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Assessment of Land Resources Potentials for Orientation of Agriculture Land Use in Ham Thuan Bac district, Binh Thuan province

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Abstract

Land resources potential assessment is a valuable method for orienting land use planning in the world as well as in Vietnam. This study aimed to (1) assess land suitability and (2) orient the effective use of agricultural land in the study area. Results indicated that Ham Thuan Bac had 107 land mapping units (LMUs) with 11 main land-use types (LUTs) such as rice, cassava, vegetables, dragon fruit, and other trees. Agricultural land with high (S1) and moderate suitability (S2) for most LUTs was small; however, marginal (S3) and not suitability (N) lands were quite large. Results of land suitability evaluation on current land use showed that land area of annual crops was mainly found at the S3 suitability level, specifically for the rice area, 67.75% was marginally suitable and 23.29% of the area was unsuitable; In terms of perennial trees, except for dragon fruits which were mainly cultivated at the S2 suitability level (78.28%), the others such as cashew and other fruit trees were S3 and N levels. Based on land suitability classification, for mainstay LUTs, we proposed to keep 8550.0ha with S1, S2, and a part of S3 area to be irrigated for cultivating rice; 9071.7ha of dragon fruit land including 694.67ha of S1 and 8377.03ha of S2 land; only cultivate annual crops, fruit trees and grazing grass on the land with suitable levels from S1 to S3 of the current status; and the remaining areas of S3 and N levels for rice and areas of S2, S3, or N levels for dragon fruit would be converted to lands for annual crops, fruit trees, or grass for livestock.

Keywords

Agricultural land use, land resources potentials, land suitability, Ham Thuan Bac district

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Introduction

Assessment of land resource potentials is a fundamental step in

the process of land use planning (LUP) when land resources are limited (Bandyopadhyay *et al.*, 2009). The rapid population growth, as well as human activities, has created pressure on agricultural land. Intensified farming activities without proper land management practices lead to the degradation of land (Abdelrahman *et al.*, 2016). Land evaluation approach allows for identifying fundamental limiting factors for agricultural production, provides information in terms of constraints and opportunities for the utilization of land, and then guides decisions based on the optimal prerequisite for land use planning and development (Motuma *et al.*, 2016; Truong *et al.*, 2014; Pham Quang Vinh & Pham Thi Thanh Huong, 2012). Thus, land evaluation is implemented before recognizing the need for some changes in land use such as agricultural development or forestry plantation schemes.

Land suitability assessment plays an important role in agricultural development and future planning (Belal *et al.*, 2014). This has been implemented to help decision-makers and agriculture development planners determine the optimal use of the land. Assessing land suitability for various crops is necessary to choose the right crop and variety for the area based on matching the suitability of the area with the crop. Various methods of land evaluation have been developed throughout the years (FAO, 1976; Sys, 1985). The Food and Agricultural Organization (FAO, 1976) recommended an approach for land suitability evaluation for crops in terms of suitability ratings ranging from highly suitable to not suitable based on climatic and terrain data and soil properties. Sys (1985) proposed a range of capability indexes to denote soil limitations for crop production. A land suitability assessment could be viewed from three different perspectives: (i) productivity; (ii) workability; and (iii) sustained use of the land (Baja *et al.*, 2001). With advances in information and communication technology, land evaluation through map analysis techniques based on the theoretical framework from FAO has been completed using a geographical information system (GIS) to analyze land capability to sustain a defined land use.

Ham Thuan Bac, a mountainous district of Binh Thuan province, has an agricultural land area of approximately 124 thousand hectares. Land resources are playing an important role in the economic development of the district. However, a serious constraint in this district is the lack of irrigation water during the dry season. Drought is one of the major factors limiting crop production in the area. Therefore, to maximize the effectiveness of the land resources, it is necessary to assess land suitability for agricultural production in Ham Thuan Bac district (Ngo Thanh Son *et al.*, 2018; Hoang Le Huong *et al.*, 2018). In drought-affected conditions, irrigation restricted areas are not suitable for crops that require water such as rice. Hence, it is an important step for the orientation of agricultural land use planning in the future.

The objectives of the study were: (1) to assess land suitability; and (2) to orient an effective use of agricultural land in Ham Thuan Bac district. The results of the study could help to estimate the potential conversion of agricultural land and to recommend an effective agricultural land use system.

Study Area

Ham Thuan Bac district is located in Binh Thuan province, Southern Central Coast of Vietnam (**Figure 1**). The natural area is 1347.21km^2 (**Figure 1**) with a population of 173,253 people (2017). In this area, the topography is quite diversified including semi-mountainous terrain, alluvial plain, and coastal sand. The climate, characterized by the tropical monsoon region, is divided into two seasons, namely the rainy season from May to October and the dry season from November to April. The average temperature is approximately 26^{o}C to 28^{o}C and the annual total precipitation varies from 1070mm (delta areas) to 1995mm (high mountains). However, precipitation is highly variable and unevenly distributed. Due to reduced rainfall in the dry season (11% of the total annual rainfall), the dry season often causes serious water shortages for food production and people's daily needs. According to reports from the Department of Agriculture and Rural

Development at Ham Thuan Bac district (2017), agricultural activities in many areas still depend on rain.

Methodology

The assessment of land quality for a specific type of land use is based on land use requirements and constraints. Such requirements and constraints are then used as the basis for establishing what is termed 'evaluation criteria' (**Figure 2**).

Regarding these 'evaluation criteria', a set of algorithms is then employed to match the existing quality of land and the requirements of that particular type of land use.

The matching procedure (FAO, 1976 and after) then establishes a ranking of the potentials of land for a given purpose. The final result of the land evaluation is a map that portrays the divisions of the area of interest into suitability classes or land unit indices for nominated land use. The first is produced from an approach called a categorical system and the second from a continuous method of land suitability evaluation.

There are at least two important groups of land attributes for land suitability analysis: inherent qualities of soils and external characteristics. In this study, soil attributes, topographic elements, and management were used to represent all groups.

Land-use factors are land use characteristics in the study area such as land-use type or land cover, thereby helping to define the land attributes requirements appropriately. This study focuses on agricultural land uses (annual and perennial crops), identified through data collection and field surveys.

The analytical procedure developed consisted of the following steps (**Figure 3**):

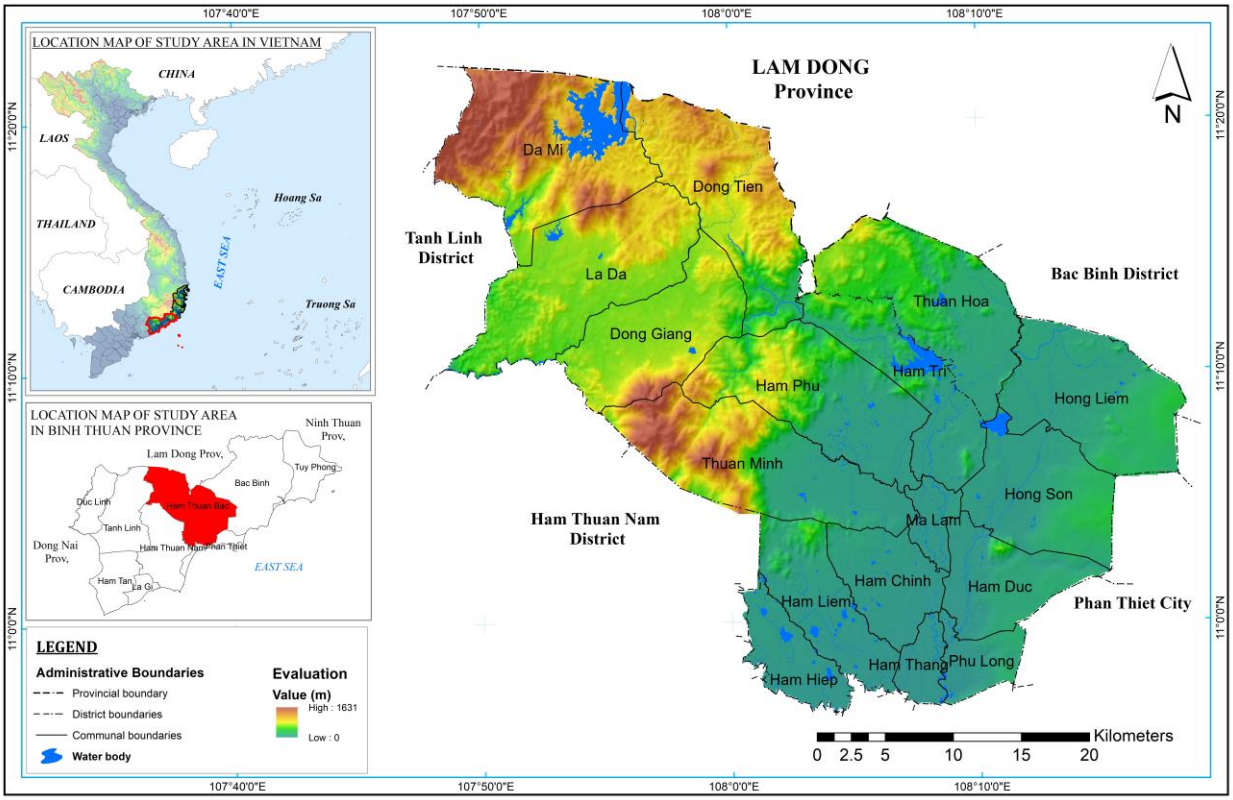


Figure 1. Study site - Ham Thuan Bac district, Binh Thuan Province

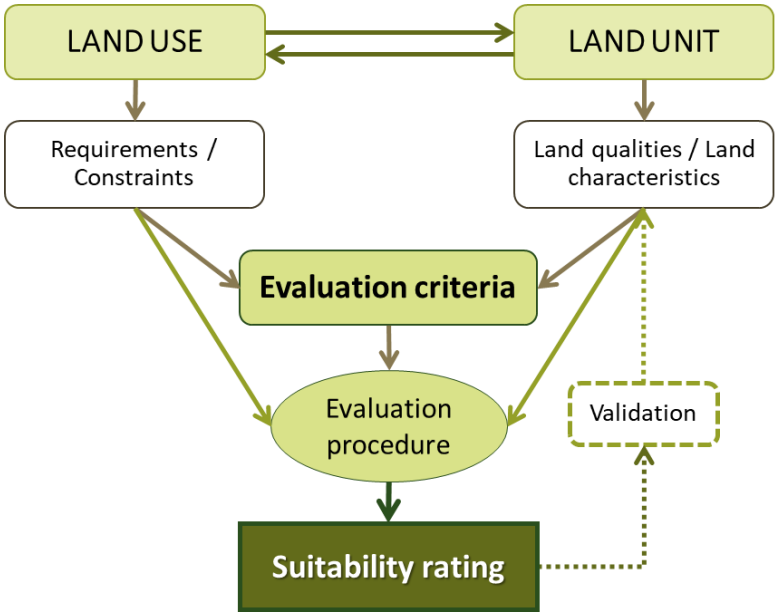


Figure 1. Components of land suitability assessment
Source: Baja et al. (2001)

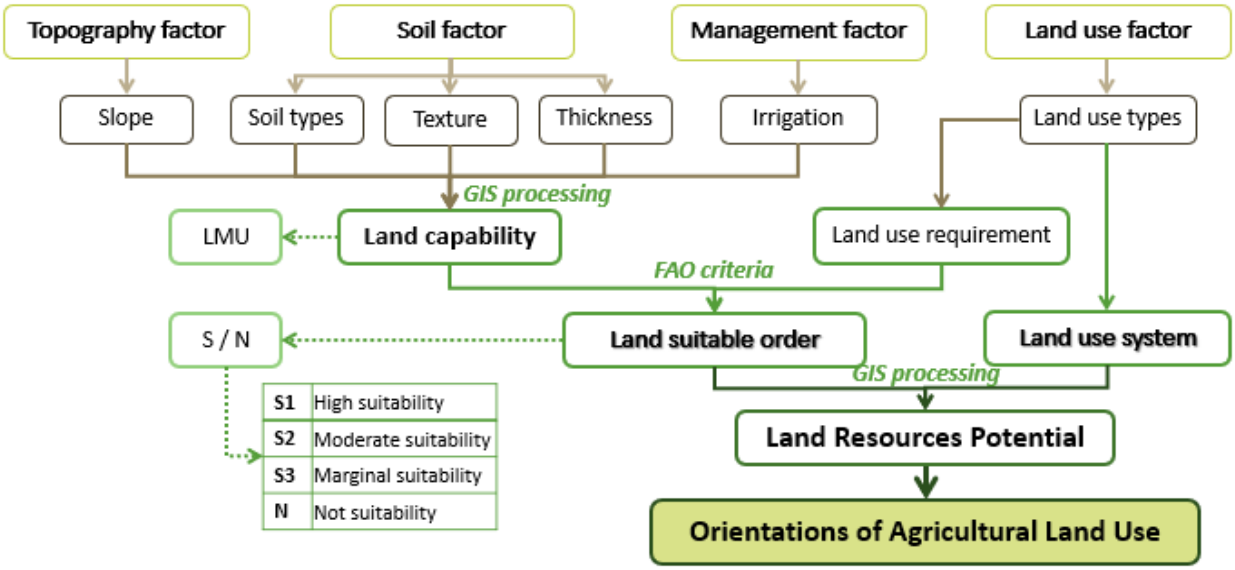


Figure 2. Methodological framework

Step 1. Determination of individual ratings of land characteristics

Each of the land attributes within variables in each group (i.e., soils, topography, and management) was first independently examined and rated from the collected data. The rating of soil attributes was done based on the available soil map which had 'crisp' boundaries, irrigation areas identified from water resources data, while that of topography was based on the DEM which had continuous values.

Inherent qualities of soils

Soil types in Ham Thuan Bac included 8 groups with 17 soil types from G01 to G17 corresponding to the following specific soil types (National Institute of Agricultural Planning and Projection, 2003) (**Table 1**).

Table 1. Soil types in Ham Thuan Bac district

Sym.	FAO soil classification		Vietnam soil classification		Area (ha)
G01	ARl	Luvic Arenosols	Cc	Sand dune soil	12,237.36
G02	ARg	Gleyic Arenosols	Cg	Glay Sandy	867.97
G03	SCh	Haplic Solonchaks	Mn	high saline soils	53.38
G04	FLe	Eutric Fluvisols	P	Alluvial soils without deposited	7,591.98
G05	FLb	Cambic Fluvisols	Pf	Alluvial soil with the variegated horizon	5,810.88
G06	FLu	Humic Fluvisols	Py	Stream alluvial soil	3,872.60
G07	AC	Acrisols	X	Gray soils	23,893.09
G08	ACg	Gleyic Acrisols	Xg	Glay gray soils	175.83
G09	FRx	Xanthic Ferralsols	Fa	Yellow-red soils on acid magma	30,950.05
G10	NTr	Rhodic Nitisols	Fk	Red-brown soil on basalt	13,717.42
G11	FRp	Plinthic Ferralsols	FL	Yellow-red soil changes due to rice cultivation	555.43
G12	FRx	Xanthic Ferralsols	Fp	Yellow-brown soil on ancient alluvial and sandstone	10,876.45
G13	FRx	Xanthic Ferralsols	Fs	Yellow red soil on clay rock	8,626.00
G14	NTh	Haplic Nitisols	Ft	Purple brown soil on basalt	2,205.56
G15	Fru	Humic Ferralsols	Ha	Red yellow humus on acid magma	2,226.21
G16	FLe	Eutric Fluvisols	D	Valley soil formed from accretion products	4,680.59
G17	LPq	Lithic Leptosols	E	Eroded soil is exposed to gravel	1,724.23
		Water	W	Waterbody	4,386.19

Soil thickness varied from 0 to 30cm (14,812.18ha), 30÷50cm (55.09ha), 50÷70cm (17,249.08ha), 70÷100cm (49,668.55ha), and the rest was greater than 100cm (4164.80ha).

Soil texture in Ham Thuan Bac district was mainly light texture (sand, loamy sand, and sandy loam) occupying 82,924.30ha (61.68%). Heavy soil texture (clay loam, silty clay, and clay) occupied 34,342.36ha (25.54%). The area of medium soil texture (sandy clay loam, loam, silty loam, silty, silty clay loam, and sandy clay) was approximately 6,383.36 ha (4.75%).

External characteristics

The slope was divided into 6 levels with approximately 50% of the natural land of Ham Thuan Bac having a very gentle slope ranging from 0 to 3^o and 3 to 8^o accounting for 54,043.51ha (40.20%) and 13,459.75ha (10.01%), respectively. The semi-mountainous area of the district has steep slope (>25^o) accounting for 31,598.28ha (23.50%). Gentle slope (8÷15^o), moderate slope (15÷20^o), and moderately steep slope (20÷25^o) occupied 10,468.92ha; 4,032.87ha; and 11,667.48ha, respectively.

The irrigation area was determined based on the irrigation map of Binh Thuan province in combination with the collected primary data. There were 88,676.01ha (65.95% of agricultural and forest land) which depended on rain (or irrigation regime from rainwater), about 23,998.99ha (17.85%) that was actively irrigated, and the remaining 12,595.81ha (9.37%) that was a semi-active irrigation regime.

Step 2. Group ratings of land characteristics

Land attributes within each group were then combined using a 'combination' function. The result was land capability or land mapping units indicating areas with qualities that differed sufficiently from other land units to affect their suitability for different land uses (FAO). Land Mapping Units (LMUs) of the Ham Thuan Bac district were built in the area of agricultural land and unused land by overlaying thematic maps including soil types, slope, thickness, soil texture, and irrigation regime (**Figure 4**). These

were the factors that had the greatest influence on farming of the study area, and in particular, there were regional differences in the study area, thus it determined the difference in the suitability of land use.

LMU = "Soil type" & "Slope" & "thickness" & "texture" & "irrigation"

$$= G_i \,\&\, SL_j \,\&\, D_k \,\&\, T_l \,\&\, I_m$$

Where, Gi - type "i" of soil, i = 01-17; SLj -level "j" of slope, j = 01-06;

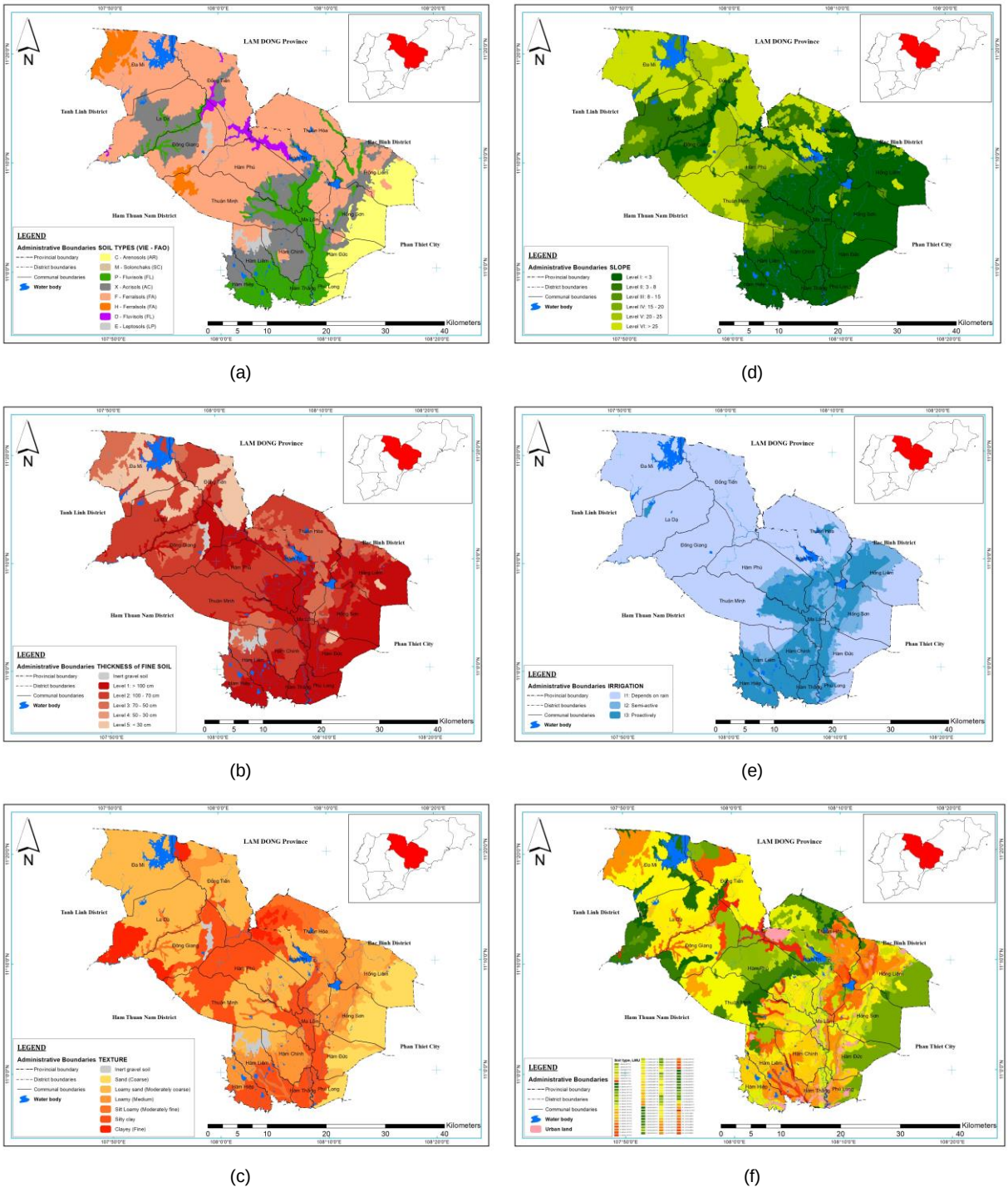


Figure 3. Thematic maps: (a) Soil types, (b) Thickness, (c) Soil texture, (d) Slope, (e) Irrigation regime, and (f) Land mapping units of the Ham Thuan Bac district

Dk - level "k" of thickness, k = 01-05 & E;
Tl - level "l" of texture, l = 01-03 & E;
Im - level "m" of irrigation, m = 01-03.

Step 3: Calculation of overall land suitability indices

Land-use requirements are described by the land qualities needed for sustainable production; land quality is a complex rating of land that has a direct effect on its use (evaluation criteria).

At this stage, based on the cell-by-cell operation in the GIS database, all groups of land variables and land requirements were utilized to produce the overall indices of land suitability for cropping. The present study used the four-level land suitability classification commonly used by FAO (1976, 1983, 1985, and 2007) including:

S1 - Highly suitable, Land having no significant limitations to the sustained application of a given use or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level;

S2 - Moderately suitable, Land having limitations which in the aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land;

S3 - Marginally suitable, Land having limitations which in the aggregate are severe for sustained application of a given user and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified; and

N - Not suitable, Land which has qualities that appear to preclude sustained use of the kind under consideration.

Step 4: Interim matching of land-use requirements with actual land qualities

Interim matching of land-use requirements with actual land qualities: matching (i.e., suitability assessment) for each land-mapping unit could be considered only for the physiological requirements of a specific crop(s) and the existing biophysical land conditions.

The first stage in matching was to compare the requirements of each land-use type with the land qualities of each land unit. The simplest procedure was to check the measured values of each land quality or characteristic against the class limits, and then allocate each land unit to its land suitability class according to the most severe limitation.

For cases in which at least one limitation was enough to render the land unsuitable for use, the method of taking the most severe limitation was valid. For example, for maize cultivation, it was of no use having level land and sufficient rainfall if the soils were highly saline. For less severe values of limitations, alternative methods of combining ratings for individual qualities could be used.

Step 5: Final matching

The interim suitability classifications produced in the preceding step might be re-evaluated taking into consideration a range of additional factors, e.g., potential land improvements, environmental impacts, and economic and social analysis. This is a key step to help managers/planners make the most appropriate decision.

Results and Discussion

Land mapping unit

Land mapping units were identified as one of the key bases for diagnosing the problem with land suitability. There were 107 LMUs in Ham Thuan Bac District in which: 6 LMUs belonged to Arenosols* (AR) group or sandy soils** (C) group (10.15% of total agricultural and unused land); 2 LMUs belonged to Solonchaks (SC) - saline soils (M) (0.02%); 18 LMUs belonged to Fluvisols (FL) - alluvial soils (P) (12.37%); 17 LMUs belonged to Acrisols (AC) - gray soils (X) (18.51%); 53 LMUs belonged to Ferralsols (FA) - yellow-red soils (F) (52.24%); 1 LMU belonged to Ferralsols (FA) - reddish-yellow humus soils in the mountains (H) (3.74%); 2 LMUs belonged to Fluvisols (FL) - lowland soils (D) (1.68%);

and 8 LMUs belonged to Leptosols (LP) - eroded soils (E) (1.29%) *(Note: * FAO's soil classification; ** Vietnam's soil classification).*

Land use requirement

Based on the current land use map (Department of Natural Resources and Environment of Ham Thuan Bac district, 2017) and the results of the survey on crop distributions in the district, there were 11 LUTs identified for agricultural purpose in Ham Thuan Bac district (**Table 4** and **Figure 5**).

As can be seen in **Table 4**, the fruit tree area occupied the largest area (31,348.82ha), of which dragon fruit accounted for 61.73% of orchard land (or 32% of total agricultural land - 19,352.71ha), whereas other fruit trees including custard-apple, avocado, jackfruit, banana, mangosteen, and mango occupied 11,996.11ha (38.27%). The annual crop was predominantly paddy rice (12,588.97ha); however, rice cultivation was dependent on rain and irrigation conditions. Thus, paddy rice could be transplanted from 2 to 3 seasons a year. Other annual crops such as peanuts, beans (5,696.45ha), cassava and sweet potato (3,070.56ha), and maize (2,372.07ha) were widely cultivated in Ham Thuan Bac. Rice was mainly cultivated in drought-prone areas, therefore, in the winter-spring season, rice and other crops were often strongly affected by drought due to water shortage. In contrast to other LUTs, grass for livestock was not allocated in the district's land use planning. Local people often grew grass in the land of annual crops or gardens, so the land area of this LUT was negligible (3.7ha).

In this paper, the suitability criteria (land characteristics) for land use types were divided into four levels from highly suitable to not suitable (**Table 2**).

Limiting values are the values of a land quality or land characteristic that determine the class limits of land suitability for a certain use. In orientation and land-use planning, the first and most important decision is to determine whether or not the land is suitable or unsuitable for production.

Land suitability classification

Based on the land characteristics and land use requirements of the LUTs of Ham Thuan Bac district, the land suitability classification was determined for 11 land-use types for 61,126.09ha of agricultural production land in Ham Thuan Bac district (**Table 3**).

Table 3 demonstrates the maximum suitable total area (S1/S2/S3) for each type of land use that could be obtained under the current conditions of the study area. The results of land suitability classification for each LUT separately indicated that for LUTs including rice, cashew, rubber, coffee, and other fruit trees (1, 8, 9, 10, and 11), if grown on the entire existing area, more than 50% of the area would be unsuitable. The remaining LUTs would be unsuitable lands, if cultivated in the entire existing area, which would vary from 6,579.72ha to 15,377.54ha, (10.76% to 25.16%) of the agricultural land. The suitability assessment for LUTs in the Ham Thuan Bac district showed that there was a small area that was highly suitable (S1) for all crops. In terms of moderate suitability level, most of LUTs had a certain area of compliance with S2 suitability level, the largest areas were cultivating dragon fruit (46.24%) and grass (54.87%). Under the marginal suitability level, if all LUTs were cultivated on the entire area, had a quite large part of the area only reaching this level, ranging from 19,265.92ha (32.52%) to 44,740.94ha (73.19%). The main limiting factors for all LUTs were inadequate rainfall and irrigation.

Applying land suitability classification for the current land use of agriculture in Ham Thuan Bac (**Table 4**, **Figure 5**, and **Figure 6)** indicated that land area of LUTs for annual crops was mainly found at the S3 suitability level, the percentage of these LUTs ranged from 67.75 to 100.00% of the current land area where, for the current cultivated rice area, 23.29% of the area was unsuitable, and 67.75% was marginally suitable; In terms of perennial trees, except for dragon fruits which were mainly cultivated on the land at the S2 suitability level (78.28%), the other perennial trees such as cashew, rubber, coffee, and other fruit trees were cultivated on

Table 2. Land use requirements of LUTs in Ham Thuan Bac district

No.	Land properties	Code	LUTs										
			1	2	3	4	5	6	7	8	9	10	11
	Soil types (FAO/Vietnam)												
1	ARl / Cc	G01	N	N	N	N	3	2	3	N	N	N	N
2	ARg / Cg	G02	3	N	N	N	N	2	N	N	N	N	N
3	SCh / Mn	G03	N	N	N	N	N	N	N	N	N	N	N
4	FLe / P	G04	1	1	2	1	1	1	1	N	N	N	1
5	FLb / Pf	G05	2	2	3	2	2	3	1	N	N	N	1
6	Flu / Py	G06	1	1	2	2	2	1	1	N	N	N	1
7	AC / Xa	G07	3	2	3	3	1	3	1	2	3	3	N
8	ACg / Xg	G08	2	N	N	N	3	N	3	3	N	N	2
9	FRx / Fa	G09	N	3	2	3	1	3	1	2	3	3	3
10	NTr / Fk	G10	N	1	1	1	1	1	2	1	1	1	1
11	FRp / Fl	G11	3	2	N	N	2	3	N	N	N	3	N
12	FRx / Fp	G12	N	3	2	3	1	2	1	1	2	3	2
13	FRx / Fs	G13	N	3	1	2	2	3	2	3	2	2	2
14	NTh / Ft	G14	N	1	1	1	1	1	2	1	1	1	1
15	Fru / Ha	G15	N	3	3	N	2	2	N	N	N	3	N
16	FLe / D	G16	3	2	N	N	1	3	2	N	N	N	N
17	LPq / E	G17	N	N	N	N	N	N	N	N	N	N	N
	Slope												
I	< 3º	SL1	1	1	2	1	1	1	1	1	1	1	1
II	3 - 8º	SL2	N	1	1	2	1	2	2	1	1	2	1
III	8 - 15º	SL3	N	2	2	3	2	3	3	2	2	3	2
IV	15 - 20º	SL4	N	3	3	N	3	N	N	2	2	N	2
V	20 - 25º	SL5	N	3	3	N	N	N	N	3	3	N	3
VI	> 25º	SL6	N	N	N	N	N	N	N	N	N	N	N
	Soil thickness												
1	> 100cm	D1	1	1	1	1	1	1	1	1	1	1	1
2	100 - 70cm	D2	1	1	1	2	1	1	2	3	3	3	3
3	70 - 50cm	D3	2	2	2	3	2	2	3	N	N	N	N
4	50 - 30cm	D4	3	3	3	N	3	3	N	N	N	N	N
5	< 30cm	D5	N	N	N	N	N	N	N	N	N	N	N
	Eroded soil	E	N	N	N	N	N	N	N	N	N	N	N
	Soil texture												
	Eroded soil	E	N	N	N	N	N	N	N	N	N	N	N
1	Light texture	T1	2	2	1	1	2	1	2	2	2	3	2
2	Medium texture	T2	1	1	2	2	1	2	1	1	1	2	1
3	Heavy texture	T3	3	3	3	3	2	3	2	2	2	1	2
	Irrigation												
1	Rainfed	I1	3	3	3	3	3	3	3	3	3	3	3
2	Semi-active	I2	2	2	2	2	2	2	2	2	2	2	2
3	Active	I3	1	1	1	1	1	1	1	1	1	1	1

Note: LUTs: 1 - Rice, 2 - Maize, 3 - Cassava & sweet potato, 4 - Sugar cane, 5 - Grass for livestock, 6 - Other cash crops, 7 - Dragon fruit, 8 - Cashew, 9 - Rubber, 10 - Coffee, 11 - Other fruit trees

Land suitability levels: 1 - S1 (High suitability), 2 - S2 (Moderate suitability), 3 - S3 (Marginal suitability), and N (Not suitability).

Source: MARD (2008) and consultations with experts.

the land with S3 and N levels in which the unsuitable land area was 65.13%, 44.47%, 85.61%, and 75.42%, respectively (in the total area of these LUTs).

The orientation of agricultural land use

According to survey results and statistics (Department of Agriculture and Rural Development of Ham Thuan Bac district, 2017; 2018), the actual cultivated areas of LUTs were much different from LUTs under the land use plan in 2017 (**Table 5**).

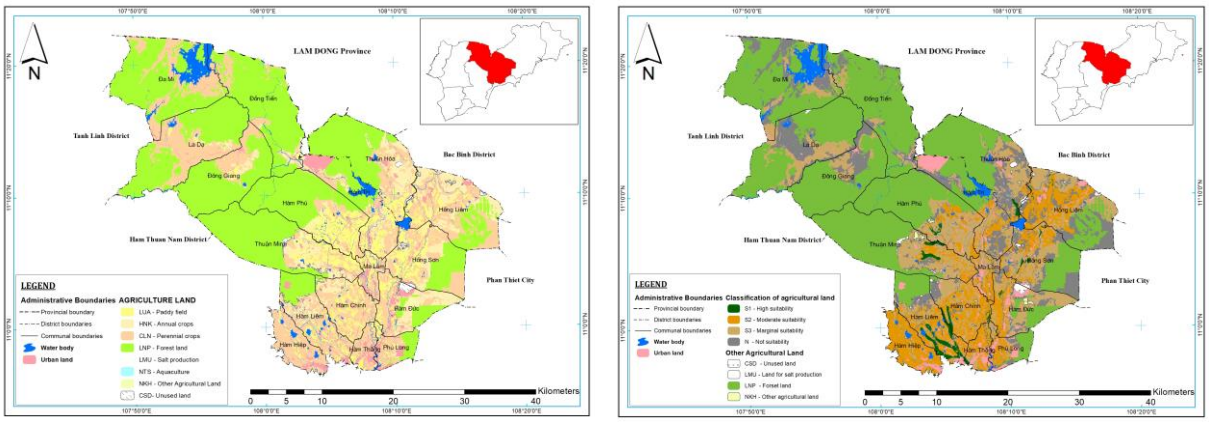
Currently, the area of rice cultivated was from 8,515 to 9,232ha depending on the season, whereas the cultivated rice area under the land-use plan in the district was 12,588.97ha, land-use efficiency was about 73%. The same was observed in all LUTs in the district. The reason for its difference is that Not suitability (N) or Marginal suitability (S3) occupied a majority of

Table 3. LUTs and land suitability potential of agricultural land in Ham Thuan Bac

No.	LUTs	Notation	Suitability levels (ha)				Total area (ha)
			S1	*S2*	*S3*	*N*	
1	Rice	LUC	1487.49	1075.24	26757.20	31806.17	61,126.09
2	Maize	CHN	1487.49	14143.29	34165.17	11330.15	61,126.09
3	Cassava and sweet potato	CHN	-	9399.02	39872.98	11854.09	61,126.09
4	Sugar cane	CHN	8.58	2,419.33	43320.63	15377.54	61,126.09
5	Grass for livestock	CHN	152.81	33540.54	20752.83	6679.91	61,126.09
6	Other cash crops	CHN	419.93	9385.49	44740.94	6579.72	61,126.09
7	Dragon fruit	CLN	1579.53	28266.76	22200.08	9079.72	61,126.09
8	Cashew	CLN	-	6299.06	19265.92	35561.12	61,126.09
9	Rubber	CLN	-	2557.13	22849.49	35719.47	61,126.09
10	Coffee	CLN	-	-	26146.86	34979.23	61,126.09
11	Other fruit trees	CLN	1579.53	14324.95	6621.59	38600.02	61,126.09

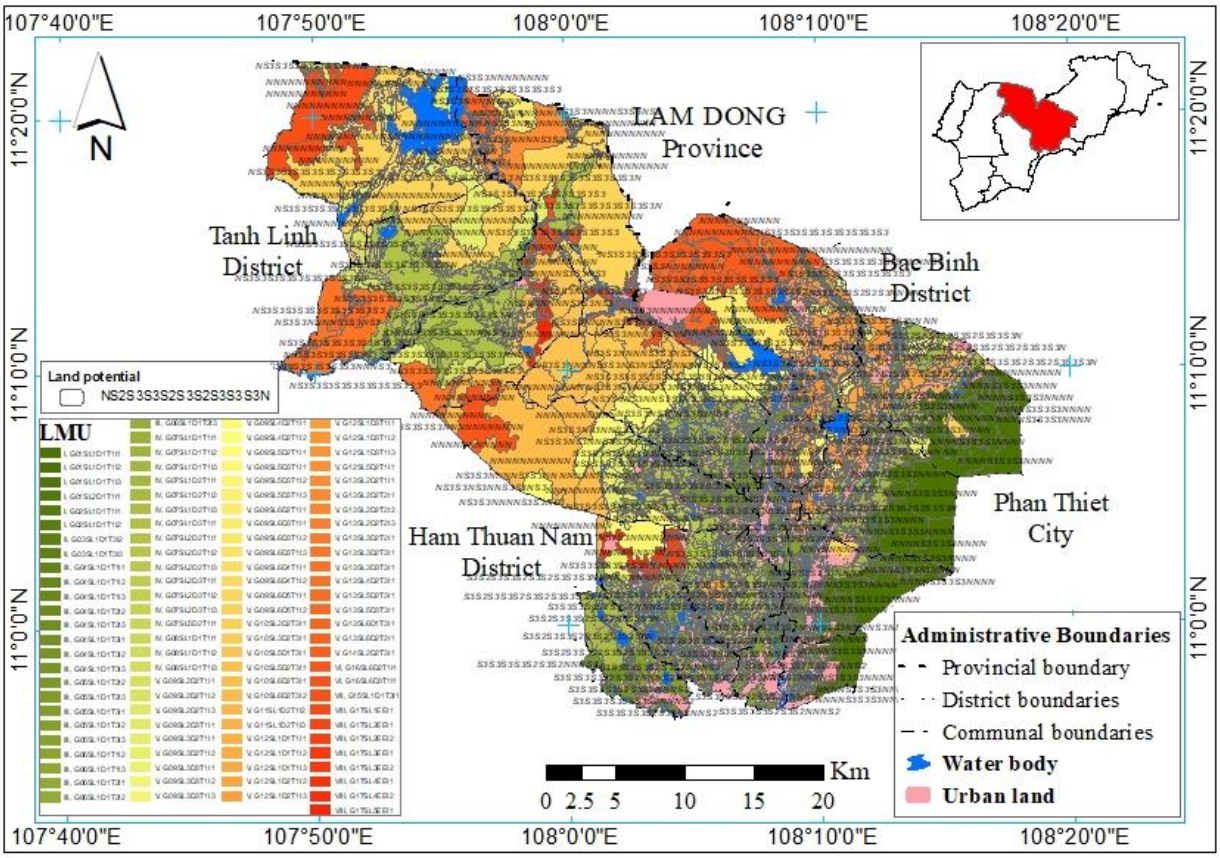
Table 4. Land suitability classification for current agriculture land use in Ham Thuan Bac

No.	LUT	Notation	Current area (ha)	Current suitability level (ha)			
				S1	*S2*	*S3*	*N*
1	Rice	LUC	12,588.97	700.19	427.49	8,529.07	2,932.22
2	Maize	CHN	2,372.07	74.55	325.95	1,848.85	122.71
3	Cassava & sweet potato	CHN	3,070.56		102.41	2,455.73	512.42
4	Sugar cane	CHN	497.91		7.04	486.09	4.78
5	Grass for livestock	CHN	3.69			3.69	
6	Other cash crops	CHN	5,696.45	31.00	1,389.46	4,166.07	109.91
7	Dragon fruit	CLN	19,352.71	694.67	15,150.11	2,455.06	1,052.88
8	Cashew	CLN	3,507.57			1,222.95	2,284.61
9	Rubber	CLN	1,887.19			1,048.06	839.14
10	Coffee	CLN	152.86			22.00	130.86
11	Other fruit trees	CLN	11,996.11		112.94	2,835.29	9,047.87
Total agricultural land			61,126.09				



(a) **(b)**

Figure 4. The current status map of agricultural land use in 2017 (a) and Map of land suitability classification for current agricultural land-use (b) of Ham Thuan Bac district



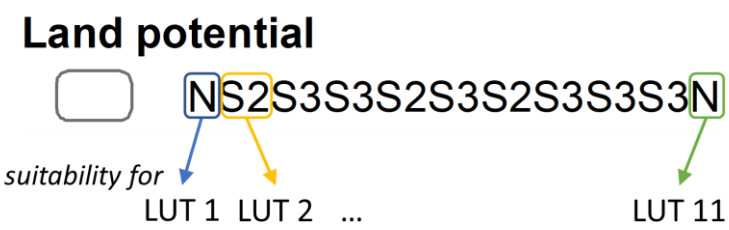


Figure 5. Land adaptation map (or land potential)

Table 5. The actual cultivated area in 2017 and 2018 in Ham Thuan Bac district

No.	LUT	Area (ha)	Actual cultivated area (ha)					
			Winter-spring		*Summer-autumn*		*Autumn*	
			16-17	17-18	2017	2018	2017	2018
1	Rice	12,588.97	8,515.0	8,545.0	9,171.0	9,000.0	9,323.0	9,079.0
2	Maize	2,372.07	75.5	68.0	528.0	619.0	1,327.0	1,526.0
3	Cassava and sweet potato	3,070.56	9.5	10.0	1,086.0	1,148.0	44.0	10.0
4	Sugar cane	497.91	269.0	164.0	1,552.0	1,403.0	39.0	41.0
5	Grass for livestock	3.69	3.7	3.7	3.7	3.7	3.7	3.7
6	Other cash crops	5,696.45	1,031.0	797.5	1247	1,410.0	1,134.0	1,438.0
7	Dragon fruit	19,352.71	9,000.0	9,071.7				
8	Cashew	3,507.57	1,365.0	1,728.0				
9	Rubber	1,887.19	1,531.0	1,531.0				
10	Coffee	152.86	1,550.0	1,634.0				
11	Other fruit trees	11,996.11	858.0	1,300.0				

the land area (**Table 4**). The district was not able to effectively use the land resources potentials if the limiting factors such as irrigation and shifting crop structure to adapt to water shortage conditions were not improved. Besides, the general limitation of the region was drought in the dry season (November to April), corresponding to winter-spring and early summer-autumn seasons.

Hence, to meet the requirements of sustainable land use to land use sustainable we proposed to: (i) Maintain the land areas which have High suitability (S1) and Moderate suitability (S2) levels; (ii) Renovate or convert to other suitable plants/afforestation for Marginal suitable (S3) land areas; and (iii) Convert to afforestation or use plants that could improve soil quality of the Not Suitable (N) land areas.

Thus, based on the actual land use in Ham Thuan Bac district, we proposed to keep stable rice cultivation in the area of 8550ha (including 1,127.68ha of rice under S1 and S2 suitability levels and 7,422.32ha rice under S3 suitability level) due to light soil texture (S3) but with active irrigation regime. The remaining area should be converted to other annual crops including rice area with remaining S3 and N suitability levels (due to yellowish-red soil). More importantly, due to the consumption market, the actual cultivated area of dragon fruit was only 9,000ha, which was much lower than the approved land use plan (19,352.71ha) of the district. Therefore, for this LUT, we recommend cultivating dragon fruit under the S1 suitability level (694.67ha) and approximately 8,377.03ha under the S2 suitability level. The proposal of dragon fruit (6,773.08 ha) under the district's plan should be shifted to annual crops, other fruit trees (mango and grapefruit, etc.), and grass for livestock. In terms of the perennial crop, the majority were cultivated under Suitability level (S3) and Not suitability level (N); therefore, we propose keeping these crops growing under S3, and the remaining area (12,302.49ha) under N level should be converted to afforestation and soil improvement plants.

Conclusions

The analytical procedures developed in the five specific steps for assessing land suitability were used to develop an effective use of agricultural land in Ham Thuan Bac district, which had an area of 61126.09ha agricultural land and unused land with 11 common land-use types, with rice (21% of total agricultural land) and dragon fruit (32%) as the two main crops. Two important groups of land attributes for land suitability analysis including inherent qualities of

soils (soil attributes) and external characteristics (topographic elements, and management) were used. Soil attributes included three factors: soil-type consisting of 17 soil types (in 8 soil groups), soil thickness consisting of 6 levels, and soil texture consisting of 4 levels. Slope characteristics consisting of 6 levels. The management characteristic is irrigation consisting of 3 regimes.

As a result of land mapping, based on the land characteristics, 107 LMUs were obtained over the entire agricultural and unused land of the study area. The majority belonged to Ferralsols (FA) groups (53 LMUs - 52.24%), followed by Acrisols (AC) (17 LMUs - 18.51%), Fluvisols (FL) (18 LMUs - 12.37%), Arenosols (AR) (6 LUMs - 10.15%), and the rest are other soil groups. The combination between characteristics of 107 LMUs and land use requirements were employed to evaluate current land use in the study area from suitable (S1, S2, and S3) to not suitable (N). The land area of LUTs of annual crops was mainly found at the S3 suitability level, where, for the current cultivated rice area, 23.29% of the area was unsuitable (N), and 67.75% was marginally suitable (S3). Meanwhile in terms of perennial trees, except for dragon fruits which were mainly cultivated at the S2 suitability level (78.28%), the other perennial LUTs (cashew, rubber, coffee, and other fruit trees) were cultivated with S3 and N levels, in which, the unsuitable land area was 65.13%, 44.47%, 85.61%, and 75.42%, respectively (in the total area of these LUTs).

To meet the requirements of sustainable land use, the following orientations have been proposed: (i) maintain the land areas which have High suitability (S1) and Moderate suitability (S2) levels; (ii) renovate or convert to other suitable plants/afforestation for Marginal suitable (S3) land areas; and (iii) convert to afforestation or use plants can improve soil quality for Not suitable (N) land areas. Therefore, for mainstay LUTs, the suggestions are to keep 8,550 hectares of land for rice with land suitability of S1, S2, and a part of the S3 levels which can be irrigated; To fit market demand, it is recommended to cultivate dragon fruit under the S1 suitability level (694.67ha) and approximately 8,377.03ha under the S2 suitability level; and the remaining areas, with S3 and N suitability levels for rice; and S2, S3, or N levels for dragon fruit, will be converted to other annual crops, other fruit trees, or grass for livestock.

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