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An Analysis of Land Use Options using CLUMondo Model to Promote Agricultural Restructuring in the Mekong Delta's Coastal Area in Vietnam

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ABSTRACT

Background: Climate change, socioeconomic, market demands and labor restructuring have led to the need for agricultural restructuring in coastal areas in Vietnam. This study was conducted to assess the factors affecting agricultural production and analyze land use scenarios to support the agricultural transformation in the coastal area of the Vietnamese Mekong Delta.

Methods: The implementation method is based on surveying the necessary dynamic level of socioeconomic and environmental factors affecting land use; the connection between the land area optimization using linear programming and the CLUMondo.

Result: The results proposed 3 scenarios to improve the efficiency of state land management for socioeconomic development and agricultural restructuring in the study area. Scenario 1 (the land-allocated results were similar to the land use map) and scenario 2 (extensive shrimp farming areas in the coastal zone will be firmly converted to intensive shrimp farming) are suitable for the district in the short term. However, Scenario 3 (the shrimp-rice area tends to convert to rice land, while agricultural land near the town will be firmly converted to non-agricultural land) is the most appropriate option when funds are available for high technology advancement.

Key words: CLUMondo, Land use, Optimization, Planning, Restructuring.

INTRODUCTION

In recent years, socioeconomic development, population growth and human activities have put increasing land resources pressure (Bandyopadhyay *et al*., 2009). The transformation of land use pattern has been affected by the interaction of many economic, social and environmental factors at many levels and spatial scales (Lambin and Geist, 2007). Many reports and scientific evidences have shown that the Mekong Delta is one of many areas, most heavily affected by climate change and sea level rise (IPCC, 2007). The abnormal changes in natural conditions especially acidified soil, saline intrusion, water quality and environment deterioration are significant complex issues for the land use types (Kam *et al*. 2006). In addition, market price fluctuations are also high potential risks affecting the effectiveness of the farming systems (Ustaoglu *et al*., 2016).

Forecasts for Land use changes are becoming more accurate thanks to contemporary simulation technology. The CLUMondo model is recognized as an excellent tool for simulating land use changes (Zhang *et al*., 2013). The working principle of the CLUMondo model (Verburg and Veldkamp, 2004) is based on empirical analysis of the dynamics and competition of spatial dynamics of land use systems to dynamically simulate land use (Arunyawat and Shrestha, 2018).

Hon Dat District is a coastal district belonging to Kien Giang province, one of the Vietnamese Mekong Delta's most considerable acid-sulfate soil. Farmers mainly live by paddy cultivation and aquaculture. However, the district's agricultural production has low efficiency and is highly dependent on natural conditions. It is also a general situation in many other areas in the Mekong Delta (Tuan and Dung, 2015).

This study's objectives aim to (1) propose a process to support agricultural land use planning by combining optimizing socioeconomic and environmental factors and the CLUMondo model, (2) apply the results of linear optimization as input to the CLUMondo model, (3) improve the efficiency of state land management for socioeconomic development and agricultural restructuring to assist planners in determining the criteria of the land use area and spatial distribution for suitable agricultural development.

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MATERIALS AND METHODS

The research method, as shown in Fig 1, consists of 3 steps: (1) Data collection; (2) agricultural land use optimization and (3) land use allocation using the CLUMondo model. In this diagram of research from Fig 1, socioeconomic and environmental factors affecting land use change are collected and analyzed quantitatively to serve as a basis for determining the required area of each type of land during the planning period. A single-objective optimization method was performed to determine the optimal area of each land use type to achieve the goal of maximum profit and ensure socioeconomic constraints. Finally, the optimal area of each land use type is used as the required area to implement the land allocation using the CLUMondo models.

Data collection and processing

The data used in the study area was collected from a variety of sources during the periods from 2019 to 2021, including: The geographical basis layers and land use map in 2019 of Hon Dat district (DONRE of Kien Giang, 2021).

The land cover data of Vietnam in 2020 provided by the Japan Aerospace Exploration Agency (JAXA) with a 30-meter spatial resolution (JAXA, 2022). Through field surveys and working with the local government staff, the land cover has been adjusted and established to be the layer of current agricultural land use for Hon Dat District in 2020.

The soil layer was built from the data of the Department of Land Resources (LRD-CTU, 2021).

Topographic slope data was processed and mapped based on data collected from NASA (NASA, 2013).

Population density data were processed based on World Pop data sources (Worldpop, 2013).

These data were converted in raster format, adjusted to be the same scale and same coordinate system and unified processing and management through QGIS software.

In addition, 16 agricultural managers at district and commune levels were also interviewed through a 5-level Likert scale questionnaire on socioeconomic factors affecting agricultural production models used for the optimization of agricultural land.

Land use optimization method

Based on the driving factors of the collected socioeconomic data source, the land use types area for the planning period will be determined based on the single-objective linear optimization method (Dantzig and Thapa, 2003). The optimization model of this study was based on the Solver module on the Excel software.

Objective function

The objective function was determined based on the orientation of land use. In this study, the objective function (Equation 1) was selected as the area of the land use types most suitable to natural conditions and maximized profit.

$$\max: \sum_{i=1}^{n} P_i X_i \quad (1)$$

In which:

X_i: Optimal area of land use type i.

Where,

$i \in [1, n]$ are the land use types.

P_i: Profit of land use i per hectare per year.

Constraints for the optimal model

The total area of LUTs in a suitable area must be less than or equal to the agricultural cultivation area shown in the system of inequality (2).

$$\sum_{i=1}^{n} X_i \leq \text{Agricultural area} \quad (2)$$

The total number of working days required by LUTs should be less than the total number of working days from the number of workers in the district.

$$\sum_{i=1}^{n} \text{Labour}_i X_i \leq \text{Total\_labor\_available} \quad (3)$$

Constraint, the maximum total output of each agricultural product, is defined in Equation 4, specifically in the study is the production expected of rice and shrimp.

$$\sum_{i=1}^{n} \sum_{k=1}^{m} X_i Y_{ik} \leq \text{Total\_Product}_k \quad (4)$$

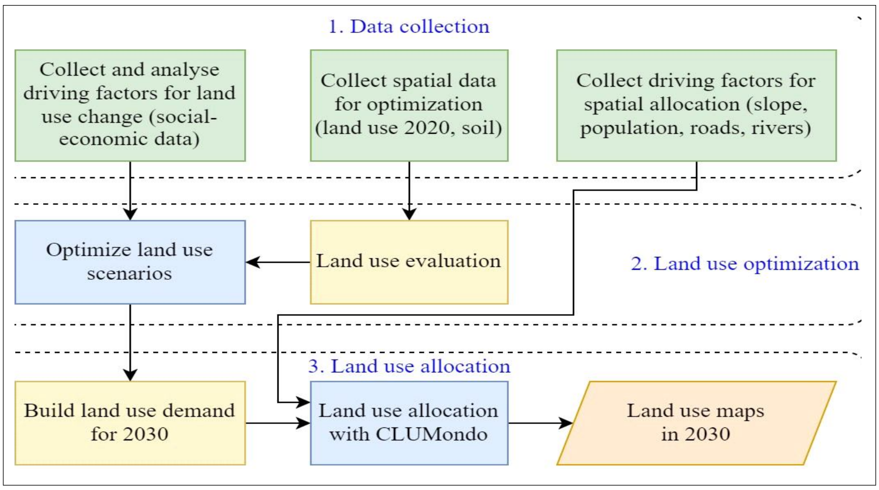


Fig 1: Research method diagram.

Y_{ik}: Yield of product k of land use type i.
i ∈ [1, n] are the land use types.
k ∈ [1,m] (Products).

Scenarios for agricultural land use

There are 3 land use plans proposed with the following assumptions: In the scenarios, the capital requirement does not exceed the current land use investment of the land use types. Agricultural products from production systems meet the demand of the market.

- **Scenario 1:** Was built according to local government planning (Hon Dat P.C., 2020). This scenario emphasizes promoting agricultural production towards the science and technology application and forest conservation.
- **Scenario 2:** Was based on optimizing agriculture's local area to get the maximum benefit from the current farming techniques and expected agricultural production.
- **Scenario 3:** According to scenario 2, improved farming techniques will be applied for better profit.

Method for land use allocation

The spatial distribution of agricultural land use types is simulated through the CLUMondo model (Verburg and Veldkamp, 2004). The inputs are the current land use map, the boundary map and the land use area demanded by simulation from the land use optimization process. The location parameters for the model in this research are chosen as follows: distance to roads, freshwater availability, salinity persistence, distance maps to rivers, soil, slope and population density. These parameters and land use conversion ability matrix are based on local experts in agriculture for calculating the regression between each land use type in the CLUMondo model.

RESULTS AND DISCUSSION

Current agricultural land

Hon Dat is a purely agricultural district with a total agricultural area of 98.480 ha, which accounts for 94.79% of the natural area of the community. The double rice crop model is the most significant area, with an acreage occupying 68.22% of the entire agricultural region. Although it is located on the coastline, the arable land area, according to the saline conditions, is relatively small, a percentage of only 3.26% compared to the total agricultural land use area (Table 1). The total agricultural land area of the district is 103,896; the total capital is 3,858 million VND. However, in the future, land use for agriculture models will be significantly affected by sea level rise and salt intrusion (Vu *et al.*, 2017).

Driving factors affecting agricultural land uses

The results of the expert opinion survey on factors affecting agricultural production in Hon Dat district are shown in Table 2. Economic and environmental factors play a more decisive role than social factors.

However, when considering factors at level 2, the most concerning ones were the consumption market, profit for the farming system, the capital capacity of the household and farming techniques. The labor factor is the least concern

Table 1: Area of agricultural land use of Hon Dat District in 2020.

Farming model	Area (ha)	Per cent (%)
Double rice crop	67.183	68.22
Triple rice crop	4.513	4.58
Other agricultural	9.298	9.44
Shrimp rice	1.677	1.70
Shrimp farming	1.534	1.56
Forest	14.275	14.50
Total	98.480	100.00

Table 2: Driving factors affecting agricultural land use in Hon Dat District, Kien Giang province.

Level 1 elemental	Scores	Level 2 elemental	Scores
Economy	3.54	Market	3.91
		Profit	3.51
		Investment costs	3.25
		Benefit-cost	2.81
Society	3.01	Capital capacity	3.49
		Farming techniques	3.56
		Labor	1.59
Environment	3.42	Salinization	2.54
		Weather	2.91
		Alum	2.98
		Pandemic	2.82

Table 3: Socioeconomic survey on the farming systems in Hon Dat District.

Land use type	Current technology				Improved farming technique			
	Profit (million VND/ ha/year)	Production (tons/ha/ year)	Cost (million VND/ ha/year)	Labor (days/ ha/year)	Profit (million VND/ ha/year)	Production (tons/ha/ year)	Cost (million VND/ ha/year)	Labor (days/ ha/year)
Double rice crop	45.51	12.73	34.68	60	54.67	14.27	35.23	60
Triple rice crop	50.27	17.83	62.06	81	64.78	20.25	62.79	81
Shrimp rice	49.07	7.57;0.4	44.63	55	243.39	8.49; 2.4	86.10	84
Extensive Shrimp	48.36	0.68	29.84	61	299.16	4.08	170.04	90
Intensive shrimp	381.03	5.68	272.17	122	894.27	11.87	470.78	212

Note: 1 USD ≈ 23,450 VND. (Source: Survey data, 2022).

for Hon Dat district as most farming models are based on family labor. These models do not require too much labor in the era of science and technology development.

Regarding socioeconomic factors, Hon Dat District has two technical levels for agriculture production. Each technical level requires different investment opportunities and achieves financial returns. Table 3 shows that the higher the technical level, the more production costs will increase moderately, corresponding that the total income and profit will significantly increase due to the improved yield.

Land use optimization

In essence, a paradigm shift or the adoption of new technology is a process that is influenced by a variety of circumstances in order to realize the ultimate goal of profit or utility maximization. Three land use scenarios were optimized based on the production demanded by Hon Dat district until 2030, as shown in Table 4.

Land use allocation

Input data for the CLUMondo model

The spatial data of the land resources to serve the development of agri-land use scenarios in the study region were formulated, including land, water, traffic and population (Table 5).

The transformation matrix between land use types was built based on local perceptions for every use. Following dominant land use types and the actual assessment, the land use conversion matrix was prepared as Table 6.

Table 4: Land use demands of Hon Dat District up to 2030 are optimized for 3 scenarios.

Scenario	Production demanded	
	Rice (tons/year)	Shrimp (tons/year)
Current land use	948,401	3,333
Scenario 1	1,000,000	9,200
Scenario 2	972,534	17,950
Scenario 3	1,017,015	18,269

Regression analysis for land use allocation

The results of the logistic regression analysis on the CLUMondo model between each factor and each type of land use are shown in Table 7. The AUC value showed that all land use types have a very high reliability. Especially the Extensive shrimp farming land had the highest reliability with an AUC (Area Under the Curve) of 0.97, followed by the Intensive shrimp farming land with an AUC of 0.95. Other agricultural land had the lowest AUC (0.71). Shrimp-rice was not analyzed because it is a specific land use type regulated by district policy to protect the ecological environment. Therefore, it does not depend entirely on the location factor.

The difficulties encountered in previous studies on land use allocation after area optimization (Nguyen Hong Thao *et al*., 2019) were solved by the CLUMondo model, in-which the optimized area was used as input land use demand for the spatial distribution model CLUMondo. The transformation matrix and the conversion resistance coefficient were built for the whole district for the land use types in this research. However, on the overall scale, there are minor cases of conversion between resistance patterns due to changing adaptation conditions. Therefore, the conversion results can be improved by applying the algorithm to each sub-region (in terms of land units) to increase accuracy.

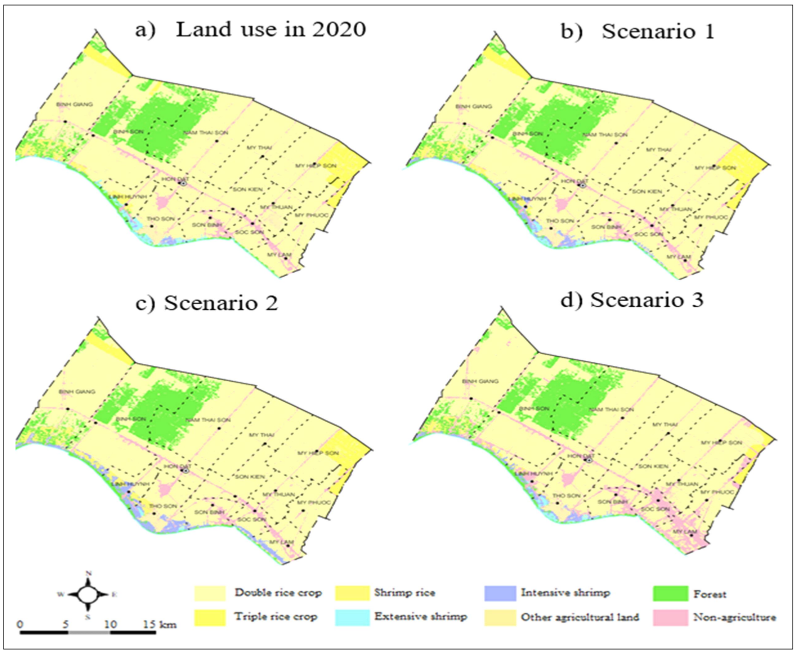


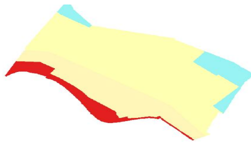
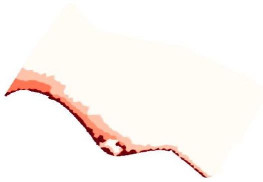
Fig 2: Spatial distribution of land use at differnce scenaios in the study area.

Agricultural land use scenarios

Based on the parameter built with the CLUMondo model for the study area, the required land use area was allocated for 2030.

Land use allocation of the three scenarios is shown in Fig 2. In Scenario 1 (Fig 2b), the land-allocated results were similar to the land use map in 2020 (Fig 2a). For Scenario 2 (Fig 2c), extensive shrimp farming areas in the coastal zone are firmly converted to intensive shrimp farming (communes Binh Giang, Binh Son, Tho Son, Linh Huynh and My Lam). Scenario 3 has the same trend of conversion of shrimp farming land, but the area of intensive shrimp farming is being converted more slowly than in Scenario 2 (Fig 2d). For Scenario 3, the shrimp-rice area tends to convert to rice land, while agricultural land near the town will be firmly

Table 5: Data layer on land resources in Hon Dat District.

Data layer	Display	Legend
Distance to the traffic systems: divided into 2 attributes, the distance less than 200m and greater than 200 m. It is a suitable distance for detecting the residential area because houses and orchards are close to the traffic routes.		< 200 meters > 200 meters
Fresh water availability: divided into 4 levels: all year round, 3-6 months, 6 to 9 months and no freshwater availability.		Whole year From 6 to 9 months From 3 to 6 months No fresh water
Saline intrusion duration: from the not salty areas to year-round salty.		365 days 0 days
Distance to the river: divided into 2 attributes, less than 100 m and greater than 100 m.		< 100 meters > 100 meters
Soil: divided into 7 main soil groups according to the FAO/WRB 2014 classification system.		SCjz GLqtin_jz GLntiodqtin_z GLntiodqtin GLntio GLptiodqtin_jz GLptiodqtin ATgl GLeu HSti PLha TCgl
Slope: divided into continuous values based on terrain elevation data.		73 meters 0 meters
Population density: divided into continuous values to show the different areas of population concentration in the whole district.		25.381435 people 0.396218 people

converted to non-agricultural land. The detailed land use regions of the 3 scenarios are shown in Table 8.

Table 8 shows that the area of agricultural land has changed significantly. In which the model of intensive shrimp farming in saltwater increases in all scenarios. It is consistent with the predicted natural conditions that will have many changes. In contrast, there is a downward trend in all scenarios of the triple rice crop. Except for scenario 3, which clearly depicts urbanization, the area of non-agricultural land has not changed in any of the other scenarios.

The production outputs of all scenarios are higher than the current ones. The rice and shrimp farming area is significantly increasing except for scenario 3. All scenarios have a total capital within the availability responsiveness of the farmer. Therefore, scenario 1 and scenario 2 are suitable for Hon Dat District in the short term. Scenario 1 is easier to implement than scenario 2 because the capital cost is not significantly different.

Table 9 shows that, in a longer time, in the condition of proactive production capital or additional capital support from other sources for farmers, scenario 3 is suitable for the district for improving the economic benefits. Moreover, this scenario yields high profits. Therefore, the economic input requirements are within the available potential of the community. Besides, applying the technology in agriculture brings increased productivity and reduces production costs and risks.

This study has proposed a solution to support the development of agricultural land use planning options for coastal areas based on land use optimization and spatial allocation in case of application in Hon Dat district, Vietnam. It is fulfilling limitations in the land use distribution in previous studies (Vu *et al*., 2017).

Table 6: Conversion matrix between land use types.

Land use type	Double rice crop	Triple rice crop	Other agricultural land	Shrimp -rice	Extensive shrimp	Intensive shrimp	Forest	Non agriculture	Conversion resistance
Double rice crop	1	1	1	1	1	1	0	1	0.8
Triple rice crop	1	1	1	1	0	0	0	1	0.7
Other agricultural land	1	1	1	1	1	1	0	1	0.7
Shrimp-rice	0	0	0	1	1	1	0	1	0.8
Extensive shrimp	0	0	0	1	1	1	0	1	0.7
Intensive shrimp	0	0	0	0	0	1	0	1	0.9
Forest	0	0	0	0	0	0	1	0	1
Non agriculture	0	0	0	0	0	0	0	1	1

Note: 1: Allow conversion, 0: Do not allow conversion.

Table 7: Regression coefficients of driving factors for land use change.

Land use type	Coefficient β_n							AUC
	Slope	Dist. to the closest road	Fresh water capacity	Dist. to the closest river	Population	Soil type	Salinity persistence	
Double rice crop	-0.054	0.000	1.035	-0.513	0.000	0.156	-0.017	0.92
Triple rice crop	0.000	0.000	-4.699	-0.692	0.000	-0.484	0.000	0.94
Other agricultural land	0.059	0.542	0.459	0.816	0.000	0.000	-0.003	0.71
Extensive Shrimp	0.000	0.000	4.938	0.000	0.157	-0.077	0.007	0.97
Intensive shrimp	0.000	0.883	0.000	0.000	0.000	0.000	0.014	0.95
Forest	0.000	-1.424	-0.786	0.000	-3.071	-0.048	0.012	0.92
Non agriculture	0.000	1.857	0.000	1.206	0.180	0.000	0.000	0.92

Note: (+): positive correlation, (-): negative correlation. 0.5 < AUC < 1.0.

Table 8: Land-use patterns in 2030 of 3 scenarios.

Scenario	Double rice crop (ha)	Triple rice crop (ha)	Other agricultural land (ha)	Shrimp-rice (ha)	Extensive shrimp (ha)	Intensive shrimp (ha)	Forest (ha)	Non-agriculture (ha)
Land use in 2020	67,183	4,513	9,298	1,677	1,213	321	14,275	5,416
Scenario 1	70,990	4,219	5,479	1,565	503	1,449	14,275	5,416
Scenario 2	69,520	4,065	5,552	1,928	112	3,011	14,275	5,433
Scenario 3	68,628	1,098	6,635	1,012	546	1,143	14,275	10,559

Table 9: Economic data of land use scenarios in 2030.

Scenario	Total capital (Billions VND/ha)	Profit (Billions VND/ha)	Rice production (tons/ha)	Shrimp production (tons/ha)	Area of rice and shrimp cultivation (ha)
Land use (2020)	2,808.7	3,547,9	948,401	3,319	74,907
Scenario 1	3,203.3	4,096,4	990,775	9,198	78,726
Scenario 2	3,572.5	4,615,8	972,064	17,950	78,636
Scenario 3	3,205.0	5,254,7	1,010,148	18,224	72,427

Note: 1 USD ≈ 23,450 VND.

The conversion trend from agricultural to non-agricultural land was evident in scenario 3. However, the process of converting from shrimp-rice to rice land in the results was still inaccurate because shrimp-rice farming needs to ensure factors adapting to the environment and policies that have not been analyzed in this study. Therefore, it can be improved in follow-up studies to integrate approaches in land use planning.

CONCLUSION

The study has proposed a process to support agricultural land use planning by combining optimizing socioeconomic and environmental factors and the CLUMondo model for the study area. The results have been demonstrated through 3 proposed scenarios: based on the local development orientation to 2030, profit optimization at the current technical level farming practices and profit optimization scenarios in case of farming techniques improvement. These three scenarios improve the efficiency of state land management for socioeconomic development and agricultural restructuring in the study area. In which, Scenario 1 and 2 are suitable for the district in the short term. However, Scenario 3 is the most suitable option when funding is available. The obtained results contribute additional ways to assist planners in determining the criteria of the land use area and spatial distribution for suitable agricultural development.

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