p-ISSN 2012-361 | e-ISSN 2782-8824
www.edjournal.cfnr-uplb.org

Ecosystems and Development Journal
Volume 10 | Numbers 1 & 2 | pp. 56–67 | 2020

Comparative analysis of two methods for site suitability assessment of cacao (*Theobroma cacao* Lin.) in Bohol, Central Visayas, Philippines

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ABSTRACT. Suitability assessment has been used in many studies to identify on a particular patch of land the most appropriate defined use given a set of criteria. Such assessment must also consider the choice of proper methodological process and platform for analysis. The study aimed to compare two site suitability assessment models of cacao in the province of Bohol. Site factors considered in the suitability assessment included land cover, climate, elevation, and soil. Two different site factor weighting approaches combined with geographic information system (GIS) were compared through the process of accuracy evaluation. The geographic information system-analytical hierarchy process (GIS-AHP) stood as a better model with percent accuracy estimate of 97.5%. Using GIS-AHP, suitable areas for cacao farm expansion was determined to be 78.6% of the total land area of the province, which suggests the potential of the province in producing cacao-beans for local consumption and export. It is recommended to test the GIS-AHP model using additional site factors not considered in the study, together with other rank-ordering criteria weighting methods, statistical models, and variants fuzzy AHPs to determine the potential application of these models in site suitability analysis.

Keywords: analytical hierarchy process, direct weight estimation, GIS, suitability analysis

INTRODUCTION

Cacao (*Theobroma cacao* Lin.) is considered as a high-value agricultural crop in the Philippines (ERDB 2015; FMB 2014; DA-BPI [undated]). It is more commonly called "cocoa" in Africa, Central America, and other parts of the world. In the Philippines, the three major cultivar groups generally grown by farmers are Criollo, Forastero, and Trinitario. The ever-increasing demands on cacao beans in the country and the world, especially on Criollo, command a higher market price. In Bohol, the provincial offices of the Department of Science and Technology (DOST), Department of Agriculture (DA), Department of Trade and Industry (DTI), and the Office of Provincial Agriculture (OPA) saw this opportunity and implemented several projects in support of cacao production in the whole province. DOST–Bohol commissioned the Bohol Island State University (BISU) to implement a DOST Region 7 funded project, "Bohol Cacao Industry Information System," a pilot research and development (R&D) initiative that aimed to document and disseminate the scientific, technological, developmental, and cultural management practices of cacao producers, traders, and processors in the province. Other components of the pilot R&D project include web-database development purposely to share documented management practices online, and crop-site suitability assessment to determine new potential cacao production areas for future expansion. Suitability analysis was identified as a relevant preliminary step before an area is assigned to any specific site development activity. Site suitability assessment, as applied in this study, is a process of understanding existing site qualities and factors which determine the location of a particular activity (Jain & Venkata Subbaiah 2007). It is the determination of the appropriateness of a given patch of land for a defined use through the consideration of a given set of criteria. The accuracy of the site suitability assessment depends on the availability of the required input data and the methods applied in the analysis. Some of the common multi–criteria analysis (MCA) methods in site suitability assessment that apply the concept of rank-ordering criteria weighting are direct weight estimation, equal weight, rank-sum weight, rank exponent weight, inverse or reciprocals weight, rank-order centroid weight, and AHP (Roszkowska 2013). In particular, AHP has been used in many land suitability and vulnerability assessment studies in the Philippines. For instance, AHP integrated to GIS was applied recently in species-site suitability assessment of native species in Pantabangan–Carranglan Watershed (Dolores *et al.* 2020), in the identification of groundwater recharge areas in Mt Makiling Forest Reserve (Sandoval & Tiburan 2019), and in locating landslide susceptible areas in Pagsanjan-Lumban Watershed (Arizapa *et al.* 2015). In other countries, AHP and GIS were used in several studies such as in site selection for solar photovoltaic power plant (Al Garni & Awasthi 2017), in land-use suitability analysis (Akinci *et al.* 2013), in locating ideal sites for sanitary landfill (Kara & Doratli 2012), and in identifying flood-prone areas (Liu *et al.* 2008). On the other hand, direct weight estimation, as a component step in semi-quantitative method, was applied in local hazard and vulnerability-related studies (Lanuza 2008; Lopez *et al.* 2008; Reyes 2015; Reyes *et al.* 2015). Based on these literature review, it is confirmed that no other work has been done in cacao suitability analysis applying direct weight estimation and AHP integrated to GIS in the country. The study compared the application of two site suitability assessment models for cacao (*Theobroma cacao* Lin.) production in the province of Bohol. Specifically, it determined the extent of the cacao farms in 11 cacao bean-producing municipalities; compared two site suitability models developed, following two different factor weighting approaches combined with GIS using accuracy evaluation; and identified potential areas in the province for cacao farm expansion using the better site suitability model.

METHODOLOGY

Study site

Bohol is known as the 10th largest island in the Philippine archipelago, situated in Region 7 - Central Visayas. Its total land area is about 4,821 km² (Travero 2016). The province is geographically located between 123˚40' and 124˚40' East longitude and extends from 9˚30' and 10˚15' North latitude (**Figure 1**).

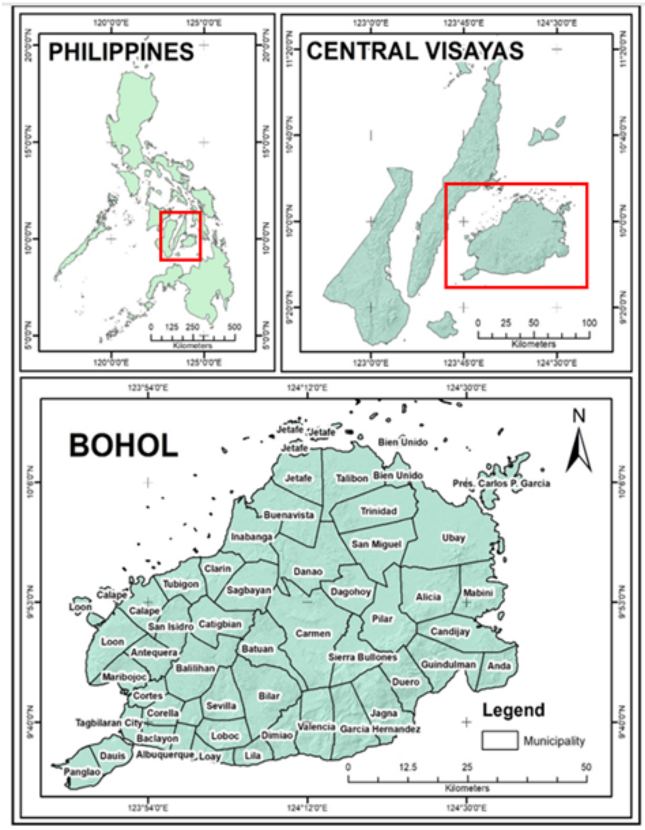

Figure 1. Location map of Bohol.

Agriculture remains the biggest sector in the province in terms of working population and land use. The total land area devoted for agricultural use is about 184,874 ha or roughly 45% of the total land area of the province. The average farm size is about 0.6 ha (DA & DTI [undated]).

Bohol is one of the most promising provinces in Central Visayas for cacao and coffee production. The best areas for these high-value crops are Carmen, Jagna, Pilar, Sierra Bullones, Mabini, Bilar, and Batuan. These municipalities were identified as the initial beneficiaries of the Bohol Coffee and Cacao Development Program (BCCDP) in 2009 (DA-RFU7 2012). Expansion of the program in later years was also implemented in other municipalities. The total areas planted with cacao from the start of the program until 2018 have reached 1,143.93 ha. Combined inventory data from the Department of Environment and Natural Resources (DENR), Philippine Coconut Authority (PCA), Philippine Statistics Authority (PSA), and DA-RFU7 provided a consolidated total estimate of 466,138 trees, 40% of which are fruit-bearing, and the rest are either young-non-fruit bearing or for rehabilitation. The average production rate of cacao wet beans from 2015 to 2017 reached 224.46 MT (DTI-Bohol 2019).

Preliminary activities

Courtesy call, planning, and coordination

To inform and obtain support and assistance from the concerned municipal and barangay LGUs regarding the study, courtesy calls and consultation meetings were conducted in 11 pre-selected municipalities as preliminary survey sites, namely: Batuan, Bilar, Calape, Carmen, Clarin, Jagna, Loboc, Pilar, Sierra Bullones, Sagbayan, and San Miguel (**Figure 2**). Planning and coordination meetings were carried out to determine the bulk of work and to assign activities to all involved personnel.

The BISU research team was divided into two groups. One group, together with several thesis students, was assigned to conduct the ground survey, farm assessment, and interview. The other group was detailed in the office to collate and interpret primary and secondary data and perform data encoding, processing, and analysis.

Secondary data collection

Secondary data such as basic information on the silvical requirements of cacao, climate data, and GIS input files such as base maps and thematic maps used in the study were obtained. Information on the site requirements of cacao (**Table 1**) was taken from the 2015 Ecosystems Research and Development Bureau (ERDB) report and the Department of Agriculture-Bureau of Plant Industry (DA-BPI) (undated). The 2000–2018 climate data, on the other hand, was acquired from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) Synoptic Station in Panglao, Bohol. Additional input data used in GIS such as base maps, land cover, IFSAR-DEM, and soil were secured from the PhilGIS website (http://philgis.org/), National Mapping and Resource Information Authority (NAMRIA), Department of Agriculture-Bureau of Agricultural Research (DA-BAR), and the Bureau of Soils and Water Management (BSWM), respectively (**Table 2**).

Table 1. Silvical requirements of cacao.

Site factor	Favored condition	
	ERDB	DA-BPI (undated)
Alitude (masl)	600–900	300–1,200
Rainfall (mm)	1,000–2,000	1,500–2,000
Soil pH	6.0–7.0	5.0–6.0
Temperature (°C)	22–32	30–32
Relative humidity (%)	80	-
Climate	-	Type IV

Though cacao is an exotic species, it thrives well in the Philippines since it is an equatorial crop. It can survive in all cocoa-producing regions, also known as "cocoa belt", within 20 degrees north and south of the equator. Cacao is a shade-tolerant small evergreen tree, often planted under the shade of bigger trees. There are four common cacao cultivars, three of which are cultivated in the country, namely: Criollo, Forastero, and Trinitario. Cacao can adapt to a humid tropical climate. It grows well in fertile and well-drained soils. It is suited in clay loam soil of good structure and rich in organic matter. It prefers an altitude of 600–900 masl. It thrives best in areas with mean annual rainfall of 1,000–2,000 mm, soil pH ranging from 6.0–7.0, temperature of around 22–32 °C, and a relative humidity of more or less 80% (ERDB 2015).

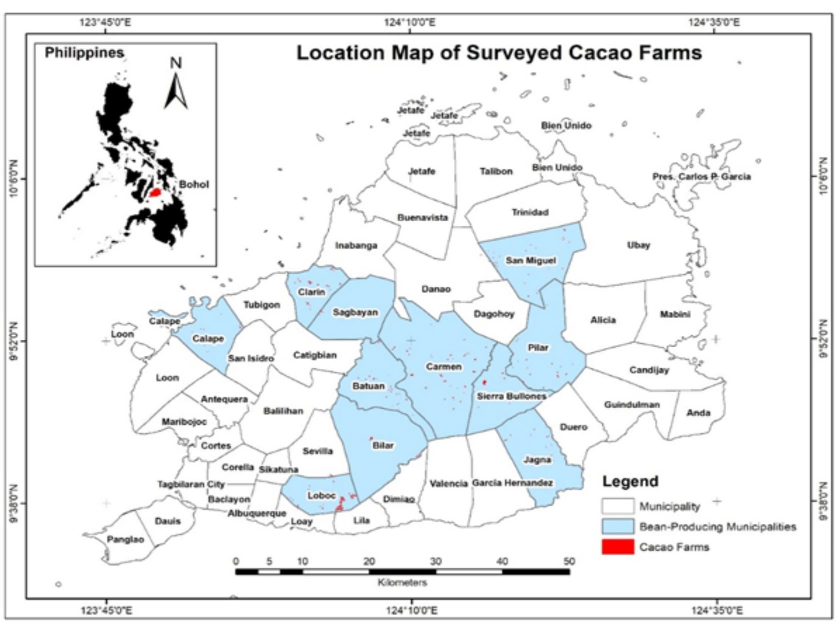

Figure 2. Map of extent and distribution of surveyed cacao farms in 11 municipalities.

Table 2. Summary of data sources.

Data	Source	Description
Base maps	PhilGIS website (http://philgis.org/)	Country and Bohol province and municipal boundaries in shapefile format
Land cover	NAMRIA	Land cover of Bohol province in 2015 in shapefile format
Climate (rainfall and temperature)	PAGASA	Historical climate data from 2000 to 2018 in csv format
Elevation	NAMRIA (acquired thru DA-BAR)	5-meter resolution IFSAR digital elevation model (DEM) in raster format
Soil series	BSWM	Soil series in shape format

DA-BPI (undated) in its cacao production guide, reported that cacao best favors a deep soil of not less than 15 cm, a pH ranging from 5.0–6.0, mean annual rainfall ranging from 1,500–2,000 mm with a dry season of not more than three months, a mean daily temperature of 30–32 °C, an elevation of 300–1,200 m asl, and a climatic type IV which has an evenly distributed rainfall throughout the year.

Actual field survey

The field survey was conducted from April to June 2019 to locate and assess cacao farms in 11 pre-selected municipalities. GPS receivers were used to determine the ground coordinates of the farms and android phones for documentation. The primary data obtained in the field include the name of the farm owner, farm size, farm condition, date of farm establishment, grown cacao cultivars and varieties, as well as ground coordinates of at least five boundary corners. In addition, farm owners were also asked how large (in percent) the pre-identified site factors (*i.e.*, land cover, climate, elevation, and soil) have influenced the growth of cacao seedlings/trees and the overall productivity of the farm. The respondents were instructed to assign percent influence ranging from 0–100% for each corresponding site factor considering a total percent factor influence allocation of 100% for all the site factors. The result of the percent factor influence allocation was used in the direct factor weight estimation. It is believed that the farmers' intuitions due to their long-time personal experiences in growing the crop and exposure to all these site factors and honest responses can be used as a straight forward and accepted (valid) basis in determining factor weights.

GIS–assisted crop–site suitability assessment

GIS input processing

ArcGIS 10.6 was used as the platform in data processing and analysis. **Table 3** served as a guide in preparing the GIS input data.

The ground coordinates taken from the field surveys were converted to polygon shapefiles by digitizing points to form polygons of cacao farms. This was performed in all surveyed farms with at least five boundary ground coordinates. Moreover, GIS input data such as land cover, climate, elevation, and soil series were generated using several functions and tools in ArcMap. Land cover (LC) layer, for instance, was prepared by providing numeric suitability score in each LC type considering the shade-tolerant nature of cacao which requires nurse trees to grow and survive. This means that those LCs with no trees and large vegetation would have low numeric suitability scores while those LCs with a considerable amount of vegetation were given high numeric scores. Open forest was assigned with moderate numeric score since all open forests in Bohol are situated in the watershed forest reserves and protected areas where planting of high-value crops like cacao and coffee is somehow restricted to the public and only farmers and upland communities with valid tenure instruments from the DENR are allowed. Moreover, land cover identified as inland water, mangroves, fishponds, and some built-up areas were considered as limiting factors and were all given a score of zero.

A simple suitability class scoring was adopted in this study following the work of Dolores *et al.* (2020). Low suitability class was assigned with 1, moderate suitability class with 2, and high suitability class with 3 (**Table 3**). Climate layer was generated for the whole province as a contribution of both rainfall and temperature data. Computation of both average annual rainfall and average daily temperature was done using the historical data obtained from PAGASA Synoptic Station in Panglao, Bohol. The suitability score assigned to the climate layer was high since the computed average precipitation and temperature values were both within the ideal ranges for cacao farm establishment. Travero (2016) reported that the whole province is classified under Climatic Type IV based on the modified Coronas Classification, which means that rainfall is evenly distributed throughout the year. Elevation layer was prepared using the spatial analyst tool. Reclassify function was used to divide the DEM values into three elevation ranges following the suitability classes in **Table 3**.

Soil series layer was used as an alternative input file in the absence of data on soil pH, fertility, and depth. The description of each soil type as a basis in giving numerical scale (score) for suitability was derived from Carating *et al.* (2012), the integrated management plan of Carood Watershed by DENR R7 & Carood Watershed Model Forest Management Council (2013), and comparing the description with the cacao preferred soil characteristics as described in ERDB (2015) and DA-BPI (undated). Raster conversion was performed in all vector files prior to overlay analysis.

Table 3. Reclassification of site factors in three different suitability classes.

Site factor	Suitability class with corresponding numeric score (rank)		
	Low (1)	Moderate (2)	High (3)
Land cover	Land cover in which establishment of cacao farms is marginally feasible: • Annual crop • Grassland • Open barren	Land cover in which establishment of cacao farms is fairly feasible: • Open forest	Land cover in which establishment of cacao farms is extremely feasible: • Brushes • Perennial crop
Climate (rainfall and temperature)	Combined average annual precipitation and average annual daily mean temperature in which establishment of cacao farms is marginally feasible: • <1,000 mm and < 18˚C and >32˚C	Combined average annual precipitation and average annual daily mean temperature in which establishment of cacao farms is fairly feasible: • 1,000 mm to 1,500 mm and 18˚C to 30˚C	Combined average annual precipitation and average annual daily mean temperature in which establishment of cacao farms is extremely feasible: • >1,500 mm and 30˚C to 32˚C
Elevation	Altitude in which establishment of cacao farms is marginally feasible: • <300 masl and >1,200 masl	Altitude in which establishment of cacao farms is fairly feasible: • 300 masl to 600 masl and 900 masl to 1,200 masl	Altitude in which establishment of cacao farms is extremely feasible: • 600 masl to 900 masl
Soil series	Soil series in which establishment of cacao farms is marginally feasible: • Bantog clay • Batuan clay loam • Beach sand • Butuan clay • Candijay clay • Hydrosol • Rough stony land • Undifferentiated	Soil series in which establishment of cacao farms is fairly feasible: • Annam clay • Baluarte clay loam • Batuan-Faraon complex • Bolinao clay • Faraon clay • Inabanga clay • Lugo clay • Mandawe clay • Sevilla clay	Soil series in which establishment of cacao farms is extremely feasible: • Calape clay loam • Ubay clay • Ubay clay loam • Ubay sandy loam

Site factor weight determination

Direct weight estimation. In this study, direct weight estimation is a process by which the potential contribution of site factors in the survival and growth of cacao is perceived directly in percent. The intention was to simplify the assignment of weights based on the perception and discernment of the concerned persons as influenced by their long-time exposure to the object or subject of interest. This process is also known as "expert judgment" especially when the experienced persons give their opinion in the context of decision making (Benini *et al.* 2017).

The result in percent influence factor allocation was directly used in direct weight estimation. **Table 4** shows the summary result of direct weight allocation. About 68.1% of the farm owners (177 individuals) assigned in four pre-identified site factors the following weights as follows: 40% for land cover, 20% for climate (rainfall and temperature), 20% for elevation, and 20% for soil (series). The weights in decimal values were computed by dividing 100 by the parameter's percent influence.

Same with AHP, direct weight estimation is a component of semi-quantitative method (Reyes 2014). It is called expert-driven or heuristic in other kinds of literature (Lanuza 2008; Lopez *et al*. 2008; ERDB 2011; Reyes *et al*. 2015). It is considered an important part of the index-based hazard and vulnerability assessment of natural and man-made disasters in the Philippines (ERDB 2011; Reyes 2014; Reyes 2015; Reyes *et al*. 2015).

Table 4. Farmer's assigned weights on pre-identified site parameters through direct weight estimation.

Parameter	% Influence	Weight
Land Cover	40	0.4
Climate	20	0.2
Elevation	20	0.2
Soil Series	20	0.2

Note: Based on the common responses of 68.1% of the cacao farm owners (N = 260).

Analytical hierarchy process. AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. Dr. Thomas L. Saaty, a renowned professor at the University of Pittsburg, introduced this concept in the late 70s. AHP is a multi–criteria decision-making approach that derives ratio scales from paired comparisons of either quantitative data including price and height, or qualitative data including emotion and preference (Alonso & Lamata 2006; Sandoval &

Tiburan 2019; Dolores *et al*. 2020). It has gained popularity throughout the years due to its application in several decision-making circumstances and its usefulness in various fields (Alonso & Lamata 2006; Dolores *et al*. 2020). Arizapa *et al*. (2015) and Dolores *et al*. (2020), interpreted from the work of Saaty (1980), explicated that the process takes into account a set of evaluation criteria and a set of alternative options among which the best decision is to be made. Weight for each evaluation criterion is developed to correspond to the decision maker's pairwise criteria comparison. The weights reflect the degree of importance of the respective criterion relative to each other which is interpreted as "the greater the value of the weight, the greater the importance of the corresponding criterion." Moreover, for a fixed criterion, AHP designates a score to each option that corresponds to the pairwise comparisons of the decision–maker on the options concerning that criterion. The values of the scores indicate the performance of the option based on the chosen criterion which is also interpreted, "the greater the value of the score, the greater the performance of the option." Consequently, the AHP joins the criteria weights and the options scores to establish a general score for each option and corresponding ranking. The general score for a particular option is a weighted sum of the scores it acquired in relation to all the criteria.

Through a short focus group discussion, expert judgement of recognized cacao production specialists from the academe and government extension and training institutions was solicited relative to the paired comparison of pre-identified site factors. The order of ranking of site factors was simplified in this study from the usual complicated AHP ranking and scale rating. However, the concept and process were still followed and the uncertainty and bias in weighting by individual experts were eliminated. In the study, a score of three (3) was assigned to the most influential factor based on how this factor was perceived to affect the growth and survival of plants (*i.e.* cacao seedlings and mature trees). Scores of two (2) and one (1) were assigned to factors with moderate and least influences, respectively. The weight of each factor was computed as the weighted sum of the scores that such factor acquired in relation to all the site factors (**Table 5**).

Arizapa *et al.* (2015) provided a formula in calculating factor weights as shown below:

$$\text{X of A} = \sqrt[n]{(ajk1 * ajk2 * ajk3 * \ldots * ajkn)} \qquad \text{Equation 1}$$

where: X = nth root of the product value
A = factor or site parameter
ajk = value(s) in the row of the factor (site parameter)

Alternatively, the above equation can be expressed as the weight of each factor determined by calculating the product of the assigned factor scores raised to the power of 1 over the number of factors divided by the summation of the computed products of all factors. The simplified computations of factor weights are as follows:

Table 5. Summary of the pairwise comparison matrix of site parameters, arranged by weight, based on ranking provided by the interviewed cacao production experts.

Parameter	Land cover	Climate	Soil	Elevation	Weight
Land cover	1	1	3	2	0.36
Climate	1	1	2	2	0.33
Soil	1/2	1/2	2	1	0.19
Elevation	1/3	1/2	1	1/2	0.12

Note: CI = 0.015 and CR = 0.017 (Acceptance value of CI and CR, < 0.1).

Land cover factor weight = $(1 \times 1 \times 3 \times 2)^{1/4}$ / 4.36 = 0.36
Climate factor weight = $(1 \times 1 \times 2 \times 2)^{1/4}$ / 4.36 = 0.33
Soil factor weight = $(1/2 \times 1/2 \times 2 \times 1)^{1/4}$ / 4.36 = 0.19
Elevation factor weight = $(1/3 \times 1/2 \times 1 \times 1/2)^{1/4}$ / 4.36 = 0.12

Consistency index (CI) and consistency ratio (CR) are indicators of factor weight acceptability. These indices are calculated to determine the validity of the computed factor weights (Tsiko & Haile 2011; Arizapa *et al*. 2015; Subiyanto *et al*. 2018). A value of equal to or less than 0.1 for both CI and CR means the factor weights are acceptable. Since the CI and CR values were calculated to be less than 0.1, then the factor weights are valid for suitability analysis. These weight acceptability indicators are computed using the following formulas:

$$CI = (\lambda max\omega - n)/(n-1) \qquad \text{Equation 2}$$

where: CI = consistency index
λmaxω = normalized average of the summation of the products of scores and the computed weights of all factors
n = number of factors

$$CR = CI/0.89 \qquad \text{Equation 3}$$

where: CR = consistency ratio
0.89 = constant value

Crop-site suitability assessment

Similar to the work of Dolores *et al*. (2020), suitability analysis in this study adopted the approach of the Food and Agriculture Organization (1976) for land evaluation. The final score of the crop-site suitability is computed using the equation below:

$$S = \Sigma WiXi \qquad \text{Equation 4}$$

where: S is the suitability index (final score)
Wi is the weight of criterion i
Xi is the score of class i

A higher value indicates that cacao is more suitable for the site factor. The final score (suitability index) was converted to a suitability category of low, moderate, and high suitability. Finally, resulting overlay maps obtained from integrating all site factor maps were developed to determine the overall suitability of cacao to the site.

Two crop-site suitability maps (models) were generated using the above equation. One was the suitability map (model) using the direct weight estimation and another using the weights derived through the AHP.

Accuracy evaluation and suitability mapping

The accuracy evaluation was performed using the intersect function in ArcMap purposely to determine which of the two-factor weighting approaches combined with GIS is better. This was done by intersecting the map of existing cacao farms with each of the suitability maps. Since the locations of surveyed cacao farms are suitable areas for cacao bean production, the map with greater overlap on moderate and high suitability classes and has the higher percent accuracy was considered more accurate and chosen to determine potentially suitable areas for cacao farm expansion. A model prediction accuracy threshold of 75% was adapted in this study following the work of Reyes (2014), Reyes (2015), and Reyes *et al*. (2015).

The advantage of this study over the works of Alonso & Lamata (2006), Ayorinde *et al*. (2014), Arizapa *et al*. (2015), Bunn *et al*. (2017), Neswati *et al*. (2019), Sandoval & Tiburan (2019), and Dolores *et al.* (2020) is the inclusion of accuracy evaluation, which was not considered in these previous studies.

RESULTS AND DISCUSSION

Extent and distribution of surveyed cacao farms in selected municipalities

The ground surveys conducted in 11 municipalities revealed a total of 148.68 ha of cacao tree farms in the province (**Table 6**). Such extent is only 13% of the expected total land area of 1,143.94 ha planted to cacao as of 2019.

The surveyed cacao farms are distributed in the following cacao-bean producing municipalities: Batuan (7.11 ha), Bilar (5.84 ha), Calape (2.13 ha), Carmen (25.14 ha), Clarin (15.97 ha), Jagna (12.78 ha), Loboc (39.13 ha), Pilar (8.05 ha), Sagbayan (9.26 ha), San Miguel (7.52 ha), and Sierra Bullones (15.74 ha). Loboc and Carmen, are among the municipalities with more than 20 ha of aggregated cacao farms within each municipality. These account for 26% and 17%, respectively, of the total land area of surveyed cacao farms. Large single parcels of these cacao farms were observed in Loboc and Sierra Bullones. The municipality with the least cacao farm extent is Calape with an area 2.13 ha, equivalent to 1.4% of the total land area of surveyed cacao farms.

Table 6. Extent (in hectares) and percent distribution of cacao farms in 11 cacao-bean producing municipalities in Bohol.

Municipality	Area (ha)	Percent distribution (%)
Batuan	7.11	4.78
Bilar	5.85	3.93
Calape	2.13	1.43
Carmen	25.14	16.91
Clarin	15.97	10.74
Jagna	12.78	8.60
Loboc	39.13	26.32
Pilar	8.05	5.41
Sagbayan	9.26	6.23
San Miguel	7.52	5.06
Sierra Bullones	15.74	10.59
Total	148.68	100.00

Map (model) accuracy evaluation

Table 7 presents the result of the overlay analysis between the existing cacao farms and the suitability map generated using factor weights derived through direct weight estimation. It showed that direct weight estimation predicted 36.94 ha and 76.67 ha of the existing cacao farms in both moderate and high suitability classes. Though model prediction accuracy was 76.4%, direct weight estimation was unable to predict about 35.07 ha as these areas fell within the low suitability class. **Figure 3** displays the map generated using direct weight estimation and GIS.

Table 8 shows the result of the overlay analysis between the existing cacao farms and the suitability map generated using AHP combined with GIS. The suitability map generated using GIS-AHP predicted 72.87 ha in the high suitability class and 72.16 ha in the moderate suitability class. These numbers form an aggregated extent of about 145.03 ha, equivalent to 97.5% of the total area of the surveyed cacao farms. With this estimate, only 3.66 ha (or 2.5%) fell within the low suitability class. Though AHP prediction in the high suitability class was slightly lower than that of direct weight estimation, it can still be inferred that AHP is more accurate than direct weight estimation since the former predicted larger areas in the moderate suitability class and very small areas in low suitability class.

Table 7. Distribution and extent of existing cacao farms (in ha) in three site suitability classes by municipality using direct weight estimation combined with GIS.

Municipality	Extent per suitability class (ha)			Total
	Low	Moderate	High	
Batuan	2.21	2.51	2.39	7.11
Bilar	5.47	0.21	0.17	5.85
Calape		1.72	0.41	2.13
Carmen	5.56	1.02	18.56	25.14
Clarin	3.44	12.26	0.27	15.97
Jagna	1.28	8.95	2.55	12.78
Loboc	7.28	4.87	26.98	39.13
Pilar	1.92	0.85	5.28	8.05
Sagbayan	4.44	4.53	0.29	9.26
San Miguel	1.69		5.83	7.52
Sierra Bullones	1.78	0.02	13.94	15.74
Total	35.07	36.94	76.67	148.68

Table 8. Distribution and extent of existing cacao farms (in ha) in three site suitability classes by municipality using analytical hierarchy process combined to GIS.

Municipality	Extent per suitability class (ha)			Total
	Low	Moderate	High	
Batuan	0.51	5.72	0.88	7.11
Bilar	2.61	3.11	0.12	5.84
Calape	-	1.79	0.34	2.13
Carmen	0.54	6.16	18.44	25.14
Clarin	-	15.70	0.28	15.97
Jagna	-	12.03	0.75	12.78
Loboc	-	12.32	26.81	39.13
Pilar	-	2.87	5.18	8.05
Sagbayan	-	8.97	0.29	9.26
San Miguel	-	1.69	5.83	7.52
Sierra Bullones	-	1.80	13.94	15.74
Total	3.66	72.16	72.87	148.69

The findings in this study are better than the results of the studies of Ayorinde *et al*. (2014) and Neswati *et al*. (2019). The former, using combined inverse direct weighted method applied in soil properties and climate data for GIS input processing and AHP in factor weighting, determined only about 19.44% of the total land area of Ife Central Government Area, Osun State, Nigeria, found suitable for cacao establishment, while the latter identified around 33.3% of suitable areas for cacao production in South Sulawesi, District of Luwu Timur, Indonesia using parametric image analysis combined with simple overlay analysis in GIS.

The prediction accuracy of AHP has been questioned in the study of Rodcha *et al*. (2019) where classical AHP was compared to some other multi-criteria decision making (MCDM) methods such as parametric and variants of fuzzy AHPs (FAHPs) in determining suitable sites for cash crops in Nakhon Ratchasima Province, Thailand. Though classical AHP provided the similar accuracy estimates compared to several variants of FAHPs, still it was considered questionable due to uncertainty in expert factor weighting. In this study, uncertainty and bias in factor weighting by individual experts were eliminated since FGD was performed to address this concern. **Figure 4** depicts the map generated using AHP and GIS.

Potential areas for cacao farm expansion

Using the GIS-AHP generated suitability map, the total area of land in Bohol that is suited for cacao cultivation is about 378,730.34 ha or around 78.6% of the total land area of the province. This was computed by adding the total areas in both moderate and high suitability classes. The bulk of these suitable areas for cacao farm expansion is concentrated in the municipalities of Ubay, Carmen, Danao, Bilar, Talibon, Balilihan, Pilar, Alicia, Trinidad, San Miguel, Buenavista, Jagna and Inabanga (**Table 9**). Among these municipalities, Balilihan, Bilar, Buenavista, and San Miguel were not officially identified as cacao-bean producing municipalities in the province based on the 2019 report of the OPA. This only shows the huge potential of the province to expand its cacao bean production in not previously identified suitable sites. Apart from 92,516.07 ha of aggregated non-suited areas composed of mangroves, inland water and built ups, there are around 10,853.59 ha in Bohol that are found marginally suitable for cacao farm development, and these are situated mostly in the municipalities of Candijay, Jetafe, Alicia, and Talibon.

Table 9. Extent and distribution of potential areas for cacao farm expansion in three site suitability classes by municipality using analytical hierarchy process integrated to GIS.

Municipality	Extent per suitability class (ha)			Total
	Low	Moderate	High	
Albuquerque		2,209.49	428.34	2,637.83
Alicia	943.91	6,137.73	4,752.91	11,834.55
Anda	179.64	2,683.40	2,090.02	4,953.06
Antequera	4.49	3,332.71	2,095.94	5,453.14
Baclayon		1,415.97	1,526.95	2,942.92
Balilihan	0.46	3,239.67	9,105.60	12,345.73
Batuan	434.36	3,940.88	4,651.73	9,026.97
Bien Unido	146.75	1,700.23	697.42	2,544.40
Bilar	512.90	9,762.03	3,517.70	13,792.63
Buenavista	170.88	8,772.67	1,727.68	10,671.23
Calape	409.96	5,849.55	958.37	7,217.88
Candijay	1,728.31	4,485.77	3,015.84	9,229.92

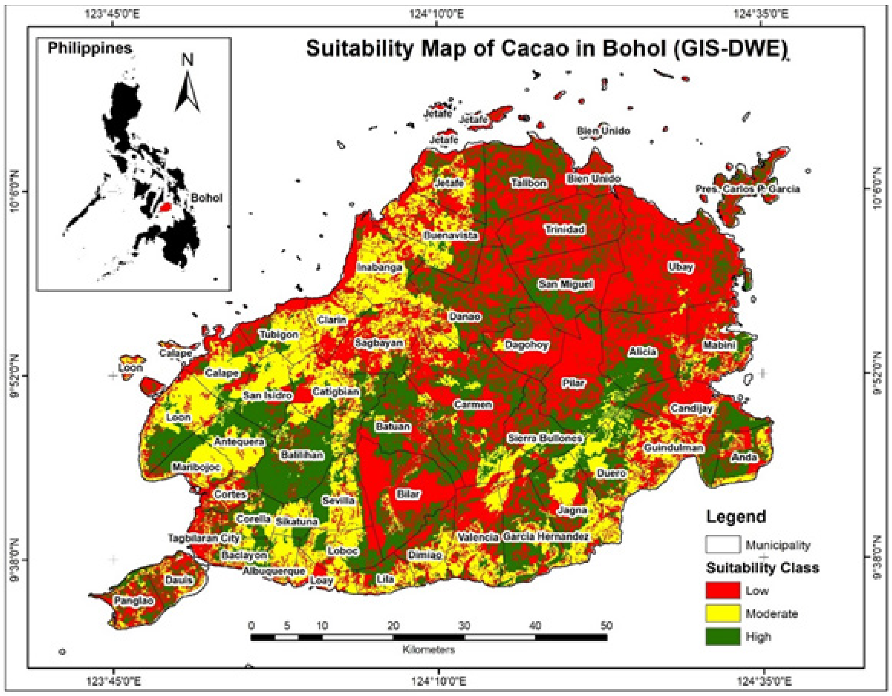

Figure 3. Site suitability map generated using direct weight estimation combined with GIS.

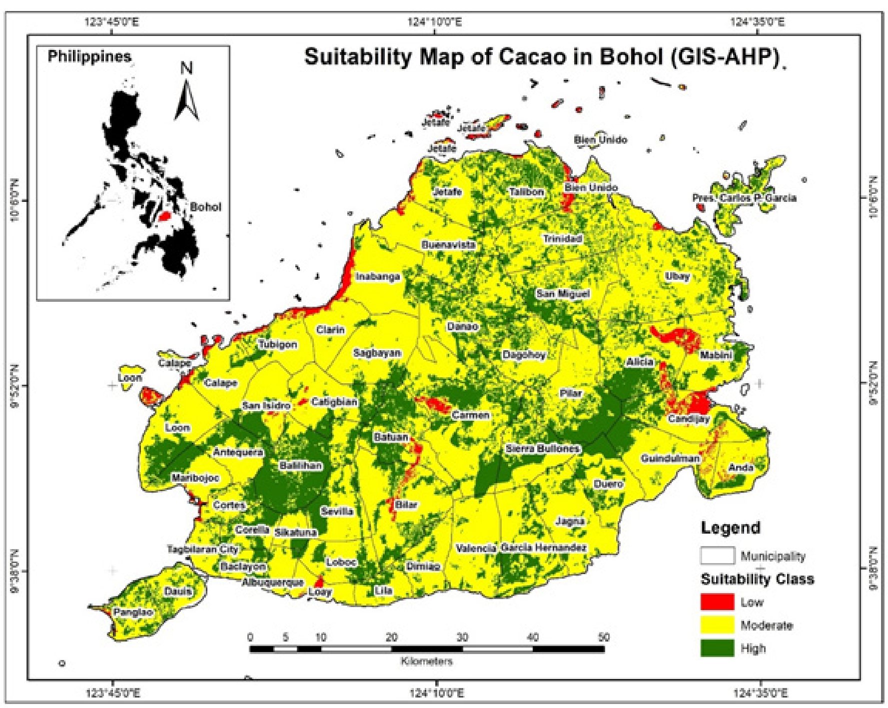

Figure 4. Site suitability map generated using analytical hierarchy process combined with GIS.

Table 9. *(Cont')*

Municipality	Extent per suitability class (ha)			Total
	Low	Moderate	High	
Carmen	493.40	14,604.61	7,042.67	22,140.68
Catigbian	129.86	5,821.01	2,486.64	8,437.51
Clarin	326.47	4,862.62	89.99	5,279.08
Corella		1,685.17	2,324.15	4,009.33
Cortes	48.64	2,145.22	849.75	3,043.60
Dagohoy		5,553.46	1,836.89	7,390.35
Danao		8,629.75	5,823.09	14,452.83
Dauis		2,573.10	1,351.08	3,924.17
Dimiao		4,352.40	1,143.73	5,496.14
Duero		5,078.49	2,278.82	7,357.32
Garcia Hernandez		6,570.46	3,313.90	9,884.35
Guindulman	294.45	7,097.59	2,518.54	9,910.59
Inabanga	733.04	8,777.68	659.92	10,170.64
Jagna		8,751.83	1,656.93	10,408.76
Jetafe	949.70	6,242.08	1,967.84	9,159.62
Lila		2,251.64	962.16	3,213.79
Loay	235.08	2,556.08	43.89	2,835.06
Loboc	26.29	3,815.82	1,898.14	5,740.25
Loon	451.92	6,684.46	2,574.40	9,710.78
Mabini	584.33	5,889.16	1,657.60	8,131.09
Maribojoc	118.31	3,365.70	1,694.09	5,178.10
Panglao	102.90	2,850.45	1,612.89	4,566.23
Pilar		7,798.56	4,343.47	12,142.03
Pres. Carlos P. Garcia	11.74	2,143.15	1,726.38	3,881.27
Sagbayan		8,231.99	1,175.36	9,407.35
San Isidro	108.43	3,467.28	2,417.77	5,993.47
San Miguel		7,205.78	4,248.39	11,454.18
Sevilla		4,441.84	2,395.47	6,837.32
Sierra Bullones		5,374.68	3,217.94	8,592.61
Sikatuna		1,476.41	711.55	2,187.96
Tagbilaran City	25.39	2,432.30	517.91	2,975.60
Talibon	943.35	7,274.37	5,051.49	13,269.21
Trinidad	82.65	8,094.60	3,442.63	11,619.88
Tubigon	462.83	4,869.28	784.97	6,117.08
Ubay	173.13	17,856.96	4,511.52	22,541.61
Valencia		8,331.37	1,142.41	9,473.78
Total	10,853.59	262,687.45	116,042.89	389,583.93

Note: Bohol's total land area = 482,100 ha; Non-suitable areas (mangroves, inland water and built up) for cacao farm establishment = 92,516.07 ha.

CONCLUSION AND RECOMMENDATION

The aggregated extent of existing cacao farms in pre-identified cacao-bean producing municipalities in Bohol is believed to be small, only about 13%, compared to the expected cacao farmland area of 1,143.93 ha. Extensive ground surveys should be done in case this data, as test samples, will be used in similar studies applying statistical analysis.

Both suitability models passed the assigned prediction accuracy threshold of 75%. However, AHP combined with GIS performed better than direct weight estimation since the former predicted 97.5% of the total land area of cacao farms in both moderate and high suitability classes compared to the latter's 76.4%.

GIS-AHP generated suitability map identified about 378,730.34 ha of land suitable for cacao farm expansion. This only shows that Bohol has a huge potential of becoming one of the provinces in the country capable of producing cacao-beans for local consumption and export. Validation of study results through ground truthing should be done in these identified suitable areas.

ACKNOWLEDGEMENT

The authors would like to thank the DOST-Region 7 for providing the research funds and DOST Provincial Science and Technology Center–Bohol headed by Mr. Marcial M. Tagaan (former Provincial Administrator) and Ms. Vina R. Antopina (current Provincial Administrator) for overall project coordination. Special thanks to Retired Prof. Jose T. Travero, former BISU Bilar Campus Director, for initially leading the project, and Dr. Marietta C. Macalolot, current Campus Director, for overall supervision and guidance. The authors are also grateful to those who participated in the focus group discussion to develop the AHP pairwise comparison matrix, namely: Ms. Deseada C. Davalos (DA–APC), Ms. Vina R. Antopina (DOST–PSTC–Bohol), Mr. Blair L. Panong (DTI–Bohol), Dr. Larry M. Pamugas (Office of Provincial Agriculture–Bohol), and Dr. Carolyn May O. Daquio (Agricultural Training Institute–Region 7).

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