

Land Unit Mapping and Evaluation of Land Suitability for Agro – forestry in Thua Thien Hue province – VietNam as an Example

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Abstract. This study covers 1 city, 2 towns and 6 districts with the total area of 503,320.53 ha. Its outcome is eight decentralization criteria including soil type, slope, terrain elevation, soil layer thickness, mechanical composition, humus content, bio-climatic conditions and irrigation. 8 single maps have been built using GIS. These 8 maps are merged into a singular map of land unit. The results show that the study site has 130 land mapping units (LMUs), of which the LMU 49 has the smallest area of 100,88 ha and LMU 111 has the largest area of 35,423.23ha. Based on the land quality of LMUs, it can be said that in the study site, 80,282.02 hectares is suitable for annual crops, 2225.80 ha for Thanh Tra pomelo planting, 15528.11 ha for rubber, and 159377.1 ha for Acacia mangium planting.

1. Statements

While presented as a natural thing, land is not only an outcome of labour, but also a special irreplaceable means of agricultural production. In the course of agricultural production, human has made artificial ecosystems to replace natural ecosystems, thus degrading their sustainability [1]. Moreover, rapid urbanization and industrialization in tandem with population growth have imposed increasing pressures on agricultural land, which is progressively narrower. In addition, irrational exploitation and use of land has led to degradation and infertility of soil in many areas [2].

For effective use, protection and management of land resources, it is of great importance to evaluate the land as a basis for maximizing the land potential [3]. According to the FAO land evaluation framework, land unit mapping is among key contents. A land unit map is a thematic map which displays all land units, characteristics and properties of the soil. For our nation, it is of great significance to conduct provincial land suitability evaluation, which is highly practical as it improves the quality of agricultural land use planning and plays as a basis for synthesizing and orientating crop restructure in association with land use restructure. [3], [4].

Recent time witnesses the Thua Thien Hue province's soaring urbanization in tandem with the transformation of agricultural land into non-agricultural and urban construction. Agricultural production area has decreased and the vogue is inclined to commodity urban agriculture, clean and market-driven agriculture. Research on land unit mapping and evaluation of land suitability for agro-forestry in Thua Thien Hue Province remains a new issue of concern mentioned nowhere, whereas it is essential for the structural transformation of crops, development of provincial agro-forestry,



enhancement of land use sustainability and protection of ecological environment and improvement of living standards of Thua Thien Hue people.

2. Overview of the study site

Thua Thien Hue province has coordinates of 16 – 16.8° N Latitude and 107.8 – 109.2°E Longitude. It features various terrain types (mountains, hills, plains, and coastal areas), tropical monsoon climate along with many extreme weather phenomena, diverse flora and dense hydrological networks, all reflecting regional typical characteristics. It has a modest total area of natural land, only 503320.53ha (of which 471313.07 ha is non-submerged), but the soil cover is susceptible to many natural and socio-economic factors, hence a highly complicated differentiation. Recent times see the city's steady shrinkage of agricultural area. The province's approved land use planning toward 2020 implies that the agricultural land area would narrow to 385552 ha in the time to come. Therefore, the remaining land fund for agricultural production must be rationally and efficiently used, so as to meet the demand for food without depleting the land resources. The area of land under the survey (agricultural production land) is 760.62 ha, accounting for 45.02% of the natural area (Table 1).

3. Methodologies

This research involves the following methodologies: *Secondary data collection*: Collecting agrochemical-soil maps, 2014 land use status map of the study site, statistics, land analysis data, reports and available local projects within the study site; *Land map correction*: Sampling more 30 soil profiles and 15 agrochemical specimens in districts of Thua Thien Hue Province; in combination with the 2014 land use status map, zoning and adjusting the land map; *Construction of information layers (single maps)*: with help of ArcGIS software preparing 8 information layers including soil type, slope, terrain elevation, soil layer thickness, mechanical composition, humus content, bio-climatic conditions and irrigation; *Land unit map*: using ArcGIS to merge single maps into a land unit map of the study site (Figure 1); Summary and statistics of survey and research results enabled by Excel software; *Comparison*: Comparing land use requirements corresponding to land utilization types in respect to land unit characteristics, so as to determine the suitability of LMUs;

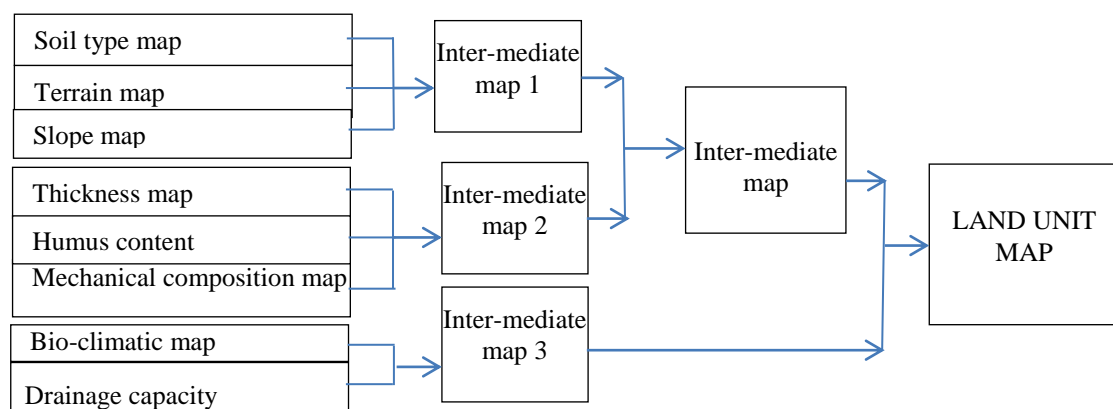


Figure 1. Overlaying single maps into a land unit map using GIS

Method for evaluation and classification of land suitability: *The land evaluation method proposed by* FAO (1976) [5] is a prominent method that for many years has been successfully applied in many developing countries as a tool for land use planning. Given the objectives and tasks set out, the researcher uses a synthetic scale and average multiplication proposed by D. L. Armand (1975) for evaluating the land suitability for development of agro-forestry in Thua Thien Hue Province. The problem looks like this

$$M_0 = \sqrt[n]{a_1 \cdot a_2 \cdot a_3 \dots a_n}$$

Where: M0: Score of land units. a1, a2, a3 ... an: Score of indicators from 1 to n. n: number of indicators used for evaluation

4. Research findings

4.1 Land unit mapping

4.1.1. Identification of land classification criteria

Land unit is a plot of land having such soil characteristics and properties suitable for each land utilization type (LUT), bearing the same conditions of land management and same potential for soil Improvement and production. Land unit map is a collection of land units in the evaluated area [6]. Land units are identified by overlaying information layers. FAO suggests that to evaluate land in areas of modest scope and similar climatic features, it may be helpful to delve into soil factors such as: soil properties (soil type, physical and chemical properties of the soil), topographic features (slope, shape, relative topography, and elevation), water properties (irrigation, drainage and inundation), and distribution of plants and animals. Given the purposes of land unit mapping and based on an appropriate evaluation of land suitability for agro-forestry, selected criteria for classification include soil type, terrain elevation, slope, soil layer thickness, mechanical composition, humus content, climatic conditions and irrigation regime (Table 2).

Table 1. Area of the study site (ha)

Land type	Area (ha)	Percentage (%)
Total area of the administrative land	503320.53	100%
Agricultural land	390889.77	77.66
Non-agricultural land	91026.20	18.15
Unused land	21.40355	4.19

Source: People's Committee of Thua Thien Hue Province, 2016

Table 2. Indicators and categorization of indicators for land use mapping of Thua Thien Hue Province

NO	Indicators	Categories	NO	Indicators	Categories
1	Soil types	1. White sand dunes (Cc);	3	Soil layer thickness	1. >100cm
		2. Sandy soil (C)			2. 70 - 100cm
		3. Highly saline soil (Mn)			3. 50 - 70cm
		4. Medium saline soil (M)			4. <50cm
		5. Deep active acid soil, medium saline (Sj2M)	4	Mechanical composition	1. Thick loam
		6. Alluvial soil accreted annually (Pb)			2. Medium loam
		7. Alluvial soil not accreted (P)			3. Light loam
		8. Clay alluvial soil (Pg)			4. Light sandy
		9. Alluvial soil with reddish-brown spotted layers (Pf)			5. Sandy
		10. Stream alluvial soil (Py)	5	Humus content	1. >3%
		11. Alluvial soil covering sandy soil (P/C)			2. 2 - 3%
		12. Wetland (J)			3. 1 - 2%
		13. Gray soil on magma acid rocks (Fa)			4. <1%
		14. Yellowish red soil on clay stone (Fs)	6	Elevation	1. <50m
		15. Yellowish red soil on metamorphic clay stone (Fj)			2. 50 - 100m
		16. Reddish yellow soil on magma acid rocks (Fa)			3. 100 - 200m
		17. Light yellow soil on sandy stone (Fq)			4. 200 - 700m
		18. Yellowish brown soil on old silt (Fp)			5. >700m
		19. Yellowish red soil mutated by wet rice cultivation (Fl)	7	Bio-climate	1. IA1a, IA1b
		20. Red muddy soil on metamorphic rock (Hj)			2. IIA1a, IIA1b
		21. Red muddy soil on magma acid rock (Ha)			3. IIIA2a
		22. Valley soil generated from slope accretion (D)			4. IVA3a
		23. Eroded soil revealing stones and gravel (E)			
2	Slope	1. <8 ⁰	8	Drainage capacity	1. Very good
		2. 8 - 15 ⁰			2. Relatively good
		3. 15 - 25 ⁰			3. Poor
		4. >25 ⁰			4. Very poor

4.1.2. Construction of single maps

a. Soil type map: Soil type is an indicator generalizing characteristics of land plots. Soil type reflects a variety of basic physical, chemical, and biological properties of soil, while giving us the perception of land use potential and land quality in respect to the growth and development of the crops [7]. Outcomes of land mapping at the scale of 1/100.000 reveal that the study site can be classified into 23 soil types under 10 groups [8]. Results of land map check and revisions in accordance with the land use status map of the study site are shown in Figure 2.

b. Terrain elevation map: The diverse topography of Thua Thien Hue features. The study site is topographically categorized into 5 ranges of altitude as follows: <50m, 50 - 100m, 100 - 200m, 200 - 700m, and >700m. Statistics show that the landform lower than 50m occupies the major part (176688ha) accounting for 35.0% of the natural area. It is followed by the 50-100m range (42040.672 ha) accounting for 8.3 % of total natural area; 100 - 200m range (53301.023ha) accounting for 10.5%, 200-700m range (168145.8192 ha) accounting for 33.4% and lastly, >700m landform accounting for 12.8%, (Figure 3).

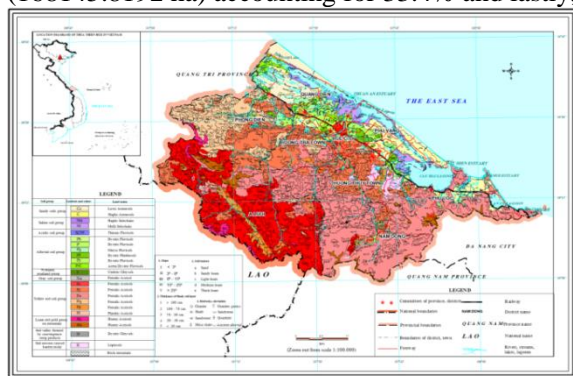


Figure 2. The soil map of Thua Thien Hue Province

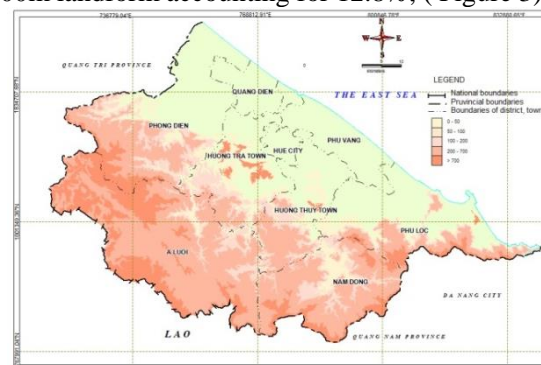


Figure 3. Terrain map of Thua Thien Hue Province

c. Slope map: Given the slope map of the study site, 4 ranges of slope can be defined as follows: $<8^{\circ}$, $8^{\circ} - 15^{\circ}$, $15^{\circ} - 25^{\circ}$, and $>25^{\circ}$. It is statistically pointed out that: land of slope less than 8° occupies an area of 135795.105 ha (making up 27% of the natural area of the study site), the range of $8^{\circ} - 15^{\circ}$ occupies 62524.053 ha (12.4%), the range of $15^{\circ} - 25^{\circ}$ occupies 122606.46 ha (24.4%), while land of slope above 25° has the largest area of 182,092.9 ha (36.2%), (Figure 4).

d. Soil layer thickness map: The thickness of soil layer, reflecting the soil's capacity of nutrient reserve, is related to topographic slope, vegetation cover and farming methods. Soil layer thickness presents as an important indicator for land unit mapping. The study site's soil layer thickness is defined in 4 levels: >100cm, 70-100cm, 50-70cm, <50cm. Statistics show that the soil layer of thickness less than 50cm accounts for the largest area of 269,125.918 ha (53.2% of the total natural area), thickness of 50-70cm accounts for 29865.538 ha (5.9%), thickness 70-100cm occupies 41283.505 ha (8.2%) and thickness >100cm occupies 165385.778 ha (32.7%), (Figure 5).

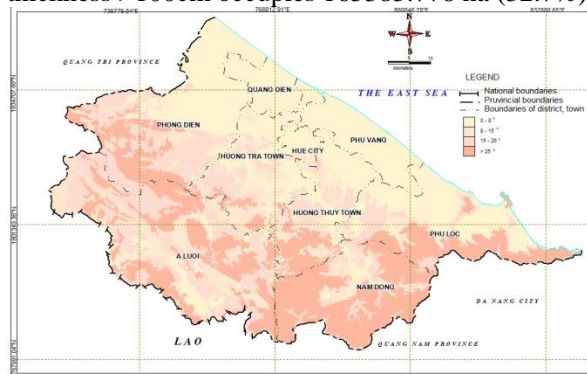


Figure 4. Slope map of Thua Thien Hue Province

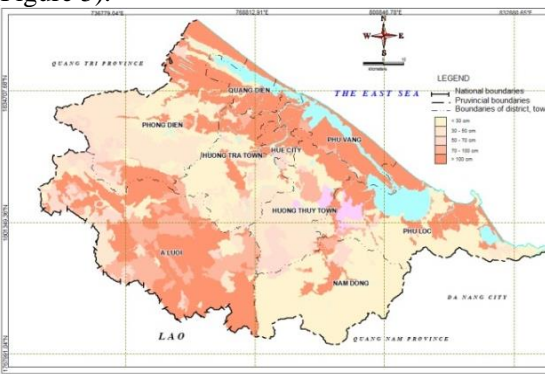


Figure 5. Soil layer thickness map Thua Thien Hue Province

e. Mechanical composition map: A given crop may adapt to soil of a certain mechanical composition. Mechanical composition determines the physical, chemical and biological properties of the soil. That is why need should arise for identification of soil mechanical composition so as to match a specific plot of

land with the right crops and appropriate technical measures. In the study site, 5 levels of mechanical composition are defined: thick loam, medium loam, light loam, light sandy and sand. Their proportions are respectively 2.4%, 26.7%, 32.4%, 25.7%, and 12.8%, (Figure 6).

f. Bio-climate: Since they substantially affect the growth, development and productivity of crops, these factors help to determine the appropriate crop structure that is economically beneficial in terms of agro-forestry. It is suggested by the bio-climate map that Thua Thien Hue Province features 4 types of bio-climatic conditions: High precipitation, very hot, short to medium dry season (IA1a, IA1b), area of 194308.2 ha; High precipitation, hot, short-to-medium dry season (IIA1a, IIA1b), area of 165388.2 ha; High precipitation, warm, short dry season (IIIA2a), area of 82149.23 ha; High precipitation, cool, short dry season (IVA3a), area of 63505.84 ha; (Figure 7).

g. Humus content map: Humus content indicates the nutrient reserves in the soil which greatly affects crop yields. The humus content of Thua Thien Hue Province is classified into 4 levels as follows: very rich > 3%, rich 2 - 3%, medium 1 - 2%, and poor < 1%, (Figure 8).

h. Drainage capacity: Thua Thien Hue territory is characterized by four levels of drainage capacity: good in mountains and hills; relatively good in mountain bases and foothills of relatively high slope; poor in flat valleys; and very poor in flat areas, ponds, lakes, lagoons, etc, (Figure 9).

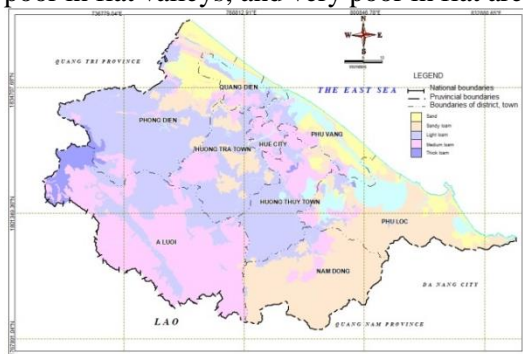


Figure 6. Soil mechanical composition map of Thua Thien Hue Province

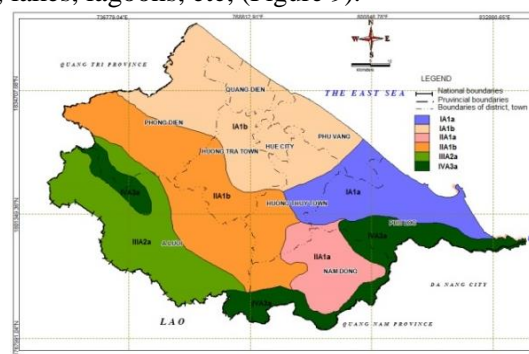


Figure 7. Bio-climate map of Thua Thien Hue Province

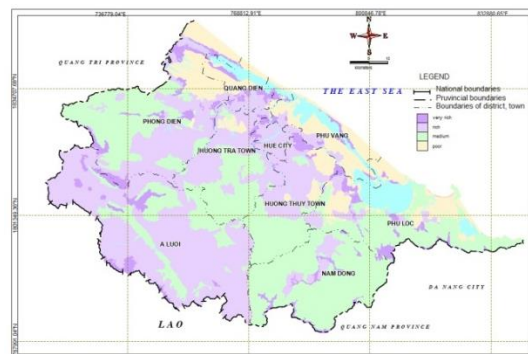


Figure 8. Humus content map of Thua Thien Hue Province

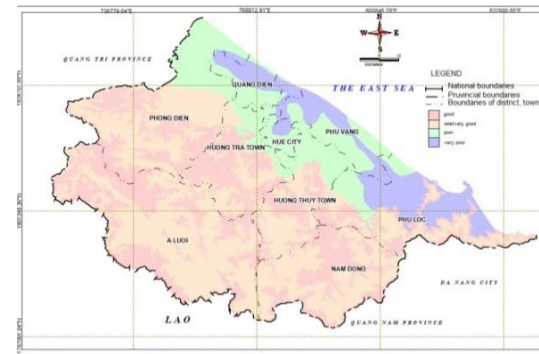


Figure 9. Drainage capacity map of Thua Thien Hue Province

4.1.3. Land unit mapping

Land unit map is the combination of information layers (single maps). Each land mapping unit contains all information expressed in single maps and is distinguished from other units by the discrepancy of categorized indicators. After single maps are constructed in respect to soil characteristics and properties, they are overlaid using ArcGIS software [4]. This comes up with an integrated land unit map (Figure 10) consisting of 130 land units. The smallest LMU is LMU 49 with an area of 100.88ha. The largest one is LMU No. 111, area of 35423.23ha.

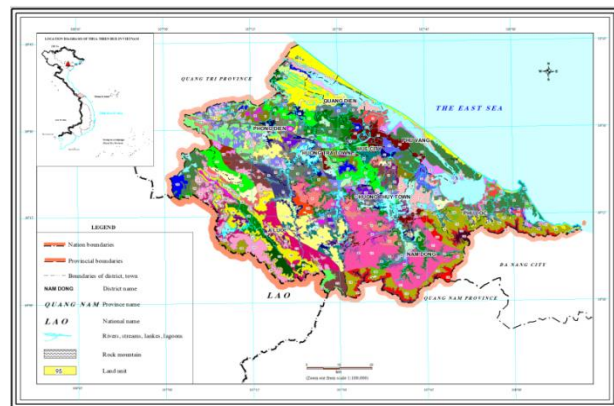


Figure 10: Land unit map of Thua Thien Hue Province

4.2. Evaluation of land suitability

4.2.1. Land use requirements per land quality

In order to evaluate the land suitability for agriculture development in Thua Thien Hue Province, we selected the following crops as the basis for evaluation: annual crops (peanut, peas, sesame), fruit (Thanh Tra pomelo), and industrial crop (rubber). Grown widely in Thua Thien Hue Province, the above-mentioned plants have appeared compatible with the local production practices, giving high economic value and high potential for improvement, soil and environmental protection. They are spearheading crops that are prioritized for expansion under the Province's agricultural development strategy toward commodity production and farmer income boost.

On the basis of summing up the research results from the project: [9], [10], [11] projects and Consultation of experts, can determine the ecological needs of all kinds of plant groups (Table3).

Table 3. Summary on ecological needs of crops

Indicators	Soil types	Slope (°)	Soil layer thickness (cm)	Mechanical composition	Humus content (%)	Elevation (m)	Bio-climate	Drainage capacity	classify
annual crops	C, Pb	<8	> 100	Light sandy	>3	<50	IA1a, IA1b	Very good	S1
	P, Pf, D, Fp, Py	-	70-100	Medium loam	2 - 3	50-100	IIA1a, IIA1b	Relatively good	S2
	Fa, Fs, Fq	8 - 15	50 - 70	Sandy, Thick loam	1 - 2	100-200	IIIA2a	poor	S3
	Remaining	>15	<50	-	<1	> 200	IVA3a	Very poor	N
ThanhTra pomelo	Pb	<8	> 100	Light sandy, Sandy phase	>3, 2-3	-	IA1b	Very good	S1
	P, Pf, Py, D	8-15	70-100	Medium loam	1 - 2	-	IA1a,IIA1b	Relatively good	S2
	Fs, Fa, Fq, Fp	15-25	50 - 70	Thick loam	<1	-	IIA1a	poor	S3
	Remaining	>25	<50	Sandy	-	-	IIIA2a,IVA3a	Very poor	N
rubber	Fs, Fj	<8	> 100	Thick loam	>3	>100	IA1b	Very good	S1
	Fa, Fq	8-15	70-100	Medium loam	2 - 3	100-200	IA1a, IIA1b	Relatively good	S2
	Fp, D	15-25	50 - 70	Light loam	1 - 2	200-700	IIA1a, IIIA2a	poor	S3
	Remaining	>25	<50	Sandy	<1	>700	IVA3a	Very poor	N
Acacia mangium	Fs, Fj, Fq, Fa, Fp, Ha, Hj	<15	> 100	-	-	-	IIA1a, IIA1b	Very good	S1
	P, Pf, P/C, C, D,	15-25	70-100	-	-	-	IA1a, IA1b	Relatively good	S2
	E, Cc, Pb	-	50 - 70	-	-	-	IIIA2a	poor	S3
	Remaining	>25	<50	-	-	-	IVA3a	Very poor	N

Note: S1: Very suitable; S2: Suitable; S3: Hardly suitable; N: Not suitable

4.2.2. Land suitability evaluation

In consideration of land use requirements for different types of land use and land units' quality, level of LMUs' suitability will be compared and identified (Table 4).

Table 4. Summary on levels of land suitability

Crops	LMU	Land suitability	Arable area (ha)
Annual crops	2, 14, 16, 18, 20, 27, 32, 35, 38, 41	S1	41369.39
	9, 10, 12, 13, 22, 25, 31, 33, 39, 40, 53, 59, 68, 69, 70, 75	S2	38912.17
	50, 56, 57, 71, 74, 78 and 90	S3	10043.89
	47 remaining land units	N	119728.83
ThanhTra pomelo	14, 16, 20, 28, 38 and 53	S1	41369.39
	12, 18, 31, 33, 41 and 75	S2	38.912,17
	9,25,34,35,40,56,58,67,68, và 70	S3	10.043.89
	58 remaining land units	N	119728.83
Rubber	31, 56 and 62	S1	41369.39
	25,27,34,53,58,70, 107 và 109	S2	38912.17
	9,67,68,75,100,105,106 và 114	S3	10043.89
	61 remaining land units	N	119728.83
Acacia mangium	9, 10, 13, 25, 27, 31, 33, 34, 38, 50, 53-59, 62, 67, 68, 70, 74, 75, 76, 78, 79, 109 and 114	S1	41369.39
	2, 6, 14, 16, 18, 20, 22, 26, 28, 32, 35, 37, 40, 41, 43, 63, 71, 95, 96, 100, 101, 103, 105-107, 119, 121 và 122	S2	38912.17
	5, 12, 19 and 39	S3	10043.89
	20 remaining land units	N	119728.83

Table 5. Categorization of land units for agro-forestry development in Thua Thien Hue Province

Land use types	Land suitability				Arable area (ha)
	S1	S2	S3	N	
1. Annual crops	41369.39	38912.17	10043.89	119728.83	90325.45
2. Thanh Tra pomelo	15305.78	6,952.30	17233.78	170562.20	39491.86
3. Rubber	4584.06	10,944.05	34344.50	160181.67	49872.61
4. Acacia mangium	68266.47	91,110.58	23651.75	27025.48	183028.80

Note: S1: Very suitable; S2: Suitable; S3: Hardly suitable; N: Not suitable

Table 5 reveals Thanh Tra pomelo, followed by rubber, features the largest "not suitable" area. This is explained by the fruit's narrow ecological amplitude and strict conditions for growth and development. Rubber hardly adapts to the stormy climate of the study site. Acacia mangium, on the other hand, enjoys the largest cultivable area. The second rank belongs to annual crops (peanut, peas, sesame), which are potential for expansion. They are not picky about the soil they are grown, but rather capable of improving the soils. Therefore, it is crucial to have an optimal layout of crops in conformity to the land potential, territorial advantages and socio-economic development strategy of the province.

Table 6. Summary on areas of different land suitability for annual crops

District	Classified by administrative units			
	S1(ha)	S2	S3	S4
Huong Thuy	1413.617	9089.616	1671.01	33535.45
Huong Tra	4977.179	4408.241	730.507	41939.01
Phong Dien	3926.623	11682.13	2279.082	77275.51
Quang Dien	315.15	-	-	16058.73
Quang Dien	12732.32	1355.105	601.229	57246.61
Nam Dong	-	12.67867	12.37523	225.0433
Phu vang	10803.24	-	-	14612.80
A Luoi	-	-	1434.724	121058.1
Hue City	3234.687	1674.428	-	2223.327
Total area	37402.82	28222.2	6728.927	364174.6

Table 7. Summary on areas of different land suitability for Thanh Tra pomelo

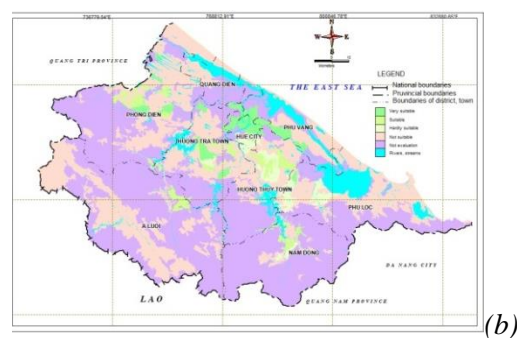
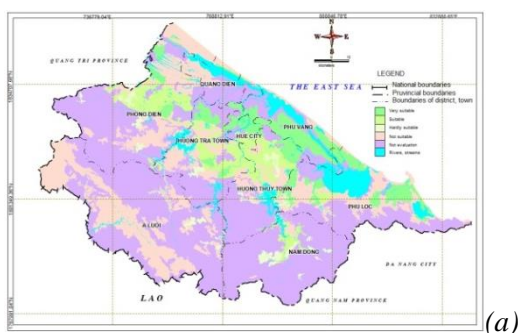
District	Classified by administrative units			
	S1(ha)	S2	S3	S4
Huong Thuy	1078.44	3625.474	4243.123	36762.65
Huong Tra	3879.901	2900.119	639.778	44635.14
Phong Dien	2158.942	4031.366		88973.04
Quang Dien	2.76103	-		16371.12
Quang Dien	351.039	-	5170.149	66414.08
Nam Dong	-	7.9775	3.809391	238.310
Phu vang	3378.059	-		14,612.80
A Luoi	-	2016.14		120476.7
Hue City	3234.687	-	957.181	2940.574
Total area	14083.829	12581.0765	11014.0404	391424.414

Table 8. Summary on areas of different land suitability for Rubber

District	Classified by administrative units			
	S1(ha)	S2	S3	S4
Huong Thuy	2982.22	2029.61	1659.22	39038.6
Huong Tra	-	2193.358	1881.462	47980.12
Phong Dien	-	-	3511.519	91651.83
Quang Dien	-	-	-	16373.88
Quang Dien	601.229	-	299.49	71034.55
Nam Dong	4.32186	6.795319	0.670861	238.3091
Phu vang	-	-	-	27831.17
A Luoi	935.947	4781.94	26535.67	90239.24
Hue City	-	957.181	-	6175.261
Total area	4523.71786	9968.88432	33888.0319	390562.96

Table 9. Summary on areas of different land suitability for Acacia mangium

District	Classified by administrative units			
	S1(ha)	S2	S3	S4
Huong Thuy	11733.25	5876.022	2630.26	25470.15
Huong Tra	20745.41	4000.988	1334.97	25973.57
Phong Dien	18866.76	4403.985	16814.03	55078.57
Quang Dien		312.389	3837.03103	12224.46
Quang Dien	3070.557	12456.92	5507.24	50900.55
Nam Dong	21.72968	-	-	228.3675
Phu vang	-	7425.18	5793.188	21732.51
A Luoi	7875.461	18572.43	-	96044.9
Hue City	1659.037	177.8683	3234.687	2060.85
Total area	63972.2047	53225.78	39151.409	289713.9



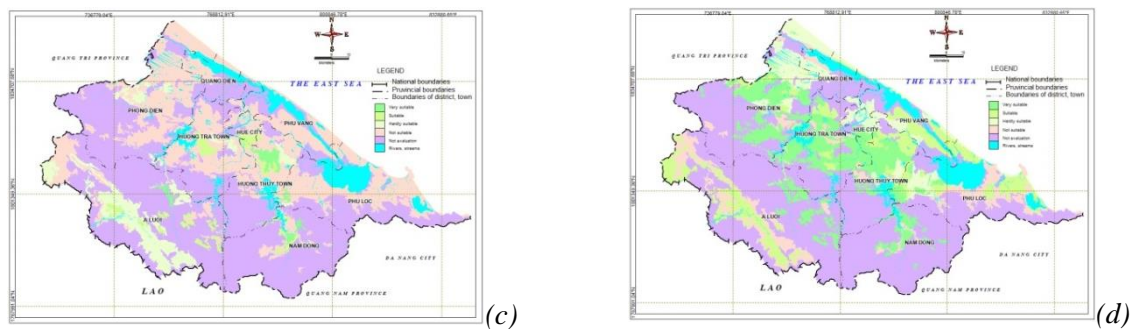


Figure 11. Map of land suitability for (a) annual crops, (b) Thanh Tra pomelo (c) rubber (d) Acacia mangium

It can be seen from tables 6, 7, 8, and 9 that the area of land suitable for annual crops is 80,281.56 ha, accounting for 15.9% of the study site. Pomelo has 22,258.08 ha of cultivable land, accounting for 4.4% of the study site. Arable area for rubber is 15,528.11 ha, representing 3.08%. Lastly, acacia mangium enjoys some 159,377.1 ha of cultivable land, occupying 31.6% of the study site. Notwithstanding, the actual numbers may be much larger, which prompts the need for soil improvement measures, irrigation systems completion and proper fertilization in order to improve crop yields.

5. Conclusion

The land unit map of Thua Thien Hue Province is constructed from 8 single maps including: soil type, terrain elevation, slope, soil layer thickness, mechanical composition, humus content, bio-climate and drainage capacity. The project works out the total number of land units in Thua Thien Hue Province, which is 130. LMU No. 49 is the smallest with an area of 100.88 ha. LMU No. 111 is the largest with an area of 35423.23 ha.

Given the land quality of LMUs, 80,282.02 ha is identified suitable for annual basis, 2,225.80 ha suitable for Thanh Tra pomelo and 15,528.11 ha suitable for rubber.

It is necessary to conduct an in-depth evaluation of the possibility to expand pomelo growing, especially rubber plantation, in typical conditions of Thua Thien Hue Province. As in agro-forestry it is the vogue to diversify crops and livestock, many more types of land uses should be added to evaluation objectives. At the same time, agro-forestry as the main production method should lay the basis for establishing a rational eco-economic model which brings about high economic efficiency and boosts the protection of land resources.

6. References

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