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A combined approach for sustainable use of mountainous agricultural land: land suitability evaluation and ecological-economic model

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ABSTRACT

In the quest for poverty reduction, developing sustainable agriculture and stabilizing cultivation areas for specialty plants can be substantially improved by a new approach, which combines land suitability assessment and designs of ecological-economic models. The land suitability was assessed according to the FAO framework and the Vietnamese standard TCVN-8409:2012. The criteria were grouped in climate, topography, and soil physicochemical properties. The seven land utilization types selected for analysis included orange, banana, tea, turmeric, cinnamon, chinaberry, and chukrasia in mountainous regions of Thanh Hoa and Nghe An Provinces, Vietnam. The results showed that the most suitable lands (S1) for cultivating these crops were 169.916 ha for orange, 201.166 ha for banana, 107.636 ha for tea, 570.744 ha for turmeric, 233.987 ha for cinnamon, 633.306 ha for chinaberry, and 280.704 ha for chukrasia. Based on that foundation, the study designed three ecological models with economic efficiency and elaborated on six formations of the models. The analyses obtained from the research also allowed the proposal of six prioritized spaces for land use and environmental protection, which were illustrated on a 1:100,000 map of proposed agricultural land use. Therefore, this study provided a detailed and reliable approach for researchers and managers in agricultural land use planning. A proper procedure for the assessment of agricultural land in mountainous areas can be suggested from this research.

Keywords: land suitability, orange, tea, cinnamon, Vietnam.

1. Introduction

Many evaluations have identified that mountainous regions in Vietnam possess numerous advantages and devel forestry, perennial industrial plants, fruit plants, pharmaceutical plants, livestock farming, and other agricultural forms (Quy, 1995). On the other hand, poverty is a significant issue that primarily recurs in rural and mountainous areas, where local livelihoods rely virtually on agriculture (The World Bank, 2018). Therefore, sustainable development in Vietnamese mountainous regions is undeniable, especially regarding food security and poverty reduction. One of such typical mountainous regions is the western Thanh

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Hoa and Nghe An. Here, there are 193/413 communes (46.7%) belonging to the group of extremely difficult communes, border communes, and security communes, according to Program 135 in 2017-2020 (Government of Vietnam, 2017).

The natural conditions of Thanh Hoa and Nghe An mountainous regions offer an exceptional opportunity for agricultural development, especially concerning profitable specialty plants. Specifically, there are many prominent names, including orange, tea, and cinnamon, and well-known brands such as "Cam Vinh" (Vinh Orange) and "Que Thanh" (Thanh Hoa Cinnamon), "Que Quy" (Quy Chau Cinnamon). In recent years, many other agricultural products, such as bananas and yellow turmeric, have emerged with quality and popularity. The forestry of this region also appears to be flourishing with the cultivation and exploitation of versatile plants. Local authorities have endorsed developing Chukrasia and Chinaberry as those two plants are substantially valuable in wood processing, forest enrichment, and environmental protection. However, over 60% of the total agricultural land is used to cultivate trivial plants like rice, corn, cassava, sweet potato, peanut, and sesame. While it is evident that specialty plants are much more capable of improving local livelihoods, the total area occupies less than 40% (NASO, THSO, 2020).

Consequently, the agriculture of this region is facing significant challenges from small cultivation sites scattered over a large area, which leads to little productivity, pests, and unstable quality. Furthermore, the lack of organization conflicts between agricultural cultivation, forestry production, and environmental protection (Nguyen and Lai, 2021). Therefore, this study selected seven land utilization types (LUTs), including orange, banana, tea, yellow turmeric, cinnamon, chinaberry, and chukrasia cultivation, to evaluate land suitability proposing ecological-economic models for mountainous regions in Thanh Hoa and Nghe An.

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On the other hand, Vietnamese rationales of ecological economics are strictly aligned with two fundamental aspects of territory exploitation and the usage of natural resources. Specifically, they are the economic aspect (to attain high economic efficiency) and the ecological aspect (to protect natural resources and the environment) (Thuan and Hai, 1999, Hai et al., 2013). As a result, ecological models have been the subjects of many studies and practical applications, especially in regions with difficulties concerning agricultural production. The studies of Thinh (2004), Hai et al. (2006), Van et al. (2013), and Anh et al. (2013) have successfully proposed ecological models capable of providing economic conditions for mountainous regions, ecotonal regions surrounding natural reservation areas, sandy coastal areas, etc.

Thus, the objective of this study is to assess the land suitability for some specific land-use types. Some typical eco-economic models are proposed that consider the economic efficiency of land use. As mountainous regions with both difficulties and potential, Thanh Hoa and Nghe An Provinces need ecological models to promote local specialty plants, aiming for comprehensively sustainable economic-social development. The results of land suitability and economic efficiency presented in this study are firm foundations to resolve this demand.

2. Data and methods

2.1. Study area

The mountainous region of Thanh Hoa and Nghe An has a total natural area of 2,174,422.2 ha, located East-West of the Truong Son Mountain range. The study area includes 11 districts of Thanh Hoa and 11 districts/communes of Nghe An (Fig. 1). The terrain shifts from the West to the East, from average mountains to low mountains and surrounding hills. Due to such terrain distribution, this region exhibits the characteristics of a tropical monsoon climate with a cold winter like Northern Vietnam and a humid rainy season like the Eastern Truong Son range (Ngoc et al., 2019). The representative soil types in this region are Acrisols and Ferrasols, which account for 75.8% of the total area. The statistics show the locations of specialty plant cultivation as follows: 9,540 ha of tea mainly in Thanh Chuong and Con Cuong; 4,000 ha of orange in Quy Hop, Con Cuong, and Thach Thanh; 3,200 ha of banana in Thach Thanh, Quan Son, and Tuong Duong (NASO, THSO, 2020). The typical scale of cultivation is of each household with less than 2 hectares scattered around regional districts.

2.2. Data

The criteria selected for assessing the land suitability of Thanh Hoa and Nghe An were categorized into three groups. Specifically, they included the climate criteria, the topographic criteria, and the physicochemical properties of soil.

The climate data were established based on the observative chain of database resulting from the activities of 33 hydrological stations and 06 meteorological stations (Hoi Xuan, Nhu Xuan, Quy Hop, Quy Chau, Tuong Duong, and Con Cuong) over 35 years from 1980 to 2014 (DCG, 2016). Indexes regarding annual rainfall, average yearly temperature, and the length of dry seasons were employed to evaluate the seven LUTs. Exclusively for orange cultivation, the study additionally used the average temperature in flowering periods (January and February) and the average temperature of two months after harvests (December, January, and February) (Fig. 2).

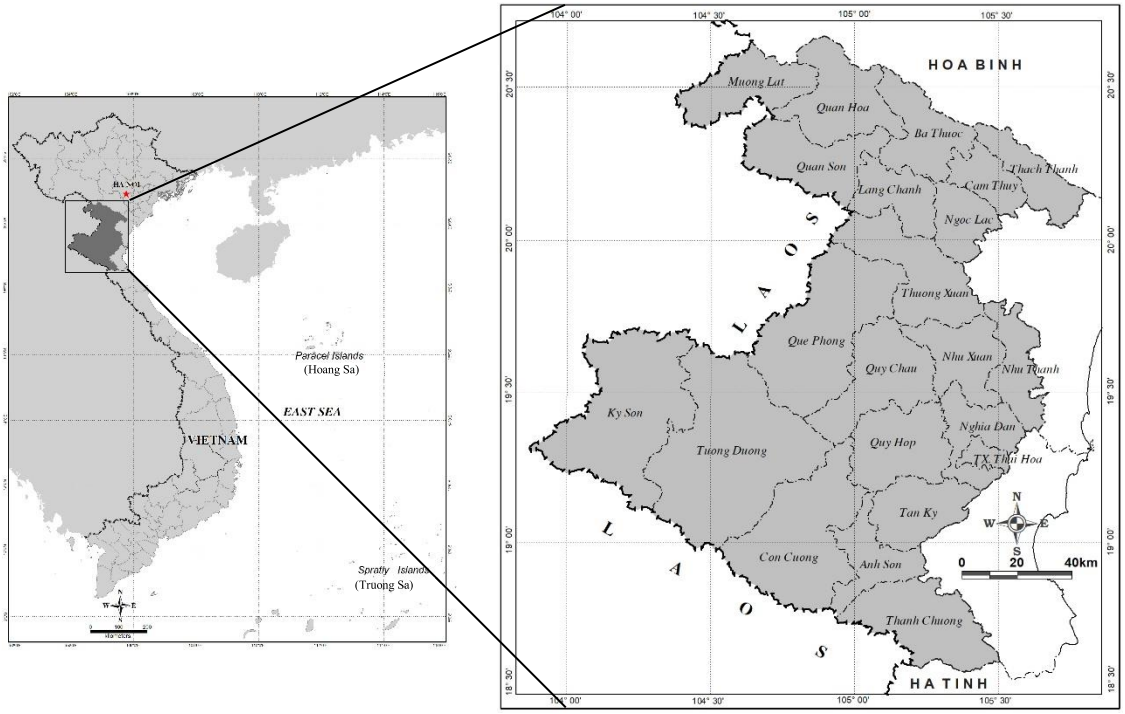

Figure 1. The mountainous region of Thanh Hoa and Nghe An Provinces in Vietnam

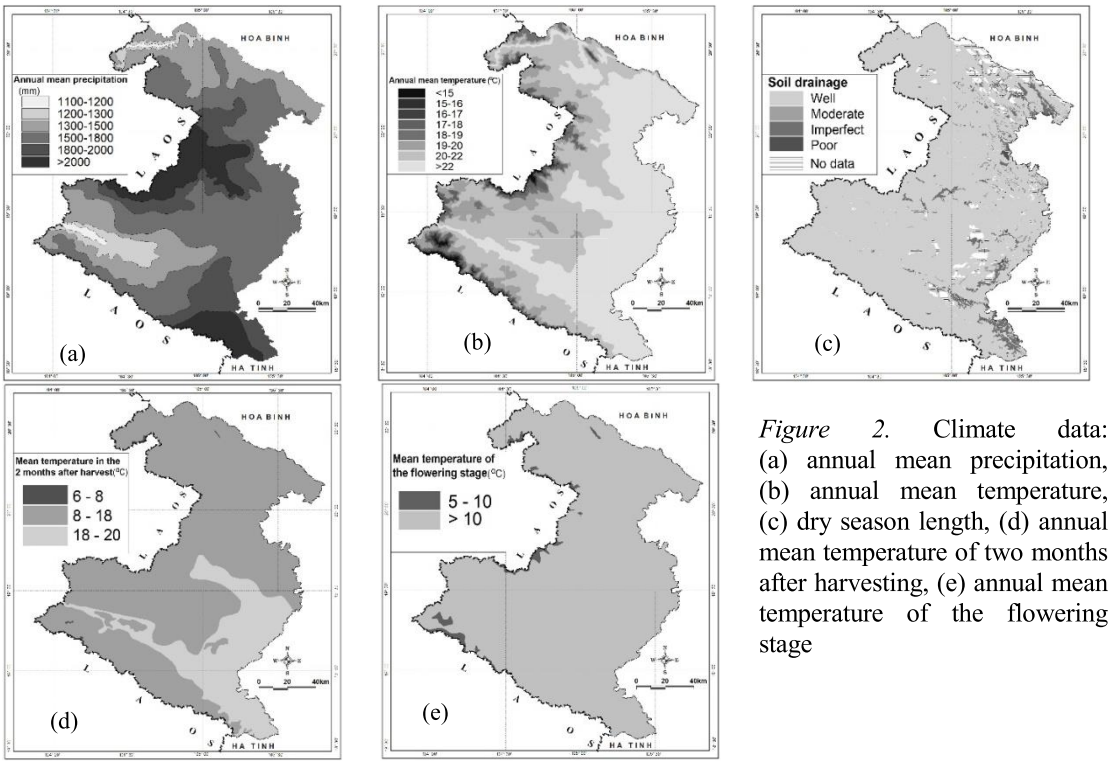

Figure 2. Climate data: (a) annual mean precipitation, (b) annual mean temperature, (c) dry season length, (d) annual mean temperature of two months after harvesting, (e) annual mean temperature of the flowering stage

The data regarding soil physics consisted of soil depth and texture, which were extracted from the soil 1:100,000 soil maps of Thanh Hoa and Nghe An Provinces (NIAPP, 2004, 2005) (Fig. 4). Soil chemistry criteria, including pH, the level of organic matter (OM), cation exchange capacity (CEC), available phosphorus, and available potassium, were calculated from the analyses of 80 soil samples collected from the study area and land in the vicinity of it (Fig. 3). These values were referenced from calculations of the average 0-25 cm soil layer according to the instruction of Sys et al. (1991), from which land units with the same type, texture, depth, and slope were inferred.

Data of the slope and absolute altitude were obtained from the DEM with a 30 m. Information regarding floods was from the 1:250,000 map of flooding in the Middle-Northern area (Thuy, 2015). From the soil maps, the level of drainage was determined based on the appearance of the gleyic layer in the soil profile, according to Sys et al., 1991 (Fig. 4).

In addition, this study has referenced the 1:250,000 distribution map of national parks and nature reserves in Vietnam, the 1:100,000 map of land use, and the 1:100,000 map of forest classification in Thanh Hoa and Nghe An Provinces (VNFOREST, 2017). As a result, a map of proposed agricultural land use for the mountainous region of Thanh Hoa and Nghe An at a scale of 1:100.000 was established.

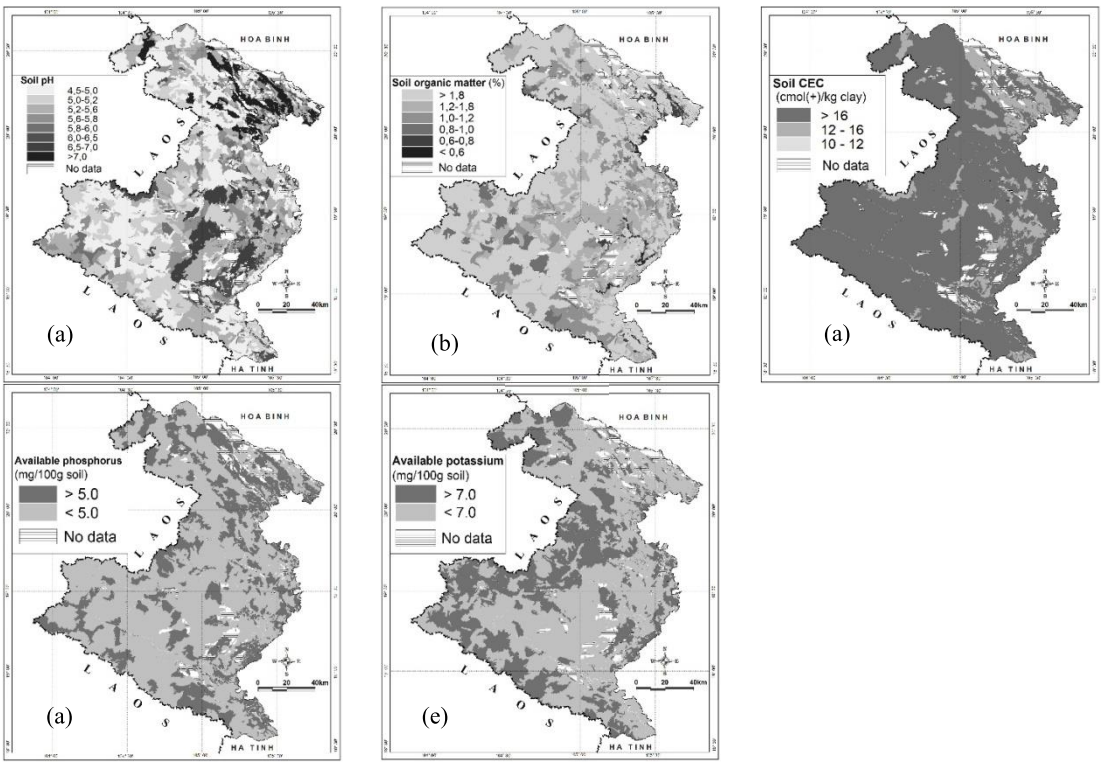

Figure 3. Chemical soil data: (a) soil pH, (b) soil organic matter -OM, (c) soil CEC, (d) available phosphorus, (e) available potassium

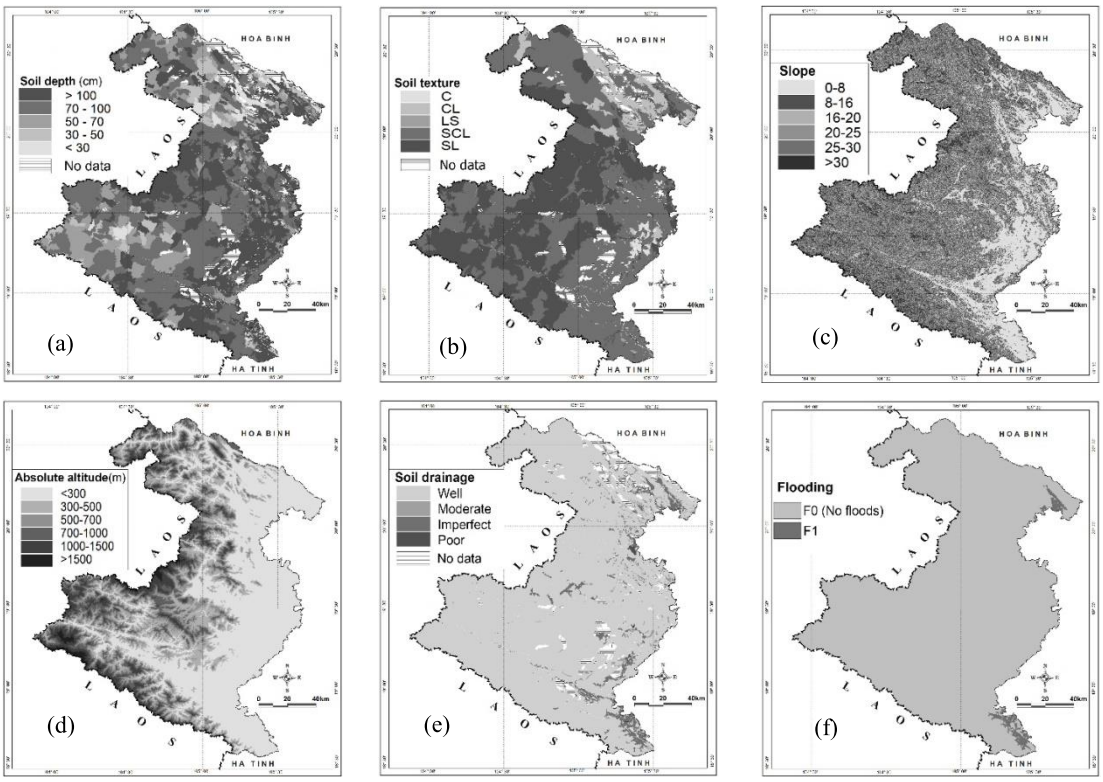

Figure 4. Physical soil, topography, and wetness data: (a) soil depth, (b) soil texture, (c) slope, (d) absolute altitude, (e) soil drainage, (f) flood

2.3. Methods

Figure 5 below depicts the general implementation procedures of this study. Specifically, there were three steps as follows:

- Step 1: Collect and standardize input data and materials into three groups: 1- Data and materials serving land assessment (land maps, topographic maps, soil physicochemical properties data, data of terrains) and LUTs; 2- Data and materials regarding the efficiency of LUTs and involved materials; 3- Data and materials serving land-use proposals (land use maps, forest classification maps, maps of national parks and nature reserves).

- Step 2: Process, extract, and aggregate input materials with a GIS to establish intermediate products such as land unit map, land use requirements, zoning of the subjects required to be unchanged (rice, population, biodiversity), and economic efficiency calculations resulting from selected LUTs.

- Step 3: Evaluate land suitability in GIS software. Select the proper LUT corresponding to priorities, economic efficiency, and the ability to incorporate other types of land usage to form ecological models. Integrate the resulting hierarchy of land suitability and potential ecological models to propose possible land use for Thanh Hoa and Nghe An mountainous region.

2.3.1. Land suitability assessment according to the FAO framework and TCVN-8409:2012

The methodology applied in this study was the FAO framework combined with instruction for agricultural production land evaluation TCVN 8409:2012. There were four levels of suitability: Very suitable (S1), moderately reasonable (S2), marginally

appropriate (S3), and unsuitable (N) (MOST, 2012). The primary content of the method was to compare the Land Use Requirement (LUR) of Land Utilization Type (LUT) with the characteristics of Land Units (LU) to form a hierarchy. Notably, it was based on the two following rules:

Hierarchy with the highest level of limits: All LUTs are limited within LURs. If one attribute of a LU is within those limits, that land LU would be classified as unsuitable. For example, a land unit is unfit for orange cultivation if it has one of the following limits: slope gradient above 30°, soil depth below 50 cm, etc.

Hierarchy following prominent factors: Some land characteristics carry decisive meanings in suitability assessment and are unlikely to be changed by human impacts, for example, soil depth, soil texture, slope, etc. Other factors are considered regular with insignificant effects on rankings.

The implementation of the land suitability assessment was as follows:

Step 1: Identify LUTs.

Step 2: Establish the land unit map (LUM), including LU with land characteristics and land quality; identify prominent factors.

Step 3: Establish the LURs and identify the limits of each LUT.

Step 4: Compare the LURs of each LUT with the attributes of LU, considering prominent and limiting factors; conclude the suitability of LU to each LUT.

Step 5: Exhibit the results graphically on land suitability maps; analyze the data via GIS software.

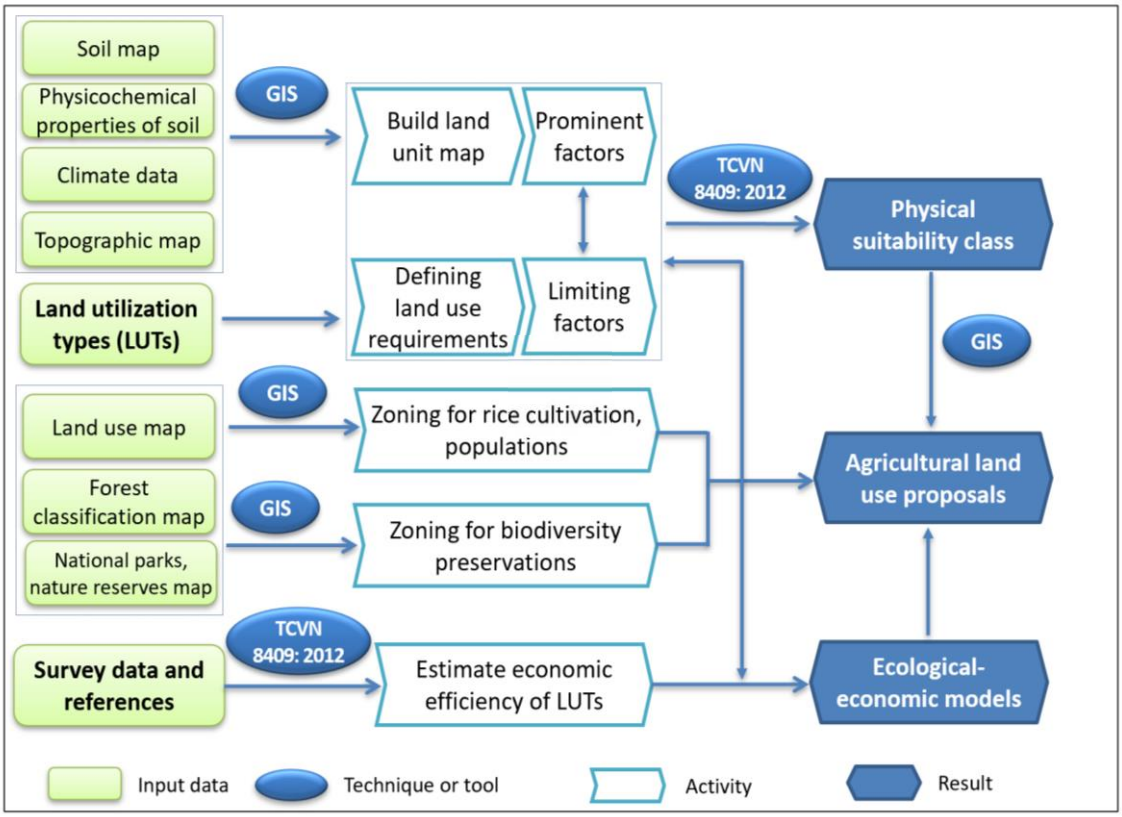

Figure 5. Analysis procedure for this research

2.3.2. Evaluation of economic efficiency

The study evaluated the economic efficiency of every LUT following the protocols of TCVN-8409:2012 (MOST, 2012). Afterward, the results were integrated with other variables (livestock farming, handicrafts) to design ecological models and further calculations regarding the economic efficiency of complete models. The efficiency of a forest variable and a garden variable was deduced on one hectare for each LUT. Particularly:

- Total cost:

$$TC = MC + HLC + SC + OC \quad (1)$$

$$TC1 = MC + LC + SC + OC \quad (2)$$

In these equations, TC is the total cost excluding the labor of households, TC1 is the total cost including the labor of households, MC is the material costs, HLC is the hired labor costs, LC is the labor costs (from both hired labor and household labors), SC is the service costs, and OC is the other costs.

- Total revenue:

$$TR = Q * P \quad (3)$$

In equation (3), TR is the total revenue, Q is the sold quantity, and P is the selling price

- Total profit:

$$TP = TR - TC \quad (4)$$

- Total sales:

$$TS = TR - TC1 \quad (5)$$

In equation (5) TS is the total sales.

- Ratio of Profit/Cost

$$R = TP/TC \quad (6)$$

In equation (6), R is the ratio between the total profit and the total cost (excluding household labor).

Input data such as the material costs, labor costs, sold quantity, and price were recorded, processed, and synthesized from 200 surveys of households and management authorities in the study area. In addition, the sold quantity and the selling price were the average values of two-three previous years (2018-2020) and were compared to the annual statistics and reports of management authorities.

2.3.3. Spatial and Geographical Information System (GIS) methods.

The study utilized computer programs MapInfor 10.5 and ArcMap 10.2 to establish an input database for land suitability assessment. GIS also provides a platform to apply statistical analysis and spatial analysis of geospatial data. The evaluation results are displayed visually through maps and data tables.

3. Results

3.1. Land usage requirements of land usage types in Thanh Hoa & Nghe An

The study analyzed the relationship between LURs for LUTs and land characteristics and identified 11-15 criteria. Table 1 below displays the land use requirements for LUTs in the Thanh Hoa - Nghe An mountainous region. Those criteria were selected in accordance with the natural conditions of the region and the hierarchy of Sys et al. (1993) and Olusegum and Julius (2015). Altitude was influential in the growth and distribution of most forest trees. As a result, the assessment process employed altitude to evaluate the cultivation of cinnamon, chinaberry, and chukrasia (MOST, 2010). Exceptionally, land use requirements for orange cultivation were appraised with 15 criteria (Table 2). In those criteria, there were 4 essential ones that directly affected productivity, the rate of fruiting, and fruit quality: the mean temperature of two months after harvest, the mean temperature of the flowering stage according to the hierarchy of Sys et al.,1993, available phosphorus, and available potassium (FAVRI, 2011). The gradient of slopes, soil depth, and altitude were the most limiting factors to LUTs in the study area.

Table 1. Land use requirements for LUTs in the Thanh Hoa - Nghe An mountainous region

LUT	Suitability class	R	Dm	Temp	H	Sl	Fl	Dr	St	Sd	pH	OM	CEC
Banana	S1	1500-2500	0-3	18-24	-	0-8	F0	D1, D2	CL	>100	5,6-7,5	>1,8	>16
	S2	1300-1500	3-4	16-18	-	8-16	F1	D3	SCL, C	70-100	5,2-5,6	1,2-1,8	12-16
	S3	1000-1300	4-6	15-16	-	16-30	-	D4	SL, LS	50-70	4,5-5,2	0,8-1,2	10-12
	N	-	-	-	-	>30	-	-	-	<50	<4,5	<0,8	-
Tea	S1	1800-2500	0-2	17-24	-	0-8	F0	D1, D2	CL, SCL	>100	4,5-5,0	-	>16
	S2	1300-1800	2-3	15-17	-	8-16	F1	D3	SL, C	50-100	5,1-6,0 4,0-4,4	-	<16
	S3	1000-1300	3-4	-	-	16-30	-	D4	LS	30-50	<4,0 6,1-6,5	-	-
	N	-	4-6	-	-	>30	-	-	-	<30	>6,5	-	-
Turmeric	S1	1500-2500	-	22-24	-	0-16	F0	D1, D2	CL, SCL, SL	>70	5,8-7,0	>1,8	-
	S2	1000-1500	-	20-22	-	16-20	F1	D3	-	50-70	5,0-5,8 7,1-7,5	1,2-1,8	-
	S3	-	-	18-20	-	20-25	-	D4	C, LS	30-50	4,5-4,7	0,6-1,2	-
	N	-	-	15-18	-	>25	-	-	-	<30	<4,5	<0,6	-
Cinnamon	S1	1800-2500	-	22-24	300-500	0-16	F0	D1	SCL, SL	>50	4,5-5,5	>1,8	-
	S2	1500-1800	-	20-22	0-300	16-25	-	D2	CL	30-50	5,5-6,5	1,0-1,8	-
	S3	1300-1500	-	18-20	500-700	25-30	F1	D3	LS, C	<30	4,0-4,5 6,5-7,0	<1,0	-
	N	1000-1300	-	15-18	>700	>30	-	D4	-	-	<4,0, >7,0	-	-
Chinaberry	S1	1500-2000	-	22-24	0-500	0-20	F0	D1	SCL, SL	>70	5,0-6,5	>0,8	>16
	S2	2000-2500	-	-	500-700	20-25	-	D2	CL	50-70	4,5-5,0	<0,8	<16
	S3	1200-1500	-	16-22	700-1000	>25	F1	D3	LS, C	30-50	4,0-4,5 6,5-7,0	-	-
	N	1000-1200	-	<16	>1000	-	-	D4	-	<30	<4,0;>7,0	-	-
Chukrasia	S1	>1800	-	22-24	0-700	0-20	F0	D1	SCL, SL	>70	5,0-6,0	>0,8	>16
	S2	1500-1800	-	-	700-1000	20-25	-	D2	CL	50-70	6,0-6,5	<0,8	<16
	S3	1300-1500	-	18-22	1000-1500	>25	F1	D3	LS, C	30-50	4,0-5,0 6,5-7,0	-	-
	N	<1300	-	15-18	>1500	-	-	D4	-	<30	<4,0; >7,0	-	-

Legends: F0: no floods; F1: a land is often flooded for a period of no longer than 1-2 months; C: clay; CL: clay loam; SCL: sandy clay loam; SL: sandy loam; LS: loamy sand; D1: well; D2: moderate; D3: imperfect; D4: poor; R: annual mean precipitation; Dm: number of dry months; Temp: annual mean temperature; Sl: slope; Fl: flooding; Dr: drainage; H: altitude; St: soil texture; Sd: soil depth; pH: soil pH; OM: soil organic matter; CEC: soil CEC

Table 2. Land use requirements for orange cultivation in the Thanh Hoa - Nghe An mountainous region

Criteria	Suitability level			
	Very suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Unsuitable (N)
Climate				
Annual mean precipitation (mm) (R)	1200 - 2500	1000-1200	-	-
Number of dry months (month) (Dm)	0-4	4-5	5-6	-
Annual mean temperature (°C) (Temp)	19-24	16-19	15-16	-
Mean temperature in the 2 months after harvest (°C) (T2ah)	8-18	6-8, 18-20	-	-
Mean temperature of the flowering stage (°C) (Tfs)	10-20	5-10	-	-
Topography and wetness				
Slope (Sl)	0-8	8-16	16-30	>30
Flooding (Fl)	F0	-	-	F1
Drainage (Dr)	D1	D2	D3	D4
Physical soil characteristics				
Soil texture (St)	SL, CL, SCL, LS	-	C	-
Soil depth (cm) (Sd)	> 100	70-100	70-50	< 50
Chemical soil fertility				
Soil pH (pH)	5,5-7,6	5,2-5,5; 7,6-8,0	5,0-5,2	<5,0
Soil organic matter (%) (OM)	>1,8	1,2-1,8	0,8-1,2	<0,8
Soil CEC (cmol(+)/kg clay) (CEC)	>16,0	10,0-16,0	-	-
Available phosphorus (mg/100g soil) (P)	> 5,0	< 5,0	-	-
Available potassium (mg/100g soil) (K)	>7,0	<7,0	-	-

F0: no floods; F1: a land is often flooded for a period of no longer than 1-2 months; C: clay; CL: clay loam; SCL: sandy clay loam; SL: sandy loam; LS: loamy sand; D1: well; D2: moderate; D3: Imperfect; D4: Poor

3.2. Land suitability of the Thanh Hoa-Nghe An mountainous region

The results of analyzing land suitability for orange cultivation showed that the very suitable lands (S1) were distributed primarily in three communes of Nghe An, including Quy Hop, Tan Ky, and Nghia Dan, and four communes of Thanh Hoa, including Thach Thanh, Cam Thuy, Ngoc Lac, and Nhu Xuan (Fig. 6a). The very suitable lands (S1) and moderately suitable lands (S2) were 169,916 ha (7.8%) and 412,519 ha (19%), respectively. On the other hand, the unsuitable lands (N) accounted for 867,203 ha (39.9%) (Table 3). The limiting factors that were disadvantageous for orange cultivation consisted of slopes above 30°, soil depth below 50 cm, flooded or poorly drained lands, pH below 0.5, and OM below 0.8%.

Table 3. Results of the land suitability evaluation for LUTs

LUTs	Suitability class (ha and %)			
	S1	S2	S3	N
Orange	169.916	412.519	622.689	867.203
	7,8	*19,0*	*28,6*	*39,9*
Banana	201.166	350.999	1.195.948	324.214
	9,3	*16,1*	*55,0*	*14,9*
Tea	107.636	579.823	826.074	558.795
	5,0	*26,7*	*38,0*	*25,7*
Turmeric	570.744	262.814	744.880	493.890
	26,2	*12,1*	*34,3*	*22,7*
Cinnamon	233.987	652.407	509.654	676.281
	10,8	*30,0*	*23,4*	*31,1*
Chinaberry	633.306	241.861	867.971	329.190
	29,1	*11,1*	*39,9*	*15,1*
Chukrasia	280.704	651.487	780.824	359.314
	12,9	*30,0*	*35,9*	*16,5*

For banana cultivation, the very suitable lands (S1) were distributed in four communes of Nghe An, including Nghia Dan, Thai Hoa, Quy Chau, and Quy Phong, and three communes of Thanh Hoa, including Cam Thuy, Ngoc Lac, and Thuong Xuan (Fig. 6c). These areas occupied 201,166 ha, corresponding to 9.3% of the region's total area. The essential factors in determining type S1 consisted of well-drained soils, no flooding, pH ranging from 5.6-7.5, a slope of 0-8°, soil depth above 100 cm, and soil texture of clay loam. In addition, the mean annual temperature suitable for growing bananas ranges from 18 to 24°C, the yearly precipitation is higher than 1500 mm, and the dry season is shorter than 3 months.

Generally, the study area is relatively suitable for tea cultivation (Camellia Sinensis). The very suitable lands (S1) and the moderately lands (S2) were 107,636 ha (5%) and 579,923 ha (26.7%), distributed in Thanh Chuong, Anh Son, and Tan Ky of Nghe An, and Thuong Xuan, Ngoc Lac, and Thach Thanh of Thanh Hoa (Fig. 6b). The very suitable lands (S1) are presented mainly in the distribution of Acrisols and Fluvisols. Tea cultivation also requires suitable annual precipitation, slopes, soil depth, and pH.

Yellow turmeric (Curcuma longa) can be grown under the canopy of forests or during intensive farming periods. The study identified very suitable lands (S1) for this specialty plant with 570,744 ha (26.2%), distributed mainly in four communes of Nghe An (Tan Ky, Con Cuong, Anh Son, and Quy Chau) and three communes of Thanh Hoa (Ngoc Lac, Cam Thuy, and Thuong Xuan) (Fig. 6d). The land

units that favored the cultivation of yellow turmeric were composed of well-drained soil, no flooding, and a texture of clay loam (CL), sandy clay loam (SCL), and sandy loam (SL) soils. Yellow turmeric also required specific slopes of 0-8°, soil depth above 70 cm, a pH of 5.8-7.0, and CEC above 40.0 cmol (+)/kg of clay for the best productivity. In addition, the suitable annual mean temperature ranged from 22 to 24°C under conditions of precipitation less than 1500 mm and a dry season length of fewer than 3 months.

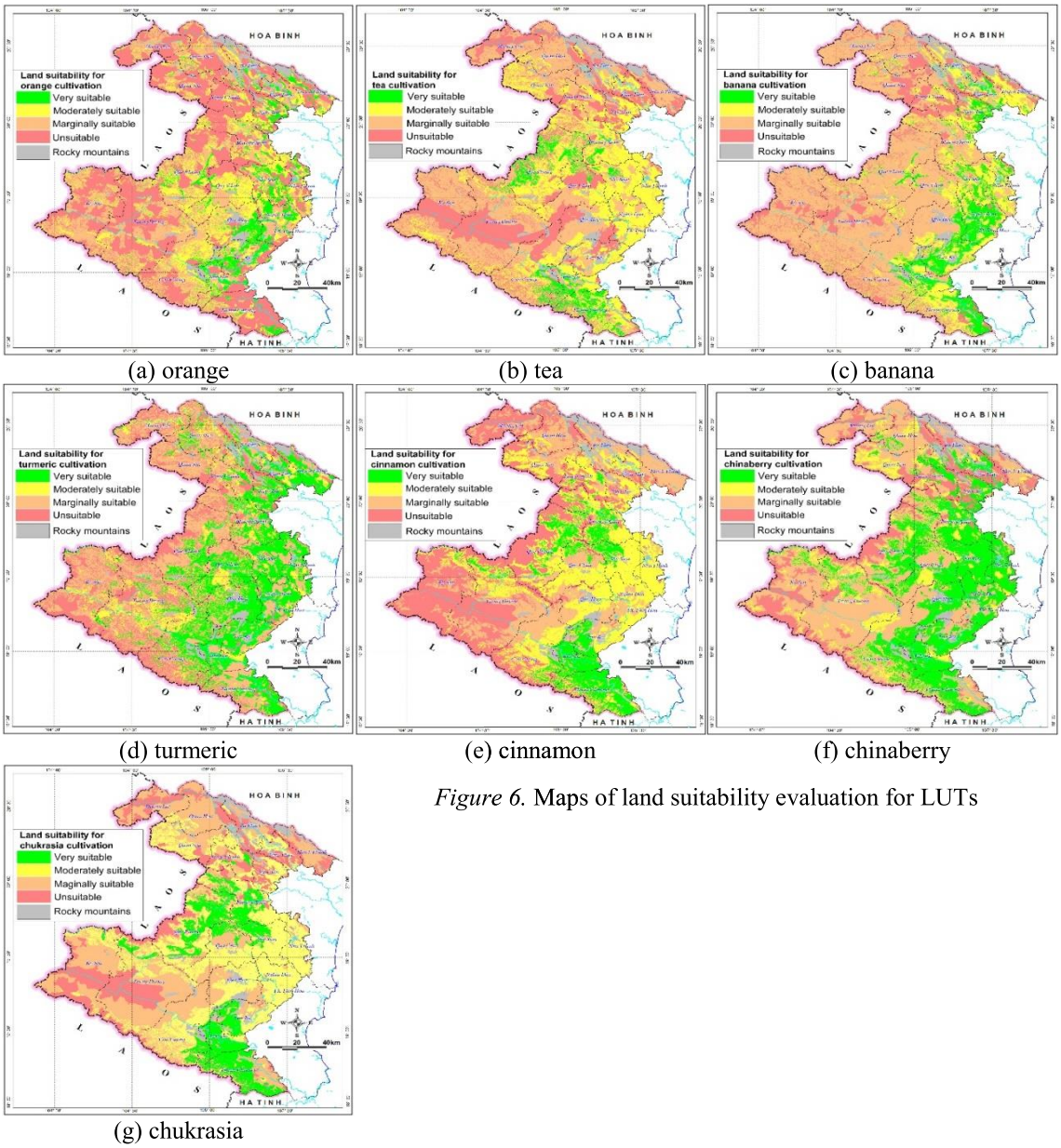

Figure 6. Maps of land suitability evaluation for LUTs

Cinnamon (Cinnamonum verum) is a versatile industrial and does not require rigorous conditions for living. The growth of cinnamon is favored when cultivation stably

focuses on a specific area. The suitable lands (S1) for cinnamon cultivation were distributed in Thanh Chuong, Anh Son, Quy Chau, Tan Ky, Que Phong of Nghe An, and Nhu Xuan, Thuong Xuan of Thanh Hoa. Those communes are the origins of the illustrious brands "Que Thanh" (Thanh Hoa Cinnamon) and "Que Quy" (Quy Chau Cinnamon). The "moderately suitable" (S2) lands were identified in Tan Ky, Nghia Dan, Quy Chau, Quy Hop of Nghe An, and Nhu Xuan, Nhu Thanh, Thuong Xuan of Thanh Hoa (Fig. 6e). The S1 and S2 areas occupied 233,987 ha and 652,407 ha, respectively, corresponding to 10.8% and 30.0% of the total area.

For chinaberry (Melia azedarach) cultivation, the suitable lands (S1) were relatively large, with 633,306 ha, corresponding to 29.1% of the total study area. These land units consisted of well-drained soil, no flooding, slopes below 15°, and soil depth above 70 cm. They were within the altitudes of 0-500 m. The soil texture was sandy clay loam (SCL) and sandy loam (SL). The communes that possess S1 lands included Anh Son, Nghia Dan, Tan Ky of Nghe An and Nhu Xuan, Nhu Thanh, and Thuong Xuan of Thanh Hoa. The moderately suitable lands (S2) occupied 33.6% (730,791.4 ha) with a 50-70 cm soil depth, 15-25° slopes, etc.

Chukrasia (Chukrasia tabularis) is a native tropical forest tree in Vietnam with a wide ecological threshold. The timber of chukrasia is considered a precious forestry product. The very suitable lands (S1) for chukrasia cultivation were located in five communes of Nghe An (Quy Chau, Tan Ky, Nghia Dan, Thanh Chuong, Con Cuong) and three communes of Thanh Hoa (Nhu Xuan, Nhu Thanh, Thuong Xuan) (Fig. 6g). The unsuitable lands (N) for chukrasia's growth consisted of factors outside its ecological threshold. Remarkably, they were slopes above 35°, poorly-drained soil, overly acidic or alkaline soil pH (< 4.0 or > 7.0), and an altitude above 1500 m.

3.3. Estimated economic efficiency of some ecological models

From the results of field surveys and land suitability analyses, this study designed and estimated the economic efficiencies of three types of economic models with six formations for the Thanh Hoa - Nghe An mountainous region. Calculations showed that models number 02 and 03 resulted in the highest total profits with 523.14 million VND and 503.7 million VND, respectively. Model 05 generated a moderate profit, but the best ratio between the total profit and total cost (R) as the investment required for this model was much less than its total revenue. Model 04 bred the lowest profit (332.77 million VND), but on the other hand, it utilized idle labor forces and promoted traditional originalities of the region. The detailed economic efficiencies of the studied ecological models were as follows:

3.3.1. Forest-Garden-Barn (F-G-B models)

This type of model consisted of "forest," "garden," and "barn" as components on an average scale of 5-7 hectares. More specifically, the regular source of income was from orange gardens and livestock barns. Long-term profits came from forestry plants such as chinaberry and chukrasia. In the forest component, the cultivation of chinaberry and chukrasia resulted in R-values of 1.74 and 1.33, respectively. However, the harvest periods would take a long time (10-20 years). The first timber could only be obtained after thinning in the 7th or 8th year. This type of model combined the specialty plant and another plant for timber with shorter harvest periods like Acacia species to build up the forest component, securing incomes from forestry for households. For the garden component, the design with orange cultivation offered substantial annual values of the total revenue and total profit. Nevertheless, it would require much investment in materials and labor (Table 4).

Table 4. The economic efficiency of Forest-Garden-Barn models

Component	Variable	Quantity	LC	TC	TR	TP	R
			Million VND				
Model 1							
Forest	Chinaberry (10 years)	800 plants/ha	24,15	25,87	123,40	97,53	1,74
	Acacia tree (6 years)	800 plants/ha	22,63	26,45	86,67	60,22	0,83
Garden	Orange (10 years)	01 ha	135,90	181,03	396,00	214,97	0,85
Barn	Chicken	50 units	4,50	6,50	19,80	13,30	2,05
	Pig	10 units	13,50	32,50	85,50	53,00	1,63
Total			200,68	272,35	711,37	439,02	1,61
Model 2							
Forest	Chukrasia (20 years)	500 plants/ha	23,93	25,74	159,50	133,76	1,33
	Acacia tree (10 years)	1000 plants/ha	24,13	28,32	108,33	80,01	1,29
Garden	Orange (10 years)	1 ha	135,90	181,03	396,00	214,97	0,85
Barn	Chicken	50 units	4,50	6,50	19,80	13,30	2,05
	Goat	10 units	13,50	35,90	117,0	81,10	2,26
Total			201,96	277,49	800,63	523,14	1,88

3.3.2. Garden-Barn-Handicraft models (G-B-H model)

This type of model was composed of "garden," "barn," and "handicraft." The garden and barn components were on a small scale of 1-3 hectares, often aligned with rural populations. The handicraft component referred to a local occupation of Banh Da (rice wrapper) making or brocade textile making. Model 03 resulted in a good profit of 503.7 million VND. Nevertheless, it required many labor forces, for the incomes were mainly from Banh Da making. The profit of model 04 was lower (332.77 million) due to the substantial investment required for orange cultivation, which was the primary income of this model (Table 5). Although model type G-B-H's total revenue and ratio R were less than those of the F-G-^{B} models, its realistic values would be higher due to the smaller area required for implementation.

Table 5. The economic efficiency of Garden - Barn - Handicraft models

Component	Variable	Quantity	LC	TC	TR	TP	R
			Million VND				
Model 3							
Garden	Banana	01 ha	14,78	41,25	116,67	75,42	1,84
Barn	Chicken	50 units	4,50	6,50	19,80	13,30	2,05
	Pig	10 units	13,50	32,50	85,50	53,00	1,63
Handicraft	Banh Da (rice wrapper)		162,00	178,02	540,00	361,98	2,03
Total			194,78	258,27	761,97	503,7	1,95
Model 4							
Garden	Orange (10 years)	01 ha	135,90	181,03	396,00	214,97	0,85
Barn	Chicken	50 units	4,50	6,50	19,80	13,30	2,05
	Goat	10 units	13,50	35,90	117,0	81,10	2,26
Handicraft	Brocade textile		27,00	48,6	72,0	23,4	0,48
Total			180,90	272,03	604,8	332,77	1,22

3.3.3. Garden - Forest models (G-F models)

The garden component of this type consisted of diverse plants, including yellow turmeric, banana, tea, and orange (Table 6). Among those, the cultivation of yellow turmeric yielded the highest R-value (4.0) because of its substantial revenue, affordable costs, and short cultivation periods. In the

forest component, cinnamon also resulted in a desirable economic efficiency with an R of 5.45. This is because the cinnamon provides consumable bark from the 4th year on. Furthermore, cinnamon timber, collectible after the 15th year, is a valuable commodity on many markets. As a model employing both yellow turmeric and cinnamon, the economic efficiency of model 05 excelled with a profit of 374.94 million VND. As for model 06, although it had a higher total profit than model 05, its total cost and labor cost were huge (308.35 million and 224.98 million, respectively).

Table 6. The economic efficiency of Forest-Garden models

Component	Variable	Quantity	LC	TC	TR	TP	R
			Million VND				
Model 5							
Forest	Cinnamon (15 years)	2500 plants/ha	15,32	16,39	123,91	107,52	5,45
Garden	Yellow turmeric	01 ha	37,80	48,00	240,00	192,00	4,00
	Banana	01 ha	14,78	41,25	116,68	75,42	1,84
Total			67,90	105,64	480,59	374,94	3,54
Model 6							
Forest	Chinaberry (10 years)	800 plants/ha	24,15	25,87	123,40	97,53	1,74
	Acacia tree (6 years)	800 plants/ha	22,63	26,45	86,67	60,22	0,83
Garden	Tea (10 years)	01 ha	42,30	75,00	130,41	55,41	0,64
	Orange (10 years)	01 ha	135,90	181,03	396,00	214,97	0,85
Total			224,98	308,35	736,48	428,13	1,39

4. Discussions

The selection of diverse LUTs and LURs for each LUT in land suitability evaluation yielded promising perspectives. This is the exact and detailed answer for "what plant/livestock to farm," which is firmly associated with poverty reduction and sustainable socio-economic development. In reality, land exploitation in the Thanh Hoa - Nghe An mountainous region has relied only on experience from production. There has yet to be a full scientific foundation. Some studies have grouped LUTs according to common traits and consequently analyzed the corresponding LURs. This resulted in overly generalized evaluations, consequently leading to application difficulties and inaccuracy as limiting factors of individual LUTs were neglected in groups. As a result, farmers and managers alike struggled to distribute land resources for agricultural products with competitive advantages. Moreover, cultivation activities became petty "movements." The direction mentioned above research creates a new approach to the territorial organization of agricultural production for researchers and managers.

In terms of methodology, the proposal of land use is more effective and optimal when land suitability evaluations are supplemented with the economic efficiency of various ecological models. Because previous individual studies did not provide adequate and synchronized information, how can LUTs be combined, and how effective can this combination be predicted? Outcomes from land suitability assessment and land use proposal indicate that the application of a GIS is necessary as it can process big data and result in reliable conclusions.

This study proposed agricultural land use orientation for the mountainous region of Thanh Hoa and Nghe An. The proposal includes six types of prioritized areas associated with ecological-economic models, which are well demonstrated on the 1:100,000 map (Fig. 7) and the statistics (Table 7). Those areas were deduced from suitability assessment, land use, and experience from

production. The areas with usage in the present are considered suitable; no change is needed. Plants of orange, banana, and turmeric with high economic values should be the priority, followed by forestry plants of cinnamon, chinaberry, and chukrasia. The order of priority for cultivating plants is: Only grow orange and cinnamon in very suitable lands (S1); Grow tea, banana, and turmeric in areas with very suitable lands (S1) and moderately suitable lands (S2); Slope-tolerant forestry plants with wide ecological thresholds can be grown on marginally suitable lands (S3).

- Areas prioritized for biodiversity preservation: These areas consist of extreme-security natural reservations and national parks responsible for preserving landscapes, wild populations, and genomic resources. A few environment-friendly activities allowed in these areas include ecological tourism, scientific research, and environmental training and education.

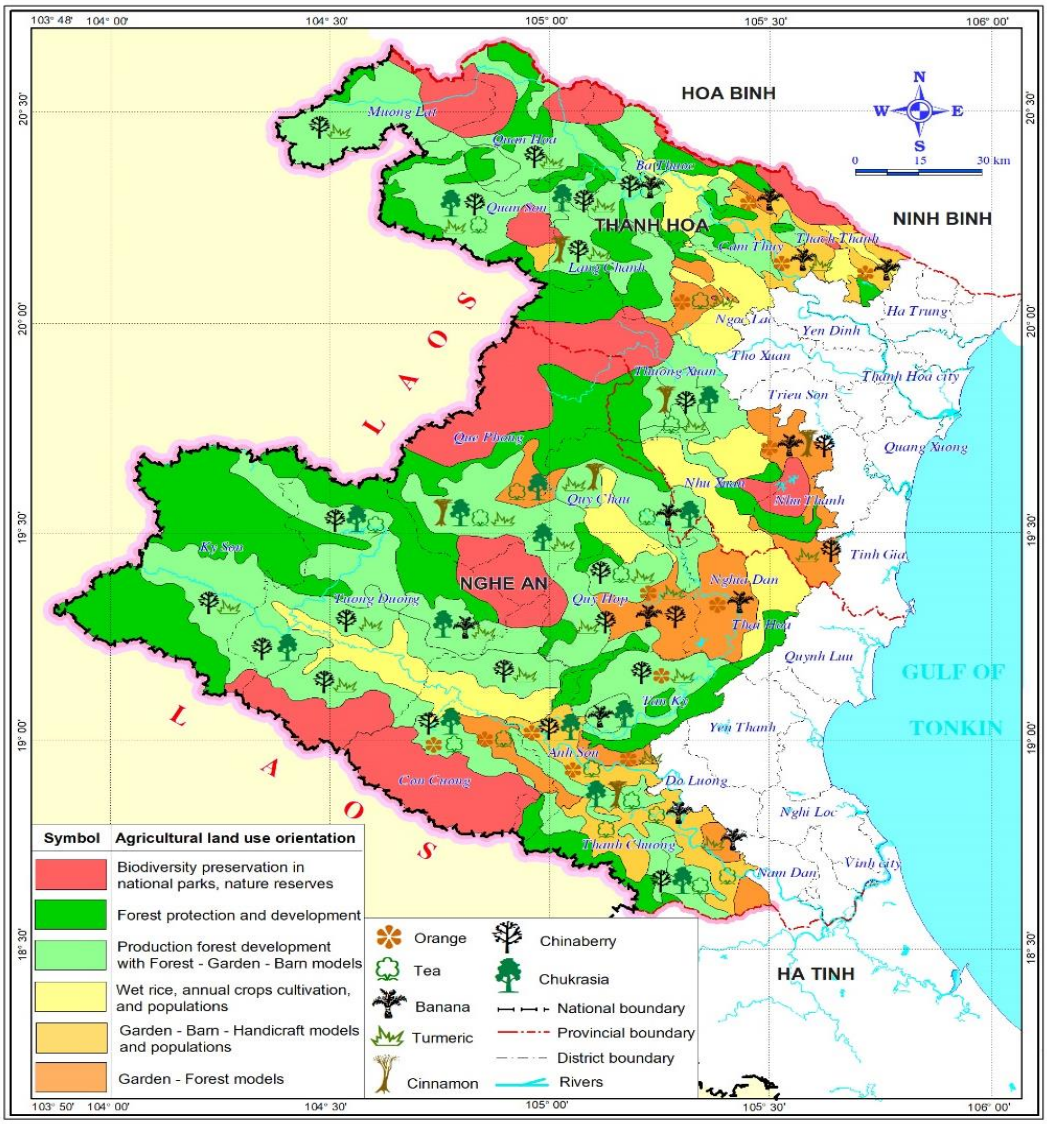

Figure 7. Map of proposed agricultural land use

Table 7. Land use orientation for the mountainous region of Thanh Hoa and Nghe An

No.	Proposed land use	Land utilization type	Distribution (commune)
1	Biodiversity preservation	Natural reservation	Muong Sai, Pu Huong, Xuan Lien, Xuan Nha, Pu Luong, Ngoc Son
		National Park	Cuc Phuong, Pu Mat, Ben En
		Landscape reservation	Ngoc Trao, Lam Son
2	Forest protection and development	Protection forest	Ky Son, Que Phong, Thuong Xuan, Quan Hoa, Lang Chanh
3	Developing wet rice, annual crops, and populations	Wet rice and annual crops cultivation	Nhu Xuan, Ngoc Lac, Nghia Dan, Ca river valley (Tuong Duong, Con Cuong)
4	Garden - Barn- Handicraft models and populations	Banana garden + Livestock barn + Handicraft	Thanh Chuong, Thach Thanh
		Orange garden + Livestock barn + handicraft	Quy Hop, Anh Son, Nghia Dan
		Tea garden + Livestock barn + Handicraft	Con Cuong, Anh Son, Thanh Chuong
5	Garden - Forest models	Orange garden + Timber forest (chukrasia, chinaberry x Acacia spp.)	Quy Hop, Tan Ky, Con Cuong, Anh Son
		Tea garden + Timber forest (chukrasia, chinaberry x Acacia spp.)	Con Cuong, Thanh Chuong, Anh Son
		Banana garden + Timber forest (chinaberry, chukrasia x Acacia spp.)	Thach Thanh, Thanh Chuong
		Turmeric garden + Chinaberry forest	Muong Lat, Quan Son, Tuong Duong
6	Development of production forest and Forest - Garden - Barn models	Cinnamon x acacia spp. forest + Turic garden + Livestock barn	Que Phong, Thuong Xuan, Lang Chanh
		Chukrasia x acacia spp. Forest + Garden (orange, tea, banana) + Livestock barn	Anh Son, Thanh Chuong, Tan Ky, Thuong Xuan
		Chinaberry x acacia spp. forest + Turmeric garden + Livestock barn	Muong Lat, Tuong Duong, Ky Son

- Areas prioritized for the protection and development of forests: These areas are oriented to protect forests in upstream regions, which are sloped terrains. They are responsible for critical ecological roles such as regulating water resources, covering land, preventing erosion, and conditioning the climate. Except for timber, protected forests can also provide livelihoods with forest-environmental services and forestry production.

- Areas prioritized for the development of production forest and F-G-B models: These areas are present in the communes of Muong Lat, Anh Son, Tuong Duong, etc. As the primary component, forests can reference the formations of mixed forests and alternated forests to cultivate long-term chinaberry and chukrasia associated with shorter-term timber plants (Acacia species) or annual plants and pharmaceutical herbs. The garden component is designed flexibly with fruit plants and perennial industrial plants such as oranges, bananas, and tea. Livestock barns can consider farming poultry and cattle in large quantities.

- Areas prioritized for the development of G-F models: The purposes for these areas have been designed in alignment with local terrains, household scales, productivity, and demanding markets. Most of these areas are gardens with orange, banana, tea, and turmeric. Forestry plants in the forest component can be grown singly or alternately with other species. Additionally, the lower level under forest canopies should be maintained to protect against land erosion. Mainly, this level can be used to grow short-term cereal plants, shade-tolerant, humidity-loving pharmaceutical plants, and alternate plants.

- Areas prioritized for developing G-B-H models and populations: These areas are distributed at land units with relatively flat terrains, which are advantageous for agriculture and perennial people. Nevertheless, they are relatively small due to their locations in rural regions, land already used for household purposes, and land for perennial plants. The design of these gardens can also incorporate agricultural cultivation with business forms or ecological tourism to elevate the profit. Simultaneously, the diversification of products from livestock farming and handicrafts can certainly contribute to the local livelihoods.

- Areas prioritized for developing rice, annual crops, and populations: The land units for this purpose possess components including slopes below 15o and a soil type of fluvisols or dystric gleysols. Although the cultivation of these types faces difficulties in water shortage and cultivation techniques, it still plays a crucial role in food security. As a result, this region of Thanh Hoa and Nghe An needs to maintain and stabilize the areas of rice and annual crops.

5. Conclusions

The study has selected and assessed land suitability for seven LUTs for the Thanh Hoa - Nghe An mountainous region, which included: Orange, banana, tea, yellow turmeric, cinnamon, chinaberry, and Chukrasia cultivation. The evaluation process applied 15 criteria for the assessment of orange cultivation and 10-12 criteria for assessing other LUTs. By using TCVN-8409:2021, the total area of very suitable lands (S1) for the seven LUTs were: 169,916 ha (7.8%) for orange; 201,166 ha (9.3%) for banana; 107,636 ha (5.0%) for tea; 570,744 (26.2%) for yellow turmeric; 233,987 ha (10.8%) for cinnamon; 633,306 ha (29.1%) for chinaberry; and 280,704 ha (12.9%) for Chukrasia. From the land suitability, the study deduced the applicability of three ecological models, including the Forest - Garden - Barn (F-G-B) models, the Garden - Barn - Handicraft (G-B-H) models, and the Garden - Forest (G-F) models. Economic efficiency calculations indicated that the F-G-B and G-B-H models offered the highest total revenue, cinnamon and yellow turmeric resulted in the highest ratio between the total profit and the total cost as their required investment were low, and orange was the most profitable plant but with the huge investment required.

The study demonstrated land usage orientation based on land suitability for specialty plants and economic efficiency. The prioritized areas for economic development and environmental protections have been displayed on the 1:100,000 agricultural land usage proposal map for the mountainous region of Thanh Hoa and Nghe An. The results of this study are also valuable recommendations for land usage plans and the determination of areas that should prioritize the cultivation of local specialty plants. In addition, this study contributes to building a standard procedure for evaluating agricultural land in mountainous regions for sustainable development.

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