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Optimizing aquaculture land-use: A case study in Dam Doi district, Ca Mau province, Viet Nam

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ABSTRACT

Land-use planning for aquaculture in accordance with natural and socio-economic conditions in each locality is a necessity for the economic development of the region. This study aims to build a model to optimize the area of aquaculture land for the development of local aquaculture land-use plans. The implementation method relies on the land evaluation, as outlined by FAO (1981), and the linear optimization model. We built the model with the goal of optimizing profit, taking into account factors such as the suitability of the land, the capacity to utilize the land area, the constraints on the desired area of land-use types, labors, and local capital. We built and applied the model in the Dam Doi district of Ca Mau province, optimizing the area for five aquaculture land-use types: ecological shrimp, traditional extensive shrimp, extensive shrimp farming, intensive shrimp, and super intensive shrimp. The three optimal options proposed include: (i) no capital limit; (ii) a limited total investment capital of 4,000 billion VND; and (iii) a limited total investment capital of 3,500 billion VND. In particular, the plan to limit capital to 4,000 billion VND was in line with the district's investment capacity and conditions. The results are references for managers to analyze many solutions for local seafood production development.

1. INTRODUCTION

Aquaculture is an agricultural activity that makes up a large proportion of economic sectors in the coastal provinces of the Mekong Delta, accounting for 60% of exported seafood output (The Government of Vietnam, 2017). The predominant agricultural activity in the Mekong Delta is brackish water shrimp farming, which encompasses various farming methods such as ecological shrimp, traditional extensive shrimp, extensive shrimp farming, intensive shrimp, and super intensive shrimp. These methods vary depending on the production level and investment capital of the farmers. Therefore, the orientation towards developing appropriate types of aquaculture to help people increase their income, limit risks, and stabilize their lives is an urgent need for fisheries managers, especially in rural areas.

The linear programming method has widely supported the establishment of land-use plans, optimizing land-use to maximize profit under constraints of capital, labor, production, and ecological restrictions (Chuvieco, 1993; Mellaku et al., 2018). Multi-objective optimization studies such as cost minimization combined with maximum area of usage (Aerts et al., 2003; Truong et al., 2024) are used in a multi-objective environment.

Appropriate optimal objectives such as maximizing profits, labor costs, capital use efficiency, and land suitability have been established on each land mapping unit (LMU) (Vu et al., 2016, 2017). The advantage of these studies is to propose optimal areas for agricultural land-use types (LUT) based on socio-economic and environmental constraints on the characteristics of each LMU instead of the whole area (Quang et al., 2023) and provinces.

To set the limits for area optimization, Phinyoyang & Ongsomwang (2021) used Markov chains to predict land use demand for area optimization. When creating area limit equations, these chains, based on probabilistic data from the past, predict the demand area is a scientific solution. More consider, Sofi et al. (2015) relied on the market demand requirements of each crop (maize, wheat, pulse, rice). Since the upland crops share similar constraints, the authors have analyzed the primary economic ones rather than the environmental factors across the entire study area.

Aquaculture models also share a common characteristic in that they are largely unaffected by natural conditions, while socio-economic factors, such as capital, market demand, or policy (based on local authorities' desire to develop production), significantly influence the distribution of land. Thus, both environment and socio-economic should be taken into account.

Dam Doi is a coastal district located in the southeast of Ca Mau province, Vietnam. This district includes 15 communes and one town, with a population of 175,383 people (2020). With the advantage of being adjacent to the sea and having two typical saline ecosystems that allow favorable conditions for Dam Doi to develop diverse and abundant aquaculture, especially shrimp farming. The total area of aquaculture land is 57,900 hectares, accounting for 78% of the district's area. In general, studies with a variety of land-use types have not yet resolved specific issues for specialized aquaculture areas, including the optimal arrangement of aquaculture types with certain constraints on investment capital and local policies. The objective of the research is to develop a mathematical model to optimize the area of different types of aquaculture through constraints on the minimum and maximum area to be achieved, adjusted, and calculated. Arrange land in accordance with local capital investment capacity in the case of the application in Dam Doi district, Ca Mau province, Viet Nam.

2. MATERIALS AND METHOD

The research method is implemented as shown in Figure 1, which includes three blocks: input data, an optimization model, and output results. Input data for the optimization model includes base maps of soil type, acid sulfate depth, salinity, and persistent salinity. Besides, the land-use maps for 2015 and 2020 (People's Committee of Dam Doi District, 2015, 2020a) are collected as the basis of building optimization constraints.

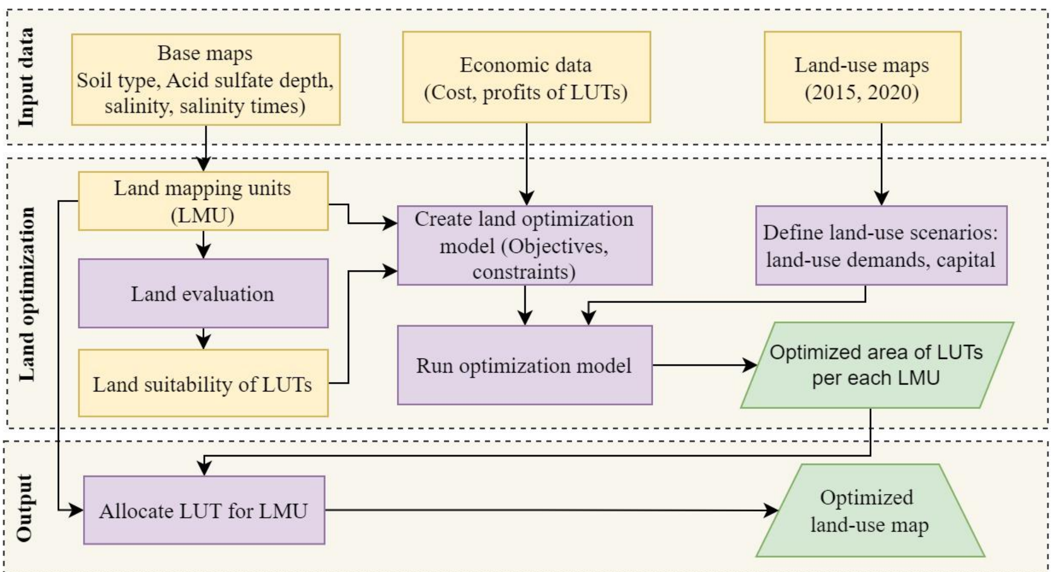

Figure 1. The research diagram

The base maps are overlaid in QGIS to build a land mapping unit (LMU) map for the study area. Based on LMUs, the land suitability of land-use types is conducted based on a land adaptation assessment according to (FAO, 1981) for the study area. The results of the land evaluation are used in the optimization model for optimizing the area of land-use types, which is built based on LpSolve 5.5 software (lp_solve, 2019) with constraints on adaptation levels, investment costs, and labor. Local initiatives and policies are introduced to the model in the required area according to local norms. The objective function and constraints are presented in detail in Section 2.3.

Based on adaptation inputs and local socio-economic development requirements, optimization plans are developed. The optimized area is arranged on land mapping units to produce a map of the options. Details of the methods are presented in the following sections.

2.1. Economic data collection

The total number of survey observations is 95 households for five main farming systems, including five households for the forest shrimp model and 5 for the super-intensive shrimp model due to the limited number of households in these systems, 30 samples for the extensive shrimp model, 30 for the improved extensive shrimp model, and 25 for the intensive shrimp model. Observations are randomly selected according to the list of households in the area. The main content of the semi-structured questionnaire survey is to learn about the lives of people in households in terms of socioeconomics and environment. where the focus is on evaluating the economic efficiency of land-use types.

Economic survey data, including profits and costs of land-use models, is statistically described as input for the shrimp farming land area optimization model.

2.2. Land evaluation

The adaptation hierarchy for LMUs is carried out for land-use types selected according to the natural land assessment method (FAO, 1981) with 4 adaptation levels (S1: highly suitable, S2: suitable, S3: marginally adaptive, and N: non-suitable). Suitability levels are standardized to serve as a basis for calculating productivity. Therefore, these values are normalized to 1, 0.67, 0.33, and 0, which correspond to adaptation levels N, S3, S2, and S1.

2.3. Land-use optimization

2.3.1. The objective function

The optimal model determines the area of different LMUs with an objective function that maximizes farming profits in a linear form as Formula 1.

$$Max: \sum_{i=1}^{n}\sum_{j=1}^{m} S_{ij}P_{ij}X_{ij} \quad (1)$$

where,
$i \in [1, n]$, and n is the number of land mapping units;
$j \in [1, m]$, and m is the number of LUTs

X_{ij} area of LUT_j in LMUi (unit: hectares).

S_{ij}: land suitability of LUTj in land mapping unit i. This value is normalized into 4 levels (0: Not adapted, 0.33: S3; 0.67: S2; 1.0: S1).

P_{ij}: Profit of LUT_j in land mapping unit i (unit: million VND/ha).

2.3.2. The constraints for optimization function

For each LMU, the total area of the LUTs must be less than or equal to the area of each LMU, as shown in the inequality system (2).

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} \leq \text{limited area of } LMU_i \quad (2)$$

The minimum and maximum area of land-use types desired by the locality (system of equations 3) for each type of agricultural product can be distributed.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} \geq \text{minimum area of } LUT_j$$
$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} \leq \text{maximum area of } LUT_j \quad (3)$$

The total labor demand of the LUTs cannot exceed the local agricultural labor resources. The total working days is based on the number of labor of the district in agricultural sectors.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} L_j X_{ij} \leq \text{Total working days} \quad (4)$$

In which, L_j: the number of working days of LUTj (days per hectare).

Total investment costs of land-use types (inequation 5) are less than or equal to total local investment capital.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} C_jX_{ij} \leq \text{total investment capital of district} \quad (5)$$

In which: Cj: Cost of LUTj (unit: million VND/ha). Total investment capital is determined as the total investment capital needed to deploy all types of uses, including people's capital, state infrastructure investment, and credit capital.

3. RESULTS AND DISCUSSION

3.1. Current land use and aquaculture activities in Dam Doi district

The agricultural land area of Dam Doi primarily focuses on aquaculture (People's Committee of Dam Doi District. (2020a). However, there was a decrease of over 735 hectares in the agricultural land area between 2015 and 2020 (People's Committee of Dam Doi District. (2015, 2020a). This decrease was attributed to the conversion of land use purposes to other types of land. Specifically, the area dedicated to aquaculture saw a sharp decrease of 4,714.5 hectares over the entire period, primarily due to the conversion of land for infrastructure construction and housing construction. On the other hand, due to the increased forest planting target, people increased forest planting rather than converting to shrimp farming.

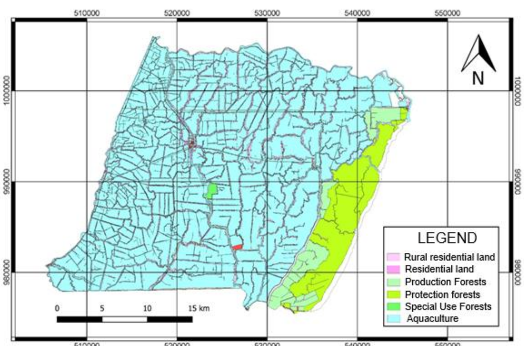

Figure 2. Land use map 2020 of Dam Doi district

(Source: People's Committee of Dam Doi District, 2020a)

During this period, there has been a tendency for the forestry land area to increase, rising from 5,900.2 ha in 2015 to 10,089.3 ha in 2020, an increase of 4,189 ha compared to the previous year. We can attribute the increase in this type of land area to an increase in the assigned forest planting target, a gradual increase in alluvial land area through inventory, and an increase in forest planting by individuals. The area of agricultural land in the district by 2020 is about 5,980.9 ha, a decrease of about 299 ha compared to 2015. The decrease in this land area can be attributed to the general trend of people converting their land for perennial crops to aquaculture land for shrimp farming or to residential land. According to the People's Committee of Dam Doi District (2020b), the district's aquaculture is still maintained with 5 main types: Traditional extensive shrimp farming (which can be combined with other aquatic species such as crab, fish, blood cockles, mussels, etc.), improved extensive shrimp farming, intensive shrimp farming, super-intensive shrimp farming, and shrimp-forest. In which: the area of extensive shrimp farming is decreasing, the area of improved extensive shrimp farming and the area of industrial shrimp farming are increasing, contributing to improving the productivity, quality, and efficiency of shrimp farming. Accordingly, the total aquaculture output in the 5 years of 2016–2020 reached 526,627 tons (an increase of 20.51% compared to the period of 2011–2015), of which shrimp were 256,180 tons. The total area for industrial shrimp farming is 2,244 ha, a decrease of 687 ha from 2015; this includes 1,099 ha for super-intensive shrimp farming and 42,000 ha for improved extensive shrimp farming, an increase of 10,000 ha from 2015. The area for shrimp farming—forest is 5,166 ha; many new production models bring high economic efficiency. However, besides economic achievements, environmental pressure in aquaculture, especially shrimp farming (intensive, super-intensive), has discharged large amounts of pollutants, causing great pressure on the natural environment. The profit of intensive and super-intensive shrimp farming is very high, so many households raise spontaneously, outside the planned area, not complying with environmental regulations. In addition, infrastructure is weak, resources are lacking and weak, the level of receiving and applying science and technology is limited, and the weather is unpredictable.

The characteristics and current status of land use and cultivated area in shrimp farming models serve as the basis for determining development indicators in building plans, which are then used to allocate these areas to the district for a 5-year cycle.

3.2. Economic factors influencing potential land-use types

Reorganizing production, choosing the type of production, and distributing and re-planning production areas more appropriately in order to promote the effective use of land potential in a reasonable way and preserve the ecological environment in a more appropriate manner is essential today. Based on the district's current land-use types, the natural environment, socio-economic conditions, and ecological conditions, we have identified five types of aquatic land-use types that are considered promising (Table 1).

Table 1. Prospective types of aquaculture farming

Code	Land-use type	Explanation
LUT1	Forest-shrimp	Ecological shrimp, shrimp farming combined with mangrove forests, natural food from the forest.
LUT2	Traditional extensive shrimp	Cultured at low density, eating natural food..
LUT3	Improved extensive shrimp	Medium-density shrimp, combined with feeding.
LUT4	Intensive shrimp	High-density shrimp. Feed lots of food.
LUT5	Super-intensive shrimp	Very high-density, applying high technology.

The results of collecting reports and surveying farmers on the socio-economic and environmental aspects of Dam Doi district show that two main economic factors affecting the choice of farming model are profit and farming costs. Profit is the primary factor that influences the selection of agricultural land-uses. However, one of the primary economic issues that directly affects the district's ability to implement aquaculture farming types, particularly high-level, high-investment production types like intensive and super-intense shrimp, is the supply of cash for aquaculture production.

Table 2. Economic efficiency and investment capital requirements for aquaculture farming types in Dam Doi district

Factor	LUT1	LUT2	LUT3	LUT4	LUT5
Area in 2020 (ha)	5,166	7,393	42,000	2,244	1,099
Cost (Million VND/year/ha)	9.04	13.02	21.04	621.02	1,222.03
Profit (Million VND/year/ha)	28.16	14.60	36.47	496.40	750.00

Notes: LUT1: Forest-shrimp; LUT2: Traditional extensive shrimp; LUT3: Improved extensive shrimp; LUT4: Intensive shrimp; LUT5: Super-intensive shrimp

Table 2 displays the results of the household survey on the cost and profit of shrimp farming systems in Dam Doi district, revealing that super-intensive shrimp (LUT5) yields the highest profit at 750 million VND/ha, but the investment cost is nearly twice as high at 1,222 million VND/ha. The next highest level is intensive shrimp, with a profit of 496.40 million VND/ha, while investment costs are lower but still higher than the profit (621.02 million VND/ha). The forest shrimp system has the lowest cost (9.04 million VND/ha), but it produces high profits (28.16 million VND/ha), nearly double that of traditional extensive shrimp (14.60 million VND/ha). The improved, extensive farming model generates an average profit of 36.47 million VND per hectare. Investment costs tend to increase gradually, from lower than the profit level to nearly double the profit level. The main barrier to the actual implementation of LUT4 and LUT5, which managers need to consider, is the high investment costs.

3.3. Land evaluation for shrimp cultivation in Dam Doi district

The union in GIS of monolayers in Dam Doi district forms land mapping units (LMU), which include texture, depth of the acid sulfate layer, salinity, and persistence of salinity. There were 9 LMUs as shown in Figure 3.

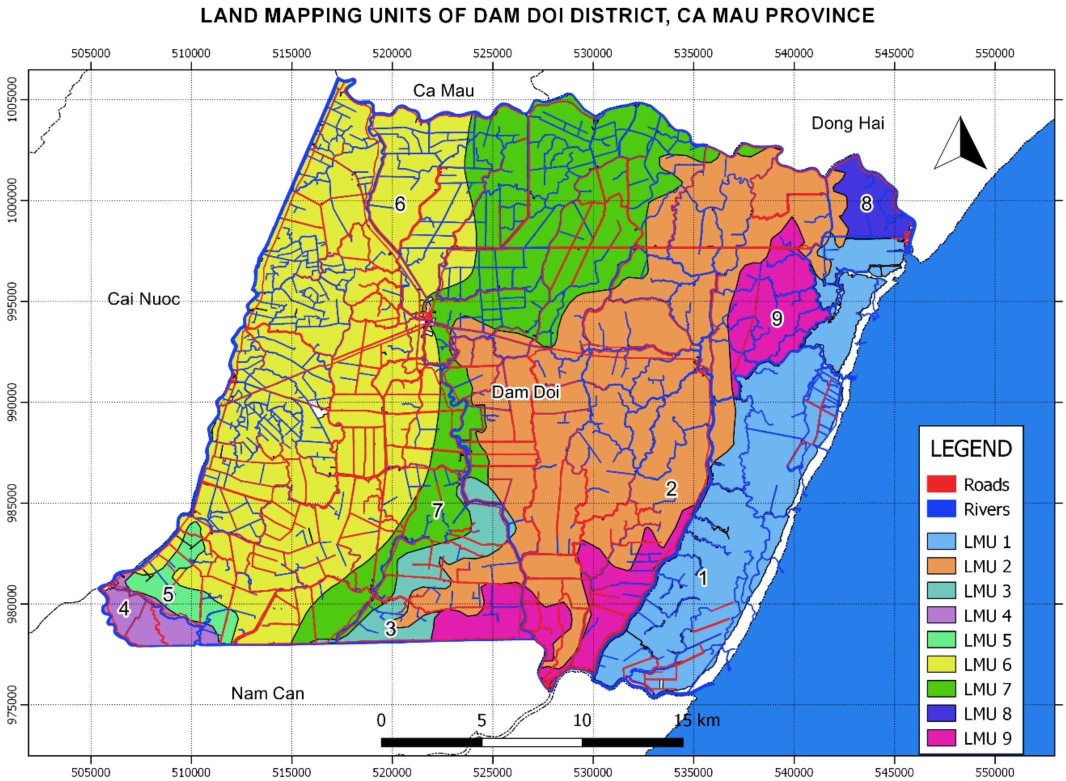

Figure 3. Land mapping unit map of Dam Doi district

(Source: Trung et al., 2019)

Naturally, the area of each LMU varies significantly. Land mapping unit 6 boasts the largest area, measuring 22,940.4 ha, while LMU8 has the smallest area, measuring 938.2 ha. The soil characteristics shown in Table 3 show that all units are located in saline zones, with salinities ranging from 8 to more than 20. The lowest salinity period is 6 – 9 months. LMU1 and LMU8 are almost saline all year round. Acid sulfate soil does not affect the alum characteristics of land mapping units 2, 5, 6, and 7.

Table 3. Properties of the Dam Doi district's land mapping unit

LMU	Area (ha)	Texture	Acid sulfate occurred	Salinity (‰)	Persistence of salinity (months)
1	9,266.89	Loam	< 50 cm	=> 20	12
2	20,388.03	Clay – Loam	-	=> 20	6 – 9
3	1,879.08	Clay – Loam	50-100 cm	=> 20	9
4	996.29	Loam	< 50 cm	12 - <20	6 – 9
5	1,002.21	Clay – Loam	-	12 - <20	6 – 9
6	22,940.44	Loam – Clay	-	8-12	6 – 9
7	12,756.23	Loam – Clay	-	12 - <20	9
8	938.22	Loam	< 50 cm	=> 20	9 – 12
9	5,228.59	Loam	< 50 cm	=> 20	9

The classification of land suitability (according to FAO, 1976) in Table 4 is based on the farming characteristics of local shrimp farming types and their requirements for land characteristics, such as alum layer depth, alum formation depth, salinity, and salinity time. Considering the scale of the suitable area for each type of land-use, it shows that the improved extensive black tiger shrimp type has a quite large area suitable at the S1 and S2 levels (68.9% of the natural area).

Table 4. Land suitability classification in Dam Doi district

LMU	LUT1	LUT2	LUT3	LUT4	LUT5
1	S1	S2	S2	S3	S3
2	N	S1	S1	S2	S2
3	N	S2	S2	S2	S2
4	N	S3	S3	S3	S3
5	N	S1	S1	S1	S1
6	N	S1	S1	S1	S1
7	N	S1	S1	S1	S1
8	N	S3	S3	S3	S3
9	S2	S3	S3	S3	S3

Notes: LUT1: Forest-shrimp; LUT2: Traditional extensive shrimp; LUT3: Improved extensive shrimp; LUT4: Intensive shrimp; LUT5: Super-intensive shrimp

3.4. Definition of the optimal options

As analyzed in Session 3.1, when preparing options for 5-year cycle development, technical factors and investment capital play a significant role in planning the area for farming systems. Technical requirements and capital constraints force the equation setting to be limited in terms of both area and total investment capital. The current size of aquaculture systems and fluctuations in local demand determine the area constraint. When it comes to capital constraints, it's crucial to identify the scenario where the maximum demand for capital yields the highest profit and then provide the capital constraints to the specific locality. Based on the approach of analyzing those options, this study has analyzed 03 options for 2025 to optimize the area of aquaculture land use types in the Dam Doi district with the same constraints but with different capital requirements. This proposal aims to maintain some fixed factors while evaluating the resources available for implementation in the locality. Based on this evaluation, it recommends that local managers conduct more detailed surveys to identify other binding factors.

- Option 1 - Investment is not limited: Optimize the area within the limits of the minimum and maximum area requirements for the land-use types, when capital is not restricted.
- Option 2 – Limitation of capital and requirements of minimum area: Optimize the area with the same constraints as Option 1 when the total capital does not exceed VND 3,500 billion.
- Option 3 – Limitation of minimum area: Optimize the area within the same limits as Option 2, but do not limit the minimum area of LUT4 and LUT5 (intense and super-intensive shrimp) or total capital to 4,000 billion VND.

Option 1 indicates that, in the most optimal case, the capital demand is significantly high. Therefore, we use Options 2 and 3 to analyze cases where the capital is insufficient for developing farming models. At that point, arranging the entire land area or investing in extremely expensive usage models (LUT5) will become impossible. We analyze the total capital data (either 4,000 billion or 3,500 billion VND) to empirically test the model's sensitivity to the capital factor. These data are not inflexible, but they provide managers with a foundation for applying the model to analyze the scale of aquaculture planning.

The local area requirements are set based on the Party's desired targets for the 5-year cycle. These targets are based on the current area at the time of setting the target. This study sets minimum area thresholds equal to the current land use status and maximum thresholds that increase according to the district's requirements. In case there is no maximum area limit, the mathematical model needs to set the largest numerical value. Since the natural area of Dam Doi district is about 82,000 ha, it is necessary to set the limit value larger than the area value of the district. Therefore, we use the value of 100,000 ha as the largest limit value in the equation.

Local authorities can use this range to scientifically analyze the targets and determine which land units require the necessary area of LUTs. Policymakers can set the minimum and maximum area constraints for 5 years, but the model's flexibility allows them to re-evaluate annually or update the targets midterm.

Table 5. The minimum and maximum area requirements for each option

LUT	Option 1 and 2		Option 3	
	Minimum area of LUT	Maximum area of LUT	Minimum area of LUT	Maximum area of LUT
LUT1	4,000	6,000	4,000	6,000
LUT2	10,000	50,000	10,000	50,000
LUT3	40,000	100,000	40,000	100,000
LUT4	1,500	5,000	0	5,000
LUT5	1,200	2,000	0	2,000

Notes: LUT1: Forest-shrimp; LUT2: Traditional extensive shrimp; LUT3: Improved extensive shrimp; LUT4: Intensive shrimp; LUT5: Super-intensive shrimp

3.5. Options for optimizing aquaculture land-use types

3.5.1. Option 1: Investment is not limited.

Figure 4 shows the optimal area map of aquaculture land types in Option 1 for each LMU. LUT3 (improved extensive shrimp) occupies the most areas (5 LMUs), boasting a total distribution area of 52,395.98 hectares. When there are no capital constraints, the areas of LUT4 and LUT5 reach the minimum required area due to the highest profit.

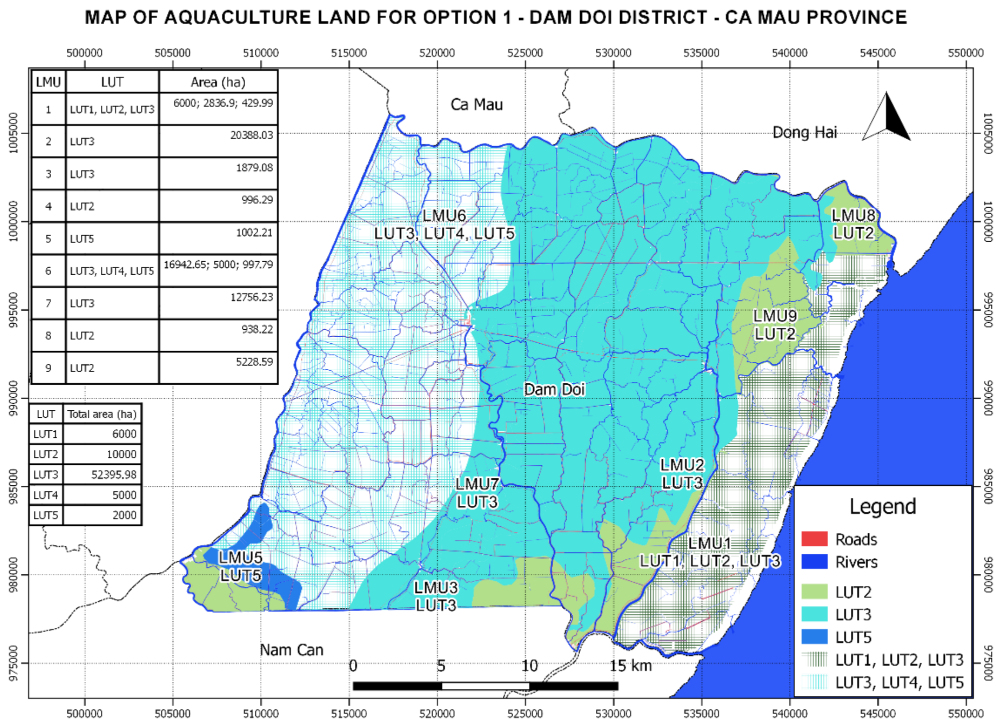

Figure 4. Area of land-use distribution map for Option 1

Table 6 details the optimal land-use distribution within each land management unit (LMU), including total capital and profit for each type. As a result, the land mapping units (LMU1 and LUM6) are divided into three forms of use, while the remaining LMUs are completely committed to one type of use. At the same time, the findings suggest that LUT3 (Improved extensive shrimp) remains the most dominant (distributed in 5 LMUs) due to the impact of land adaptation factors, followed by the extensive shrimp model (spread in 4 LMUs). The land-use categories shrimp-forest (LUT1) and intense shrimp (LUT4) occupy the smallest area, amounting to 6,000 ha in LMU1 and 5,000ha in LMU6.

Table 6. Area of land-use types distributed for Option 1

	LUT1	LUT2	LUT3	LUT4	LUT5
LMU1	6,000	2,836.90	429.99	0	0
LMU2		0	20,388.03	0	0
LMU3		0	1,879.08	0	0
LMU4		996.29	0	0	0
LMU5		0	0	0	1,002.21
LMU6		0	16,942.65	5,000	997.79
LMU7		0	12,756.23	0	0
LMU8		938.22	0	0	0
LMU9	0	5228.59	0	0	0
Total area (ha)	6,000	10,000	52,395.98	5,000	2,000
Total profit (Million VND)	168,000	62,262.37	1,884,640.52	2,480,000	1,500,000
Capital (Million VND)	54,000	130,000	1,100,315,58	3,105,000	2,440,000

3.5.2. Option 2: Optimizing aquaculture area with capital constraints

Figure 5 displays the resulting map of land-use types for Option 2. Overall, this alternative's LUT layout is similar to in Option 1. However, there are differences in this alternative on LMU6, in which the area of LUT5 is lower than that of Option 1 due to limited investment capital; instead, the area of improved extensive shrimp farming increases compared to Option 1.

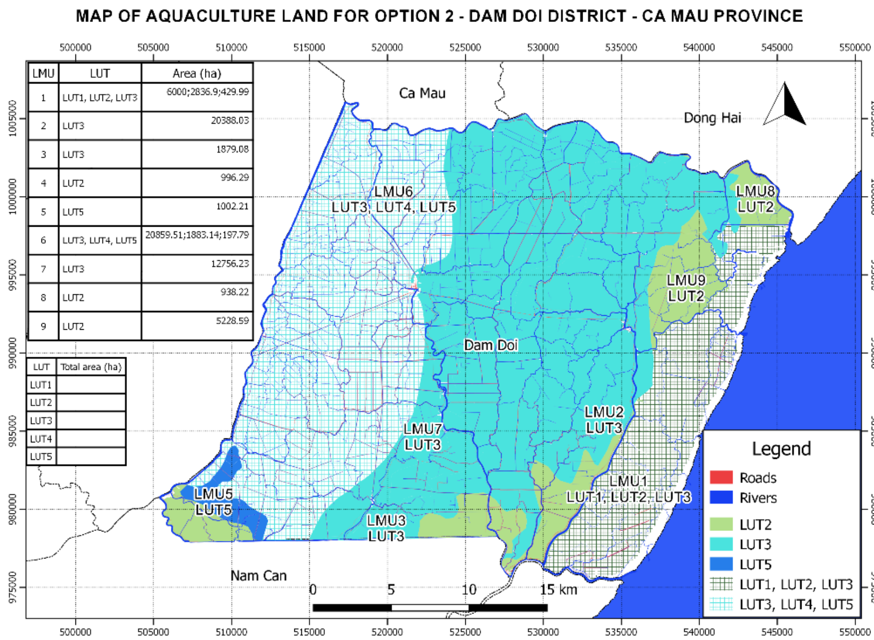

Figure 5. Area of land-use types distributed for Option 2

Regarding the specific area of Option 2, Table 7 shows that the land-use types LUT1 and LUT2 are still similar to Option 1. However, LUT3's distributed area stands at 56,312.84 hectares, surpassing that of the other 4 LUTs. Meanwhile, LUT5 (super intensive shrimp) occupies a total area of 1,200 ha, which falls short of Option 2 about 2,000 ha requirement due to the binding total investment capital of 3,500 billion VND.

Table 7. Area of land-use types distributed for Option 2

	LUT1	LUT2	LUT3	LUT4	LUT5
LMU1	6,000.00	2,836.90	429.99	0.00	0.00
LMU2		0.00	20,388.03	0.00	0.00
LMU3		0.00	1,879.08	0.00	0.00
LMU4		996.29	0.00	0.00	0.00
LMU5		0.00	0.00	0.00	1,002.21
LMU6		0.00	20,859.51	1,883.14	197.79
LMU7		0.00	12,756.23	0.00	0.00
LMU8		938.22	0.00	0.00	0.00
LMU9	0.00	5,228.59	0.00	0.00	0.00
Total area (ha)	6,000.00	10,000.00	56,312.84	1,883.14	1,200.00
Total profit (Million VND)	168,000.00	62,262.37	2,027,605.91	934,037.44	900,000.00
Capital (Million VND)	54,000.00	130,000.00	1,182,569.64	1,169,429.94	1,464,000.00

3.5.3. Option 3: Optimizing aquaculture area with increased capital.

While the arranged area of LUT5 in Option 2 fails to meet the required area due to limited local investment capital, Option 3 takes into account the distribution of LUT areas when capital is limited, but does not impose a minimum area constraint on the LUTs. Figure 6 displays the map of option 3, which alters the layout at LMU6 to accommodate only two types of use: LUT3 and LUT4. LUT5 is not positioned. This is the most obvious difference in this option compared to the results of the two preceding options. This shows that LUT5 is unnecessary when it is not mandatory due to its high investment cost. Allocating capital to other options for optimal total profit is better than arranging the super-intensive shrimp farming model.

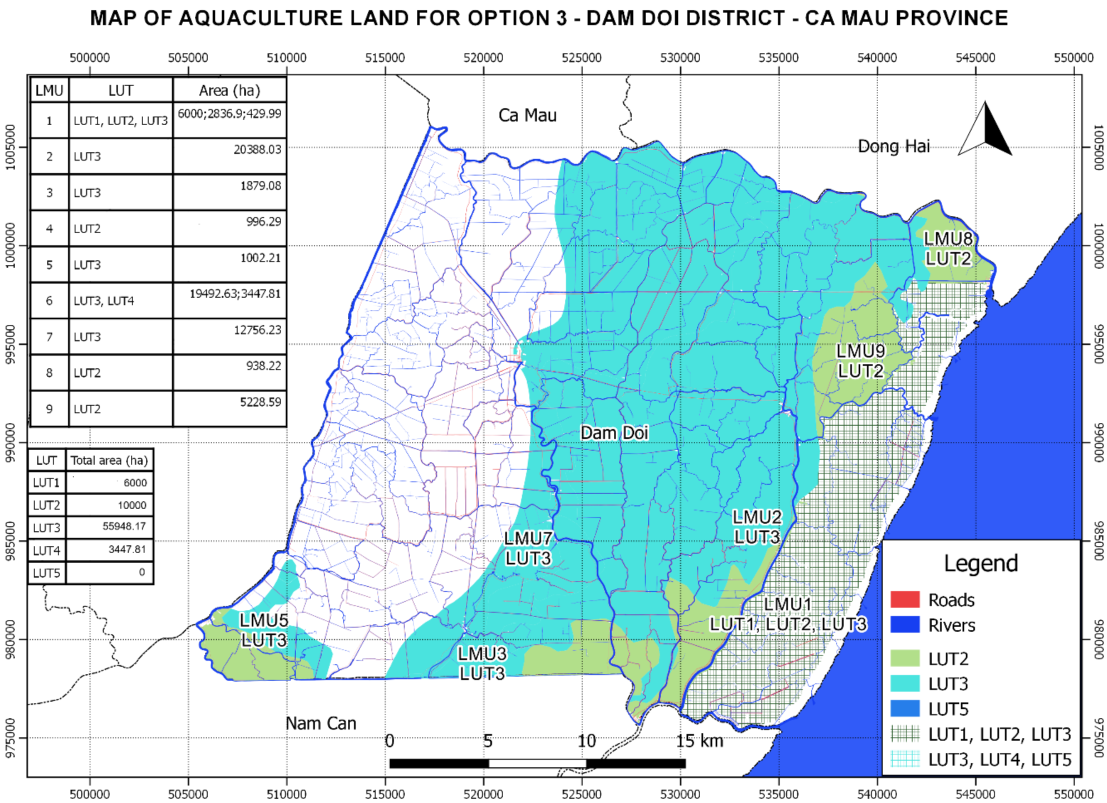

Figure 6. Area of land-use types distributed for Option 3

Table 8 shows the specific area of LUTs on each land mapping unit. LMU6 is exclusively arranged for LUT3 and LUT4, which have areas of 19,492.44 ha and 3,447.81 ha, respectively. According to this ideal design, LUT5 is not placed in any LMU, yet LUT4 has the largest area of the three plans. According to the current situation in the locality, when capital allocation is limited, localities must have appropriate agricultural and fishery extension policies or monitor and support when people implement LUT5 in LMUs that are well suited to this type of land-use.

Table 8. Area of land-use types distributed for Option 3

	LUT1	LUT2	LUT3	LUT4	LUT5
LMU1	6,000.00	2,836.90	429.99	0.00	0.00
LMU2		0.00	20,388.03	0.00	0.00
LMU3		0.00	1,879.08	0.00	0.00
LMU4		996.29	0.00	0.00	0.00
LMU5		0.00	1,002.21	0.00	0.00
LMU6		0.00	19,492.63	3,447.81	0.00
LMU7		0.00	12,756.23	0.00	0.00
LMU8		938.22	0.00	0.00	0.00
LMU9	0.00	5,228.59	0.00	0.00	0.00
Total area (ha)	6,000.00	10,000.00	55,948.17	3,447.81	0.00
Total profit (Million VND)	168,000.00	62,262.37	2,014,295.46	1,710,113.76	0.00
Capital (Million VND)	54,000.00	130,000.00	1,174,911.57	2,141,090.01	0.00

3.5.4. Evaluating the costs and profits of options for arranging aquaculture land areas.

The capital and profit analysis of the three choices (Figure 7) reveals that Option 1 has the largest profit because there are no restrictions on investing capital. The land arrangement is 81,656.06 ha, accounting for more than 90% of the district's natural area (81,004.66 ha). However, the lack of constraints restricts this choice, raising the possible risks.

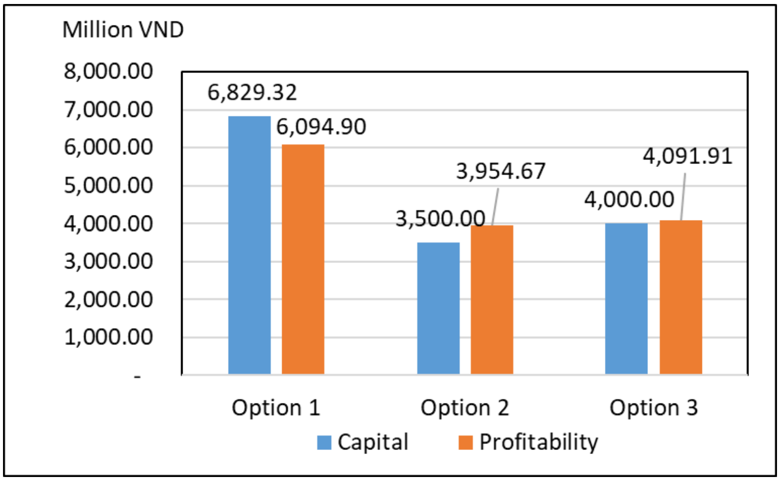

Figure 7. Comparison of investment capital and profitability of options

Option 2 has the lowest total profit out of the three options. Limited capital resources and the inability to optimally arrange the district's entire land area prevented the locality from achieving the proposed land-use arrangement. Option 3 yields a profit that falls within the middle range of the three options. This is a plan to fully allocate the required land area with sufficient capital. Furthermore, this plan generates substantial profits using locally implementable capital. This shows that the arrangement of land-use types for this option is consistent with the local investment situation.

4. CONCLUSION

In this work, a mathematical model was developed to optimum the area of aquaculture land-use types with the purpose of maximizing earnings while taking into account natural adaptability, necessary space, and resources. Capital allocated according to local development direction to support the establishment of local agricultural land-use planning plans. The model enables surveying choices to optimize local area and investment capacity for aquaculture farming systems, assisting district level in making agricultural land-use decisions.

Three options have been developed to optimize land areas for aquaculture in Dam Doi district, Ca Mau province: (i) unlimited capital; (ii) a total limited investment capital of VND 4,000 billion; and (iii) a total limited investment capital of VND 3,500 billion. In particular, the option to limit capital to 4,000 billion VND is suitable for the district's capacity and investment conditions.

The limitation of the study is that the spatial distribution of LUTs only stops at the LMU level, not showing the specific farming area at the pixel level on the map. Furthermore, the land evaluation classification of certain land use types currently relies solely on basic indicators, such as soil, water, and salinity. This feature does not narrow the spatial distribution of LUTs for land arrangement, causing many types of shrimp farming systems to be arranged in a large land unit. To overcome this limitation, future studies should incorporate additional spatial factors that directly influence aquaculture models in land units. These factors include the main electricity network, canals that provide clean water, and the level of water environmental safety. These are major factors determining the arrangement of improved extensive, intensive, and super-intensive aquaculture models.

Despite its limitations, this study proposed an optimization model that can assist agricultural managers and land managers in making agricultural land-use decisions.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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