass Atlas of the Philippines in 2000
Area of the province	Agricultural Resource Map

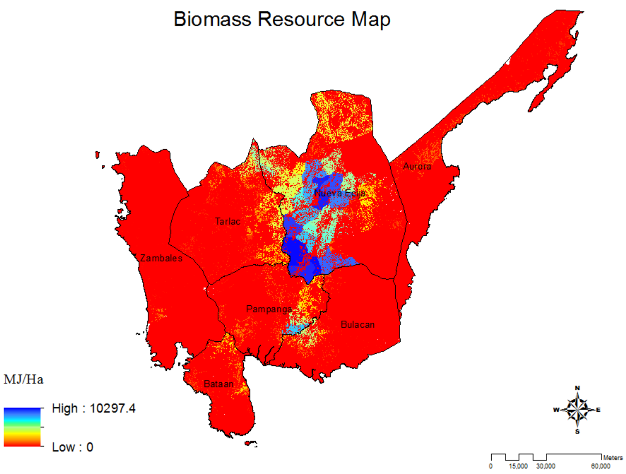

Figure 2. Biomass Resource Map for Rice Hull in Central Luzon, Philippines

2.2 Selection of Criteria

A hierarchy of factors and constraints were decided and their relative weights were determined for site suitability analysis. Multi Criteria Decision Analysis was employed and experts from academe, government, industry, and the environmental sectors were invited to a criteria determination workshop. Factors were categorized as physical, environmental, and socio-economic. Afterwards, weights for each factor were determined using Analytic Hierarchy process. Different experts answered AHP survey forms and these were then consolidated. Using the Analytic Hierarchy Process, the factors were computed and adjusted until a 10% or less consistency ratio was achieved.

2.3 Data Gathering

Data and maps needed for site suitability analysis were gathered from different agencies and institutions in the country. Administrative boundary was from Philippine GIS Data Clearinghouse and is not consider as authoritative. On the other hand, protected areas and key biodiversity maps were gathered from Biodiversity Management Bureau, which is the responsible agency to conserve and manage sustainably the countries biodiversity resources. Indigenous People Location map was from the National Commission on Indigenous Peoples that protects the rights of indigenous people in the Philippines. Moreover, Land cover and built-up areas map were gathered from Forest Management Bureau, the primary agency that provides technical guidance for effective protection, development and conservation of forest and watersheds. Waterbodies was gathered from National Mapping and Resource Authority that conducts hydrographic surveys and produces hydrographic maps. Road network was collected from Department of Public Works and Highways and transmission lines was gathered from the National Grid Corporation of the Philippines. And lastly, slope was derived from SAR data given by Bureau of Agricultural Research. The data gathered were summarized in Table 2.

Table 2. Data Sources for Site Suitability Analysis

DATA/MAP	**Source**
Administrative Boundary	Philippine GIS Data Clearinghouse
Protected Areas	Biodiversity Management Bureau
Indigenous People Location	National Commission on Indigenous Peoples
Slope	BARSAIL
Waterbodies	NAMRIA
Land Cover	Forest Management Bureau
Key Biodiversity Areas	Biodiversity Management Bureau
Built-up Areas	Forest Management Bureau
Road Network	Department of Public Works and Highway
Transmission Lines	National Grid Corporation of the Philippines
Agricultural Map of Central Luzon	LANDSAT 8

2.4 Site Suitability Analysis

The gathered data for the determined factors undergone several processes such as pre-processing, standardization and aggregation. The pre-processing of the data involved geo-referencing of maps if necessary as well as setting them to correct projection. Utility function was used for standardization of data which involves an expert giving weights on the range of suitability of the factors based on his preference. After standardization, aggregation was done. The weights obtained from AHP survey were applied to each map layer and were aggregated using Weighted Sum Tool under the Spatial Analyst Tool in ArcGIS**.** The resulting map is the final suitability map showing the potential sites for power plant development.

3. RESULTS AND DISCUSSION

Biomass resource assessment was conducted in Central Luzon Region. After applying Equation 1, a theoretical potential of 26142.49 MT/ha was computed. Since, provinces in Central Luzon are among the top producing sites in the country, it yields high value of Bn. However, the generated value does not automatically indicates that 100% of rice hull produced is available for energy production. To get the actual availability for energy production, Equation 2 was employed. The highest available potential for Central Luzon is 10,297.4 MJ/Ha in San Antonio, Nueva Ecija.

Three level hierarchy of factors and constraints agreed upon by experts are summarized in Table 3. Indigenous people location and protected areas were considered constraints complying with national government's regulations while nearness to waterbodies, slope of the region, and land use were considered physical factors. Key biological areas on the other hand, falls under environmental factor since, it involves important ecological areas and endangered species. Meanwhile, nearness to built-up areas, nearness to transmission grid, and nearness to road network are considered accessibility factors because of their effect on the operation of the facility.

Table 3. Hierarchy of Factors and Constraints

CONSTRAINTS	**FACTORS**		
	Physical	**Environmental**	**Socio-Economic**
Protected Areas	Slope	Key Biodiversity Areas	Nearness to Built-up Areas
Indigenous People Location	Waterbodies		Nearness to Major Roads
	Landcover		Nearness to Transmission Lines

The weights given to each criteria were summarized in Table 4. Resource had more weight than non-resource factor because it provides the information on the availability of biomass energy needed to operate and sustain the power plant. For the second level, the weights given to each factors were almost equal. In the third level, land use and nearness to major roads have higher weights compared to other factor within their group. Land use was used to identify the areas where power plant development is allowed. On the other hand, nearness to major roads is important since it is an essential factor in minimizing the transportation cost of residues and operational cost of a power plant.

Table 4. Determined Weights of Factors and Constraints

Level		**Factor**	**Weight (%)**	**Total Weight (%)**
1		Resource	61.8	100
		Non-Resource	38.2	
2		Physical	29.5	100
		Environmental	39.6	
		Socio-Economic	30.9	
3	Physical	Slope	24.9	100
		Waterbodies	31.6	
		Landcover	43.5	
	Environmental	Key Biodiversity Areas	100	100
	Socio-Economic	Nearness to Built-up Areas	23.6	100
		Nearness to Major Roads	46.1	
		Nearness to Transmission Lines	30.3	

After determining weights of different factors using AHP, maps were processed using GIS tools applying the weights determined. The Constraint Map (Figure 3) shows that majority of Central Luzon can be a potential site for power plant development. On the other hand, Factors map (Figure 7), which is derived by aggregating the Physical, Environmental, and Socio-Economic maps (Figures 4-6), shows that potential sites for power plant development are distributed within the region. Furthermore, overlaying the constraints and factors map produced the suitable sites from non-resource factor (Figure 8). It shows that highly suitable sites for development are located in the southwest part of the province of Nueva Ecija.

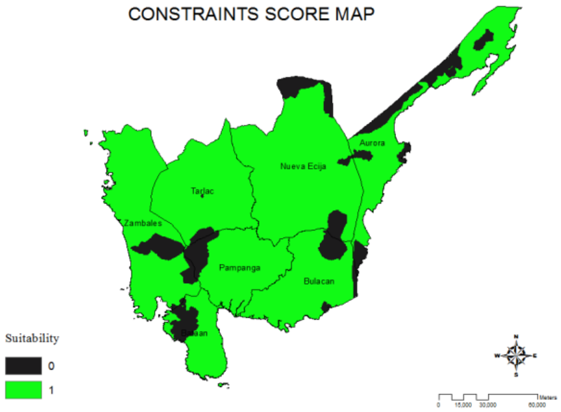

Figure 3. Constraints Score Map for Central Luzon

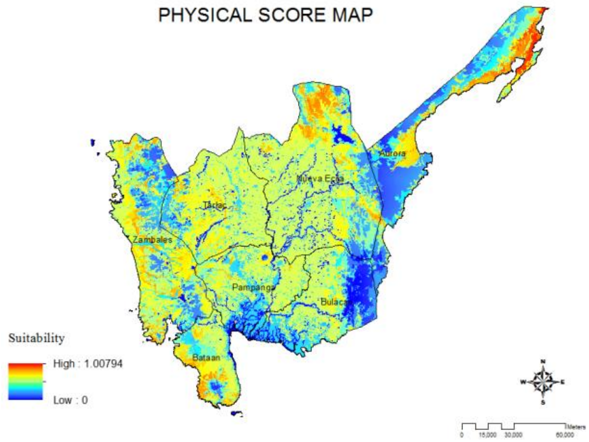

Figure 4. Physical Score Map of Central Luzon

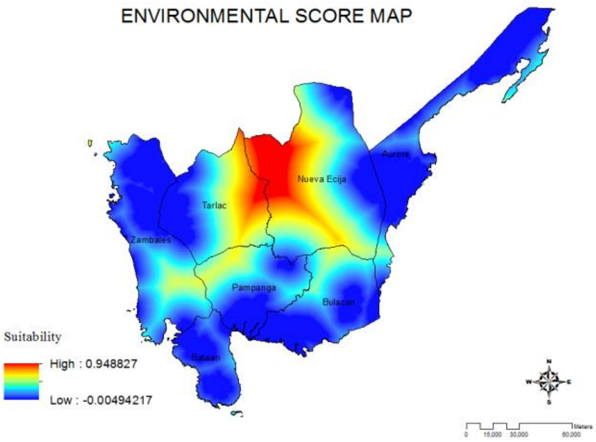

Figure 5. Environmental Score Map of Central Luzon

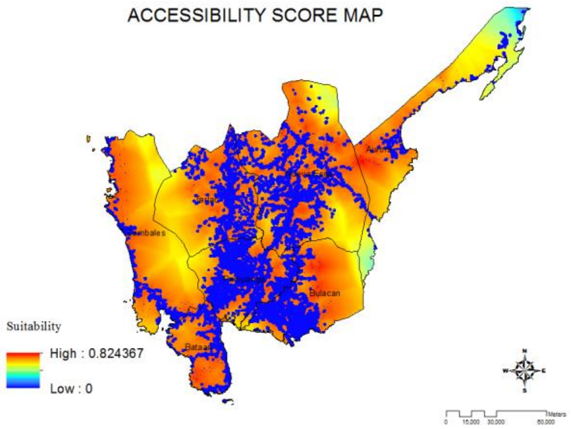

Figure 6. Accessibility Score Map of Central Luzon

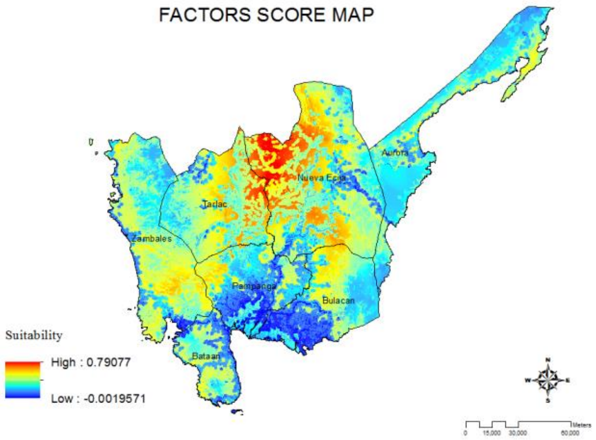

Figure 7. Factors Map of Central Luzon

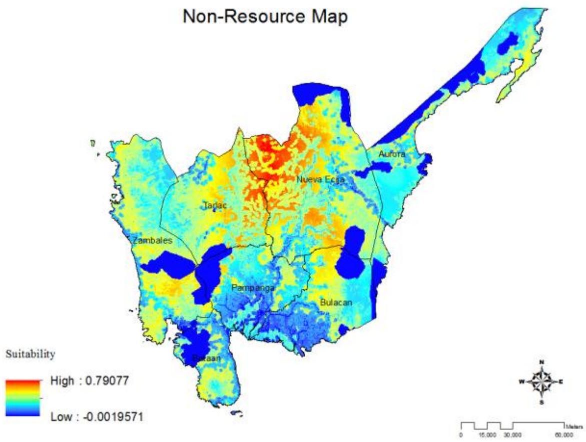

Figure 8. Non-Resource Map of Central Luzon

Moreover, non-resource suitable map was aggregated to biomass resource map (Figure 2) resulting to the final suitability map (Figure 9). The resulting map shows that the most suitable areas are located in the municipality of Talavera, Nueva Ecija (Figure 10) with a total area of 388.44 Ha and can generate 2.85 MW of power. It agrees to the characteristics of the area in the municipality which are surrounded by abundant rice areas, generally with flat land surfaces, and accessible roads and grid networks, as shown in Figure 11. More importantly, the identified areas with the highest suitability are also the location with the highest concentration of biomass potentials which is the most important factor to consider when siting a biomass power plant

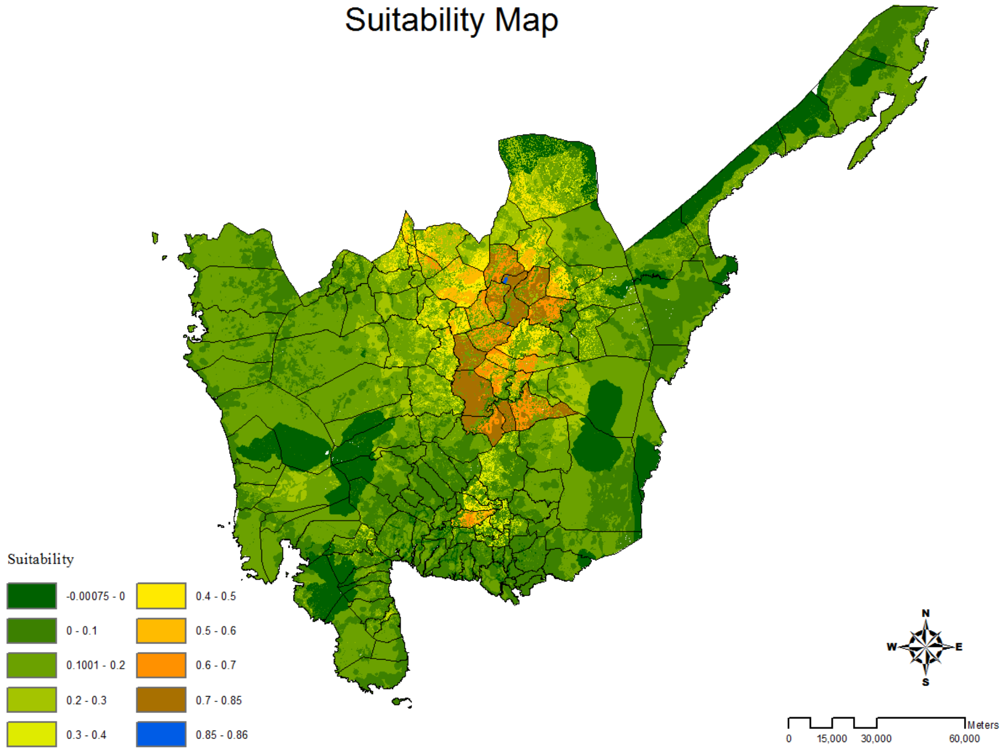

Figure 9. Suitable Site for Biomass Power Plant Development in Central Luzon

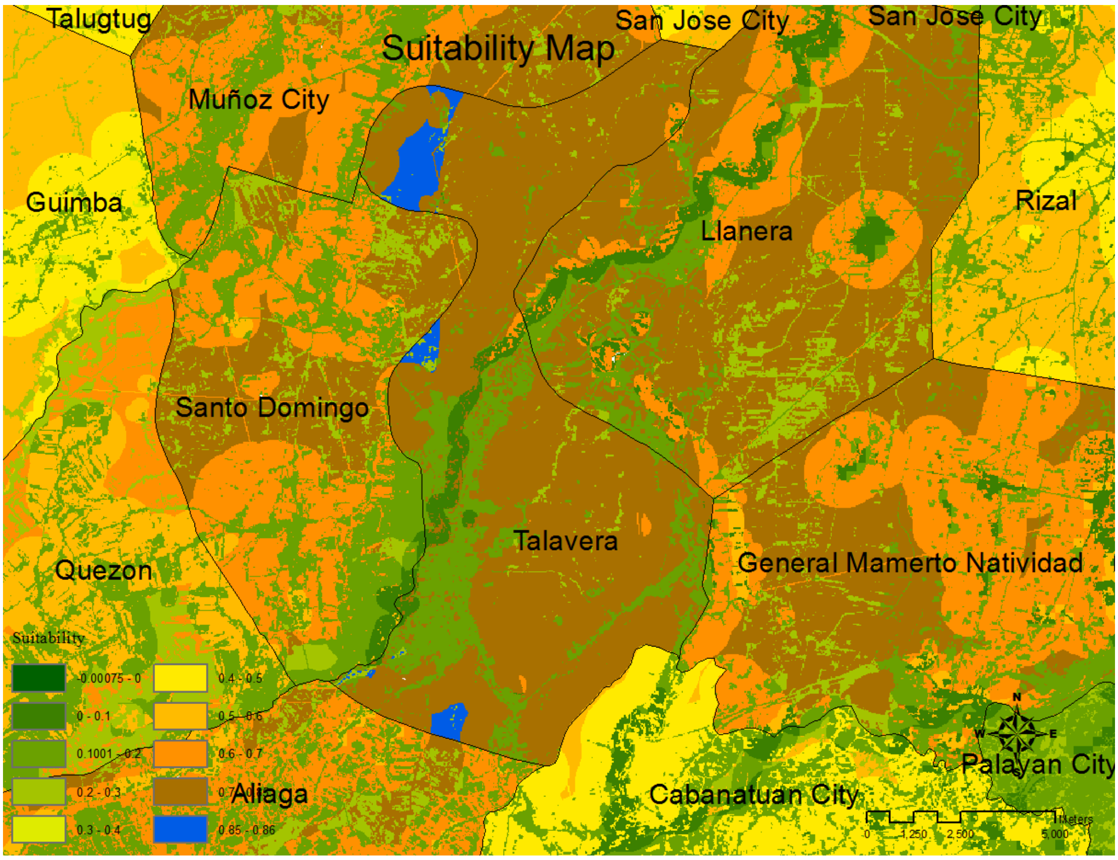

Figure 10. Most Suitable Site for Biomass Power Plant Development in Central Luzon

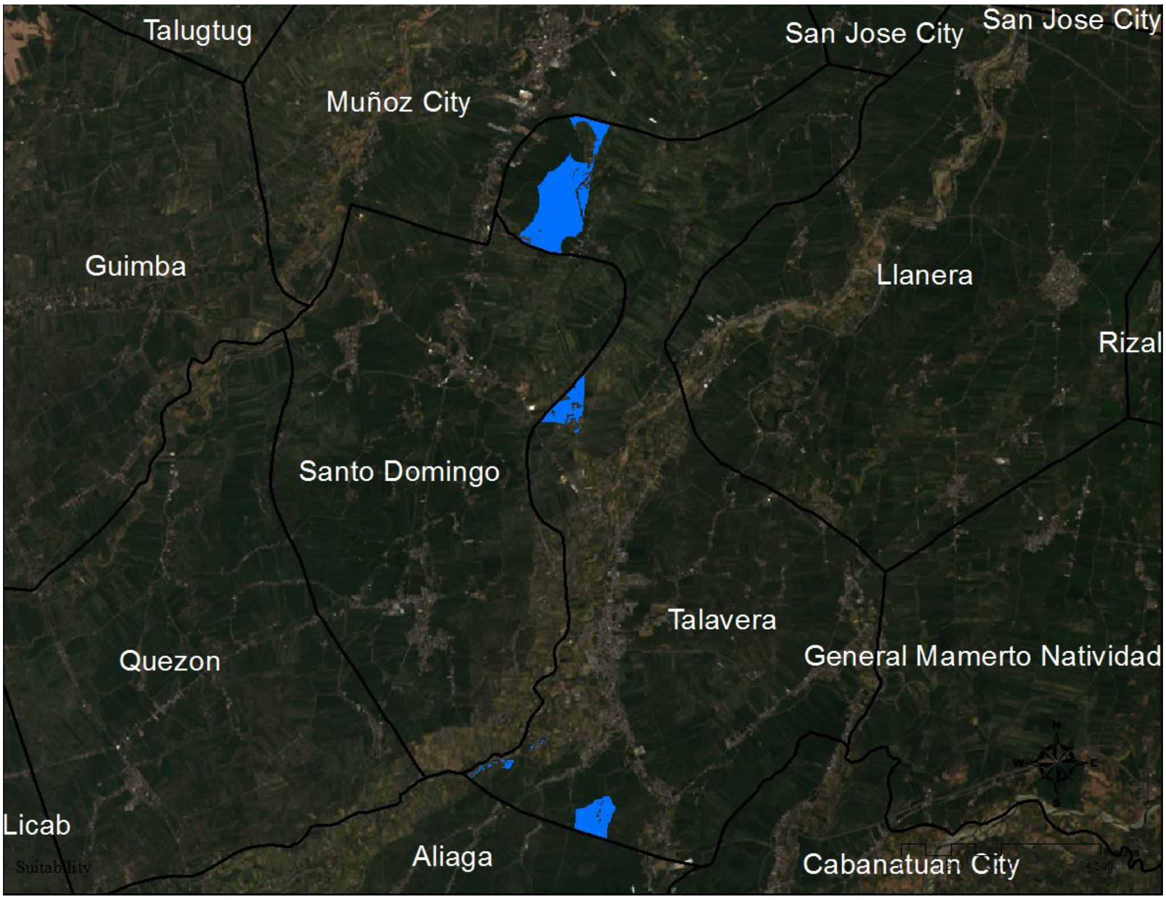

Figure 11. Suitable Ares in Talavera Nueva Ecija

4. CONCLUSIONS AND RECOMMENDATIONS

The Philippines, specifically Central Luzon, has an abundant source of biomass. It could supply abundant agricultural residues (rice husks), as feedstock in a biomass power plant. The ease of collection, widespread availability and lack of processing required for burning of rice hulls makes it an interesting source of feedstock for biomass power plant. However, lack of research on biomass resources impedes development of bioenergy facilities. Effective utilization of surplus biomass for energy production can be done by conducting biomass resource assessment. Biomass resource assessments quantify the existing or potential biomass material in a given area. However, aside from resource availability, other factors such as physical, environmental, and accessibility aspects must be taken into consideration. Hence, this study develops an integrated method combining biomass resource assessment of rice hull and energy planning methods for locating suitable site for biomass power plant development in Central Luzon, Philippines using remote sensing technologies, mathematical models, and Geographic Information Systems (GIS).

Biomass resource assessment yields that Central Luzon can produce 26142.49 MT/Ha, however not all are utilized for energy production because of competing uses for other industries. The highest available potential for energy production in the region is 10,297.4 MJ/Ha. After the resource assessment, Site Suitability Analysis was conducted and produced a suitability map that considers resource availability and non-resource factors. It shows that 388.43 Ha within the municipality of Talavera, Nueva Ecija are the most suitable sites for development of biomass power plant and can be utilized to generate about 2.85 MW of power. The result can be attributed to the characteristics of the located suitable areas wherein they are surrounded by abundant rice fields, with flat land surfaces, and are accessible to roads and grid networks.

Further analysis can be conducted which accounts for transport cost and economic aspects of rice hull for determining the optimal site for the power plant.

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