Suitability Mapping for White-fleshed (Hylocereus undatus) and Red-fleshed (Hylocereus costaricensis) Dragon fruit Farming in Butuan City Using Multi-Criteria Decision Analysis and GIS

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Abstract: *This study uses GIS-based software to create a suitability map for white-fleshed and red-fleshed dragon fruit farming in Butuan City. Different sets of parameters were employed under biophysical, social-economic, and climatic factors, moreover multi-criteria decision-making (MCDM) approach through pairwise comparisons and the Analytical Hierarchy Process (AHP) was particularly utilized to derive the suitability ratings per parameters taken from the experts. With that, four suitability classes were used to categorize suitability: High, Moderate, Low, and Not Suitable. Results showed that Butuan City with a total area of 66, 490.13 hectares (ha) has an overall suitable area of 61, 964.11 ha. Additionally, 13,780.98 hectares (20.73%), 29,606.67 hectares (44.53%), and 18,331.84 hectares (27.57%) were rated high, moderate, and low suitability, respectively. The remaining areas consisting of 4,770.64 ha (7.17%) were the areas unsuitable for farming. Among the 13 districts of Butuan City, District 8 has the highest suitable area comprised of 10 barangays.*

Keywords: Dragon Fruit Farming, Suitability Map, MCDM, GIS

1. INTRODUCTION

Dragon fruit has been identified as a minor crop for development, prestigious health food, and is considered a new money crop for farmers because of its market value. Particularly, the market price of this crop ranges from PhP150-180 per kilo in the local market and $7 (P302.96) per pound in the United States which contains about 2-3 pieces [1]. Moreover, evidence from specific countries suggests that dragon fruit production is increasing. Many countries, including Vietnam, China, Mexico, Columbia, Nicaragua, Ecuador, Thailand, Malaysia, Indonesia, Australia, and the United States, are producing and expanding significantly [2]. With about 40,000 acres dedicated to producing dragon fruit, Vietnam is the world's largest fruit exporter, with an annual output volume of about 1 million metric tons [3].

Moreover, dragon fruit shows a competitive advantage for both the local fruit industry and the global market [4]. In the Philippines, the industry is still little yet it is expanding, with increasing production from 256 to 2,090 tons between 2012 and 2021 [3]. Ilocos Region, Cagayan Valley Region, CALABARZON, Central Luzon, and Central Visayas are the top-producing regions in the Philippines [4]. Yet this expansion does not compete with other neighboring countries in Asia in terms of production and production area. As for that, experts expect to grow around 10,000 ha of dragon fruit production in the country over the next five years to meet demand in both local and global markets [5].

In accordance with this, it is vital to secure lands in order to maximize resource usage. As a result, crop suitability evaluation for the given crop is required in order to obtain a more efficient land usage for the optimum yield achievable [6]. The issue with dragon fruit crop suitability is determining the optimal environmental and soil conditions required for plant growth and development. These include determining the optimal temperature, humidity, rainfall, and soil pH levels for dragon fruit growth [7]. The goal of this study is to establish sustainable and lucrative dragon fruit farming systems capable of supplying a continuous and high-quality supply of dragon fruit to meet the rising demand using the GIS-based MCDM land suitability assessment method to classify the study area which is Butuan City with respect to the white-fleshed dragon fruit and red-fleshed dragon fruit potentials.

2. STUDY AREA

Table I. The Districts of Butuan City

Districts	Barangays Covered
District 1	Agao, Datu Silongan , Diego Silang, Humabon , Leon Kilat , San Ignacio, Sikatuna , Rajah Soliman, Urduja
District 2	Dagohoy , Golden Ribbon, Imadejas , JP Rizal, Lapu-Lapu, New Society Vil.
District 3	Holy Redeemer, Limaha, Tandang Sora
District 4	Ambago, Bayanihan, Doongan
District 5	Agusan Pequeño, Babag, Bading, Fort, Poyohon , Lumbocan,, Obrero , Ong Yiu, Pagatpatan
District 6	Bancasi, Dumalagan, Libertad, Masao, Pinamanculan
District 7	Bonbon, Kinamlutan, Maon, Pangabugan, San Vicente, Villa Kananga
District 8	Amparo, Bit-os, Bitan-agan, Dankias, Dulag, Bugabus, Nongnong, San Mateo, Tungao, Manila de Bugabus
District 9	Bilay, Don Francisco, Florida, Maguinda, Maibu, Mandamo, Sumile

Continuation

Districts	Barangays Covered
District 11	Baan Km 3, Baan Riverside, Banza, Bobon, Cabcabon, Mahogany, Maug, Tiniwisan
District 12	Ampayon, Antongalon, Basag Bugsukan, De Oro, Taligaman
District 13	Anticala, Baobaoan, Los Angeles, Pianing, Santo Niño, Sumilihon, Taguibo

Figure 1 depicts the study area, which is the city of Butuan, situated in the province of Agusan del Norte in the Caraga region of the Mindanao islands with a Type II climate. Butuan City has GPS coordinates of 8° 57' 5.5764" N and 125° 31' 39.8100" E [8]. It is composed of approximately a total land area of 66, 490.13 hectares. A total of 372, 910 populations have inhabited the city with a population density of 457 inhabitants per square kilometer [9]. Additionally, the study area is composed of 86 barangays with thirteen (13) districts as shown in Table I.

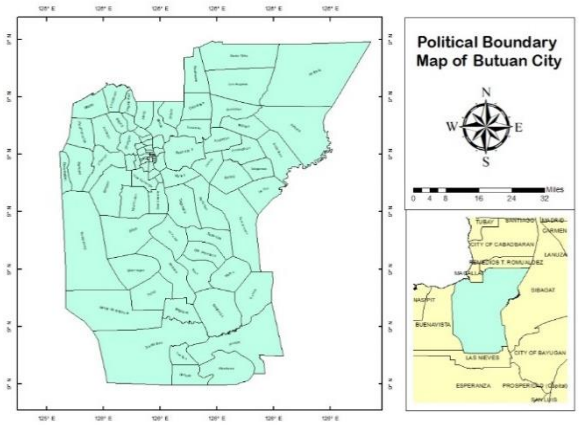

Figure 1. Political Boundary Map of Butuan City

3. MATERIALS AND METHODS

3.1 Data Collection

Table II. Sources of Secondary Data

Component	Criteria	Sources
Biophysical	Land Use and Land Cover	Center for Resource and Assessment Analytics and Emerging Technologies (CReATe)
	Soil Type	CReATe
	Soil pH	Food and Agriculture Organization (FAO)- Open Source
	Slope, Aspect, and Elevation	CReATe; Department of Environment and Natural Resources-Wildlife Resources Permitting Section
	Water Sources	Small Scale Irrigation Project (SSIP)- Caraga
Socio-Economic	Road Networks	CReATe
Climatic Condition	Temperature	TerraClimate-Open Source
	Rainfall	TerraClimate-Open Source
	Evapotranspiration	TerraClimate-Open Source

A range of data was gathered from various reliable sources (i.e., thematic maps) in order to evaluate the crop suitability of white-fleshed dragon fruit and red-fleshed dragon fruit in Butuan City. Particularly, this study utilizes both primary and secondary data. The secondary data includes a range of data that was gathered from various reliable sources (i.e., raw maps and datasets) to evaluate the crop suitability of white-fleshed and red-fleshed fruit in Butuan City. Secondary sources are presented in Table II. Moreover, researchers select important factors in dragon fruit farming based on secondary data such as published studies, books, and other online references. Each important factor was subdivided into various criteria, particularly LULC, soil type, soil pH, topography (slope, aspect, and elevation), and water sources for the biophysical factor. Moreover, the socio-economic factor includes the road networks which were assessed through their accessibility to potential farm areas. And lastly, the climatic factors comprise temperature, rainfall, and evapotranspiration. The raw data and data sets for the mentioned parameters were pre-processed to generate thematic maps.

On the other hand, the criteria were also employed in the Analytical Hierarchy Process (AHP) questionnaire which was answered by experts in the field approach to calculate the weight of each criterion which was done through pairwise comparison with a consistency ratio of not more than 10%. In particular, AHP, which is also called Saaty Method, is a complex decision-making tool introduced by Thomas Saaty. It is a theory of measurement primarily performed through pairwise comparisons and relies on the experts' judgment to derive a rating for each criterion or parameter selected. In this study, each weight of the parameters was computed using an AHP calculator by Goepel namely AHP Analytic Hierarchy Process (EVM multiple inputs) version 15.09.2018 [10]. Then the calculated weights per criterion together with the thematic maps were integrated into the ArcGIS ArcMap 10.8 in order to generate and extract a suitability map for dragon fruit farming from datasets.

3.1 Data Analysis

The data was collected from the AHP questionnaire, actual field, and data from different agencies was pre-processed before integrating into the GIS application. After gathering data from many sources and offices, criteria for the suitability range were developed. First, raw maps such as the rainfall map, evapotranspiration

map, LULC map, digital elevation model (DEM), slope map, temperature map, road map, and others was processed. The initial map data was used in generating the suitability map for dragon fruit. Furthermore, the suitability indicators and land suitability classes were utilized in the study to facilitate the evaluation of suitability map procedures. Thus, the four suitability categories were identified as High, Moderate, Low, and Not Suitable [11]. After that, validation and assessment between the suitability map data and the actual production area data were done.

4. RESULTS AND DISCUSSION

In this chapter, the spatial distribution of the significant datasets is shown. Various types of raw maps were collected and processed to derive particular output maps that were needed to generate the goal of this study which is the Suitability Map on Dragon Fruit farming in Butuan City.

4.1 Weighted suitability rating for each criterion

The decision-making analysis and evaluation method using the Analytical Hierarchy Process allows the suitability rating of each criterion to be defined while processing the suitability map. The computed Eigenvector vectors from the result of the AHP calculator finalized the evaluation of weights per criterion. These Eigenvector vector values were tested for its consistency ratio (CR) which must not be higher than 10%. In this study, the said values are within the range of the allowable consistency ratio. In Table III, the resulting weights for each of the factors and criteria are displayed, which was later utilized in weighted overlay analysis in the GIS domain.

Table III. Weighting Matrix for Each Criterion

Main Factors	Weight	Criterion	Overall Weight per Criteria	Weight of Criterion per Factor
Biophysical	0. 547	LULC	0.145	0.27
		Soil Type	0.138	0.25
		Soil pH	0.050	0.09
		Slope, Aspect, and Elevation	0.155	0.28
		Water Sources	0.059	0.11
Socio-economic	0.043	Road Networks	0.043	1.00
Climate	0.41	Temperature	0.172	0.42
		Rainfall	0.172	0.42
		Evapotranspiration	0.066	0.16

In Table III, it is shown that among the main factors biophysical gained the highest weight which is 0.547, followed by climatic factors having a weight of 0.41 and lastly the socio-economic factor having a weight of 0.043. The result shows that biophysical factors gain the highest weight of importance, particularly the slope, aspect, and elevation parameters among the main factors. This is particular as dragon fruit is sensitive to the topography, as it is a long-day plant and does require a 25-50% shading factor for optimal growth, which is connected to the aspect parameter [12]. According to experts interviewed, slope and elevation are related to the good drainage and flooding risk of an area, which are also crucial in dragon fruit farming as the crop is a cacti plant. On the other hand, since Butuan City already has accessibility to road networks across barangays both rural and urban areas, as well as farm-to-market roads thus the experts' importance rating on the socio-economic factors are comparatively lower than the other two factors. It indicates that this factor is not as important to dragon fruit production.

4.2 Suitability map of the three main factors

To fulfill the main goal of this study and generate a map showing the suitability of Dragon fruit farming in the city of Butuan, the thematic maps were processed accordingly, and developed specific criteria maps needed for the study. Moreover, one final map that represents the suitability of dragon fruit production was generated from the weighted maps of the 3 main factors which are the biophysical, socioeconomic, and climatic factors.

In Figure 2, the Biophysical Suitability Map and its distribution, show the total area of Butuan City which is approximately 66, 490.13 hectares. From that total area, 13.18% of it is found to be highly suitable comprising approximately 8,761.53 ha. On the other hand, 52.04% of the total area is considered to have moderate suitability with an area covered of 34,604.39 ha. Moreover, 28.18% is considered to be low in suitability constituting 18,738.35 ha of the remaining area. Lastly, 6.60% of it is found to be unsuitable particularly the rivers, and other water bodies constituting approximately 4,385.86 ha.

While socio-economic factor includes the availability and accessibility of road networks to study areas, such as main roads and farm-to-market roads, linking to its marketability and perishability. Figure 3 shows the distribution of suitable and non-suitable areas with respect to the road networks present across Butuan City. From the result, a total of 86.55% which is approximately 57, 546.70 ha of the total area of Butuan City is found to be highly suitable, and the remaining 13.45% comprising 8, 943.43 ha is classified as moderately suitable. With that said, there are no unsuitable areas of Dragon Fruit in terms of accessibility to road networks. This is due to the large accessibility to road networks even in the upland areas of Butuan City.

Moreover, in terms of climatic conditions as shown in Figure 4 there are approximately 13,769.66 ha (20.71%) that are moderately suitable, and 106.44 ha (0.16%) that are considered highly suitable. On the other hand, there is also an approximate area of 3508.48 (5.28%) that is classified as unsuitable. Particularly, the highly suitable area is located at the upper part of Barangay Santo Niño. Overall, a huge percentage of areas in Butuan were suitable in terms of climatic conditions. However, it mostly comprises of low suitability rating. This is due to

the fact that even though this crop has a vast tolerance to various types of climate it also has a particular range of optimal climate requirements for maximizing its production.

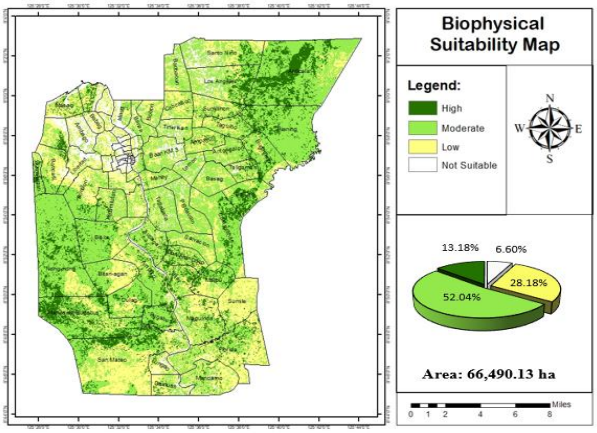

Figure 2. Biophysical Suitability Map

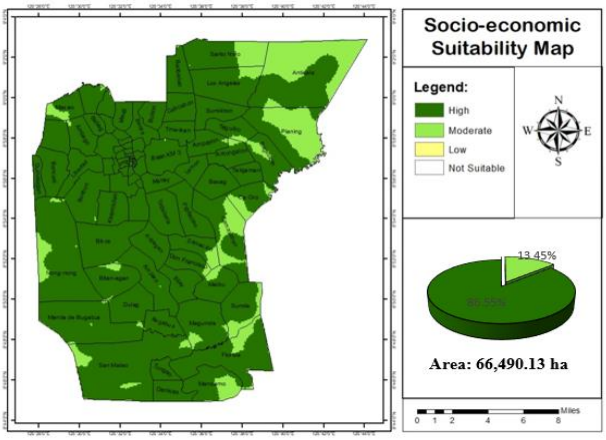

Figure 3. Socio-economic Suitability Map

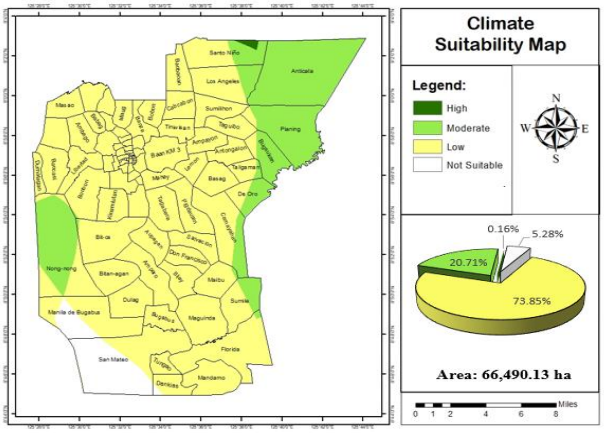

Figure 4. Climate Suitability Map

4.2.1 Comparison of the Main Criteria

Figure 5 shows the graphical representation for the comparison of three main factors in terms of suitability rating in hectares. The results specified that in the biophysical aspect, there is approximately 62,104.28 ha that are suitable areas for dragon fruit production. It particularly comprises 93.45% of the total area. On the other hand, for the socio-economic factor, there are no characterized suitable unsuitable areas, which means 100% of the study area is suited as almost all over the City are covered with road networks. Lastly, for the climatic condition, suitable areas accounting for 62,981.66 ha (94.72%) of the total area are characterized as suitable.

Particularly, among the factors, biophysical factors have the highest area of suitable areas. Meanwhile, for low suitability areas, climate factors the accounts largest area covered, for moderate suitability, biophysical factors comprise the highest area covered and lastly for the high suitability rating, the socio-economic factor which is only composed of the road networks. This indicates that among the factors the degree of suitability varies.

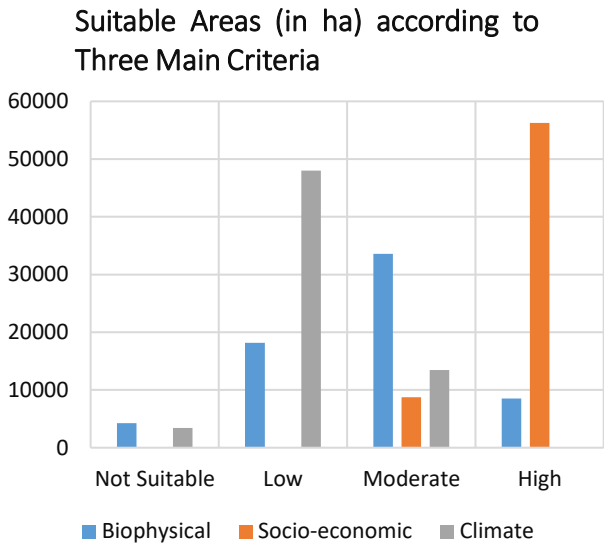

Figure 5. Comparison of Suitability Rating per Criteria

4.3 Final suitability map for dragon fruit farming

The three main factors were processed through the GIS domain using the Weighted Overlay Analysis in order to achieve the final suitability map. The specific suitability ratings that were obtained from the computed Eigenvector values in the AHP calculator were utilized. Particularly the main factors gathered approximately a percentage of 54.7 % for biophysical, 4.3% for socio-economic, and 41% for climate. With that said, Figure 18 presents the map that was produced using the aforementioned approach. It was clear that the city is suitable for Dragon Fruit farming in terms of biophysical, socioeconomic, and climatic factors.

According to the results, in terms of its biophysical, socio-economic, and climatic factors, Butuan City was clearly capable of Dragon Fruit farming with a total land area of 61, 719.49 hectares (92.83%) which are suitable. The overall highly suitable area was 13,780.98 hectares (20.73%). For the moderately suitable land area, it covers 29,606.67 ha. Which is equivalent to 44.53% of the total land area. On the other hand, approximately 27.57% of the land area is found to be low in suitability rating which covered 18,331.84 hectares. And lastly, it is found that there is an approximately 4,770.64 ha. comprising 7.17% of the total land area that is not suitable for dragon fruit farming.

The overall suitability map of Dragon Fruit farming in Butuan City is presented in Figure 6. The majority of the total area covered is considered moderate in suitability

rating yet there are particular areas around the city that are considered highly suitable areas. The high suitability areas mean that these are the optimal environment suited to achieve the maximum production
of the crop.

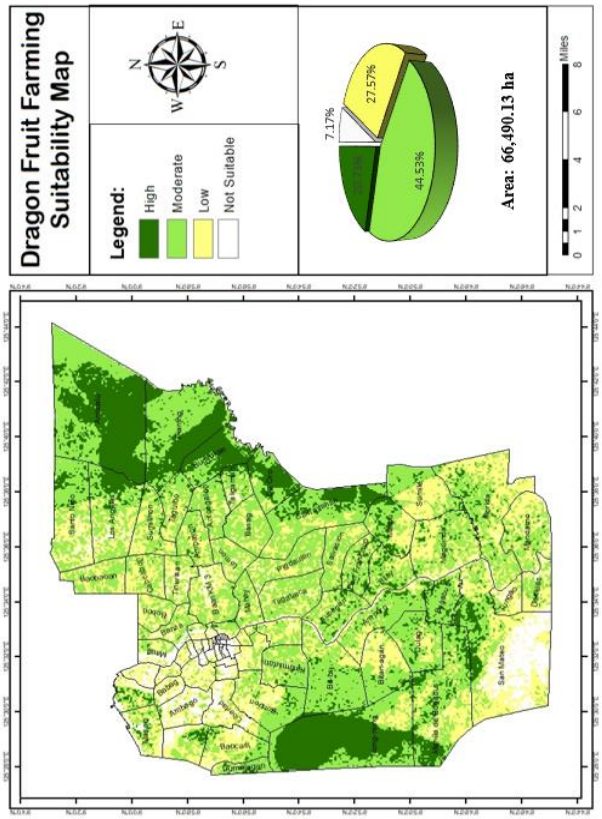

Figure 6. Dragon Fruit Suitability Map

4.4 Suitable areas in Butuan City Districts

Table IV. Suitable Area for Dragon fruit farming per District of Butuan City

District	Total Area per District (ha)	Total of Not Suitable Area (ha)	Total of Suitable Area (ha) (Low, Moderate, High)	Percentage of Suitability	Rank
1	74.90	54.55	20.35	0.031%	13
2	203.58	155.31	48.27	0.073%	11
3	138.52	98.22	40.30	0.061%	12
4	1,207.79	425.78	782.01	1.176%	10
5	1,296.54	381.06	915.48	1.377%	9
6	3,183.91	410.89	2,773.02	4.171%	8
7	3,035.78	158.19	2,877.59	4.328%	7
8	17,759.13	1,714.24	16,044.89	24.131%	1
9	9,093.98	188.29	8,905.69	13.394%	3
10	6,937.83	214.86	6,722.98	10.111%	4
11	4,104.38	710.05	3,394.33	5.105%	6
12	4,547.35	33.89	4,513.46	6.788%	5
13	14,906.43	225.31	14,681.12	22.080%	2
Total	66490.13	4770.64	61719.49	92.825%	

Particular barangays covered in each district of the study area are shown in Table IV. Results show that among the 13 districts in Butuan City, District 8 (Amparo, Bit-os, Bitan-agan, Dankias, Dulag, Bugabus, Nongnong, San Mateo, Tungao, and Manila de Bugabus) has the most number (in ha) of suitable areas indicating 16,044.89 ha. Followed by District 13 (Anticala, Baobaoan, Los Angeles, Pianing, Santo Niño, Sumilihon, and Taguibo) with 14,681.12 ha, and District 9 (Bilay, Don Francisco, Florida, Maguinda, Maibu, Mandamo, and Sumile) with 8,905.69 ha. This indicates that these barangays are covered with a more suited environment for the crop regarding the parameters stated in this study. Particularly among the Barangays in District 8, Brgy, Nong-nong has the most areas with high suitability ratings. This implies that this barangay carries the closest range of values for each parameter with respect to the optimal environment for dragon fruit in terms of biophysical, socio-economic, and climatic factors.

4.5 Map Validation

Table V. Dragon Farm Location with its Production

Farm Location (Barangay)	Production (kg/hill/season)
Aupagan	3-5
Pigdaulan	3
Sumilihon	3-4

In validating the map suitability data, the validation area with the actual production of the crop was identified. In this study, Brgy. Aupagan with approximately 158 hills of dragon fruit (48 old and 110 new), Brgy. Pigdaulan with approximately 96 hills and lastly Sumilihon with approximately 4000 hills, serves as the validation area for the suitability map linking with its production per hill. The actual production per area stated produces 3-5kg/hill/season, 3kg/hill/season, and 3-4kg/ hill/season respectively which is also indicated in Table V. This means that this production area falls into the average production rate per hill in the Philippine setting which ranges from 3.24-3.80 kg/hill [13]. However, it is observed that the production rate of Brgy. Pigdaulan farm is below the average production rate in the Philippine setting but still it can produce dragon fruit harvest. Based on the actual site validation, large trees (i.e., mango trees, Talisay trees, etc.) are present in the vicinity of the farm which contributes to the increase in the shading rate of the area which is not good for dragon fruit production. On the other hand, this is an indication that the actual areas shown in Figure 7 were having the accurate suitability rating the same as the suitability map generated.

In particular, Brgy. Aupagan, Brgy. Pigdaulan and Brgy. Sumilihon lies under the suitable areas which are in low and moderately suitable areas respectively. In connection with its approximate production (kg/hill/season) and the categories (moderate and low) where they fall in the map, it indicates that the map generated was accurate in terms of its production rate as it shows that these areas are potentially suitable for Dragon Fruit farming.

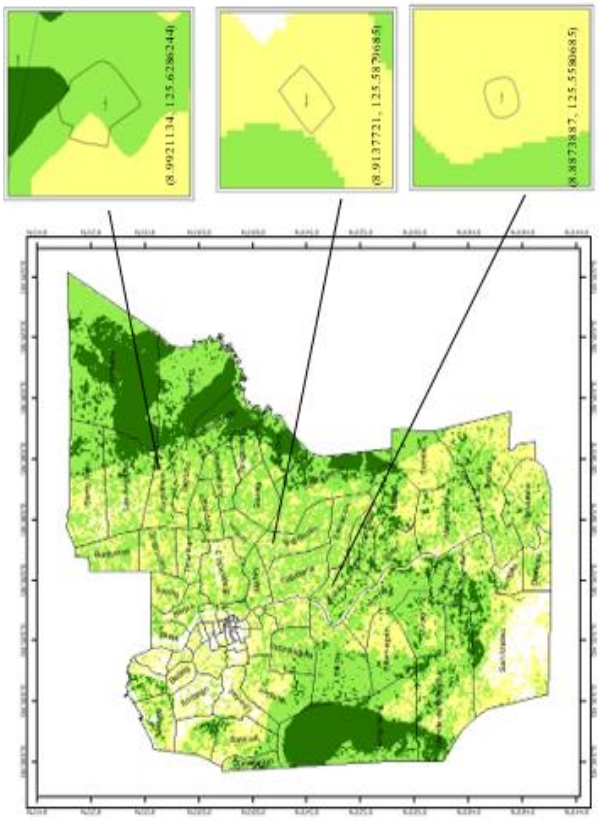

Figure 7. Validation Map

5. CONCLUSION

The present study aims to generate a suitability map of dragon fruit farming in Butuan City considering various important factors, particularly biophysical, socio-economic, and climatic factors. The suitability map was generated with the combination of the secondary data from raw maps and data sets and integrated with the secondary data from the AHP results through AHP questionnaires answered by experts in the field.

In generating a suitability map, the parameters including LULC, soil type, soil pH, topography, water sources, road networks, temperature, rainfall, and evapotranspiration need to undergo a decision-making process using AHP in order to accurately weigh each to be overlaid in the suitability map using ArcGIS ArcMap Software. This decision-making process enables the researcher to assess the level of suitability of dragon fruit farming in the study area.

In this study, the level of suitability for the crop in terms of calculated weights is 54.7% for the biophysical, 4.3% for the socio-economic, and 41% for the climatic factors, respectively. Moreover, four (4) suitability classes are used in categorizing suitability which are High, Moderate, Low, and Not Suitable. Based on the interpretation of the results, in terms of its biophysical, socio-economic, and climatic factors, Butuan City was clearly capable of Dragon Fruit farming with a total land area of 61, 719.49 hectares (92.83%) which are suitable, and a total land area of 4,770.64 hectares (7.17%) of which were unsuitable. The overall highly suitable area was 13,780.98 hectares (20.73%). For moderately suitable land area, it covers 29,606.67 ha. Which is equivalent to 44.53% of the total land area. On the other hand, approximately 27.57% of the land area is found to be low in suitability rating which covered 18,331.84 hectares. And lastly, it is found that there is an approximately 4,770.64 ha. comprising 7.17% of the total land area that is not suitable for dragon fruit farming.

Based on the results, the researchers conclude that the multi-criteria decision-making approach, particularly Analytical Hierarchy Process, reliably aids in generating an accurate and reliable evaluation of suitability ratings of various parameters through the GIS domain. Furthermore, using various tools in the software, particularly the weighted overlay process, the generation of suitability maps on dragon fruit production becomes possible.

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