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Potential land for agriculture development in three coastal districts of Ben Tre province in the Mekong delta, Vietnam

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Abstract:

The research objective was to determine the suitability of land regarding physical and economic conditions as a basis to support managers in planning effective agricultural development strategies that are suitable and sustainable for land potential in a future affected by climate change. In this research, physical and socio-economic data were collected by field surveys, household interviews (330 households), and agricultural manager discussions. Additionally, the methodology of land suitability evaluation was based on Food and Agriculture Organization (FAO) (1976 & 2007) and Geographic Information System (GIS) tools, which were used to determine suitability classifications for land-use types (under different physical and socio-economic conditions) in three coastal districts within the Ben Tre province. The results showed that agricultural production status in the research area was divided into three agro-ecological zones including the freshwater zone, brackish water zone, and saltwater zone of which the highest rate of agricultural land area was aquaculture. The next major proportion of agricultural area belonged to land for planting perennial crops and land for planting annual crops. Besides, 7 and 8 land suitability zones were determined, respectively, depending on physical and economic conditions, for 11 main land-use types. This research contributes toward basic knowledge that aims to support local decision makers in their transformation of agricultural land and adaptation of salinization in the future.

Keywords: **agro-ecological zones, Ben Tre province, potential land, salinization, sustainable agriculture.**

Classification number: **5.1**

Introduction

In recent years, the Mekong delta has been heavily affected by climate change events such as prolonged drought, erratic rain, unseasonal rain, local flooding, and saltwater intrusion, which all disturb the agricultural production of farmers [1-3]. Ben Tre is one provinces in Vietnam that will be most affected and vulnerable to climate change in Southeast Asia [4, 5].

The coastal zone in Ben Tre province consists of three coastal districts, namely, Binh Dai, Ba Tri, and Thanh Phu. This zone has a diverse ecosystem with three main agro-ecological zones including the freshwater zone, brackish water zone, and saltwater zone. The river system comprises a relatively dense network of river courses that receive freshwater and sediment from Hau and Tien rivers (two main parts of Mekong river) [6].

Recently, salinization status has become more complex and has strongly affected agriculture production in the coastal zones of the Ben Tre province [7]. In addition, small-scale farms still occupy a large ratio of land there. Potential land for agriculture has not been suitably used yet, which leads to conflict in local land use processes and especially in boundary areas between freshwater and saltwater zones [8]. Besides, to ensure the economic development of Ben Tre and the increasing requirements for the quality of agricultural products were about product quality when society was developed [9]. In addition, saline intrusion and sea-level rise affected crop yield and quality [10]. At the same time, land resources were degraded due to the abuse of chemical fertilizers and pesticides used for the farmer's agricultural intensification [11-13].

Regarding the above issues, research was conducted to assess the suitability of land and its natural and economic conditions for agricultural land use types as a basis to support managers with rationally orienting land use as well as economically and effectively exploiting land resources in the coastal areas of the Ben Tre province under the impact of future climate change. Specifically, this study (1) performs physical land suitability evaluations; (2) provides quantitative economic land suitability evaluations, and (3) integrates physical-economic land suitability evaluations.

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Methods

Study scope

This study selected Ben Tre's three coastal districts including Thanh Phu, Binh Dai, and Ba Tri districts (Fig. 1) as a case study area because it is an area that has been heavily affected by saline intrusion and sea level rise, which strongly affects the type of agricultural land use [10].

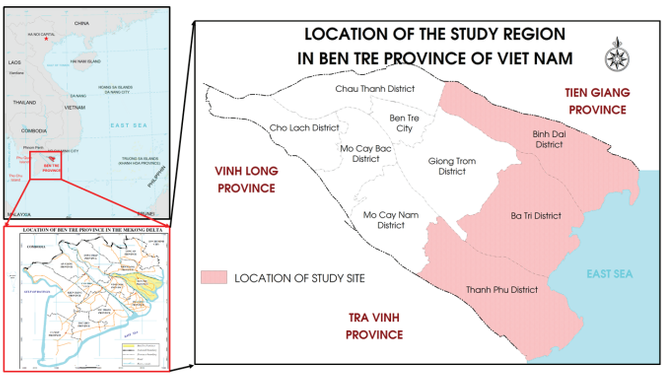

Fig 1. Location of study site.

Data collection and analysis

Secondary data collection: Data and documents used including agricultural land-use status, present land use map, land use planning, and other relation data that were collected in study area of Ben Tre's coastal zone.

Primary data collection: Field surveys were conducted to determine major available agricultural land use. In addition, the study was conducted by random interviews with 330 farmer households, and the number of questionnaires was distributed to eleven land use types in Ben Tre's three coastal districts (30 households/land use type) [14]. The information collected includes farmers' agricultural production conditions such as investment costs, profits, advantages and disadvantages in production of farmers. Three PRA (participatory rural appraisal) with local farmers and agricultural manager discussions were conducted to collect extra data and validate household interview data.

Data analysis method: Collected data was aggregated by Microsoft Excel to support the process of analysing, evaluating, and comparing data about total investment costs, profits, and capital efficiency (benefit/cost) of land use types, which was based on economic suitability analysis for each land use type. The maps were normalized on coordinate system VN 2000/WGS 84 zone 48 (6 Degrees). Next, the maps were digitized, overlapped, and edited by Mapinfo software to establish thematic maps.

Data processing and evaluation method

The research used was land suitability evaluation methodology [15, 16] that determines physical and economic land suitability, respectively, for local major land use types (Fig. 2.)

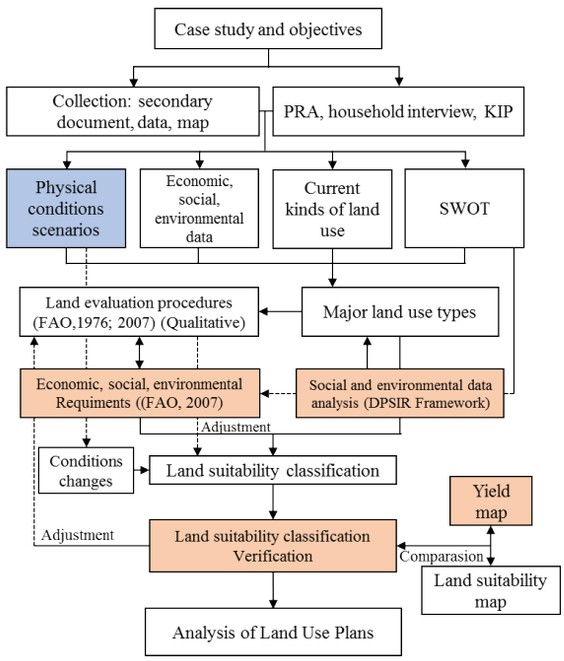

Fig. 2. Framework of land suitability evaluation methodology.

Results and discussion

Land mapping units

The result of PRA with local farmers, agricultural manager discussions, and surveys showed that five land characteristics strongly affected agriculture production in the coastal zone of Ben Tre province including soil types, salinity, time of salinity duration, depth of occurrence of sulfuric horizon, and depth of occurrence of sulfidic horizon. Based on these characteristics, five single information maps were established, respectively, and overlapped together to delineate a Land-mapping units map that has twenty land-units in three coastal districts of Ben Tre's coastal zone from year 2018 (Table 1 and Fig. 3). Of which, land unit No. 19 had the largest area (34.94%) occupying 36,451.3 ha, and there were characteristics of saline soil, water salinity greater than $16^{0}/_{00}$, and salinity time was 12 month, not alum. Based on this data, these land units could be suitable for the development of land use types of the brackish and saline ecological sub-region. In contrast, land unit No. 16 had the smallest area (0.01%) occupying 13.4 ha, and possessed characteristics of saline soil, non-salinated, and not alum. This land unit could develop land use types belonging to a freshwater ecological sub-region. However, attention should be paid to the leaching of salinity in the soil. The characteristics of the remaining land units and the area distribution of each land unit are detailed in Table 1.

Table 1. The information of land units in three coastal districts of the Ben Tre province.

LMUs	Soil types	Salinity (‰)	Salinity duration (month)	Depth of occurrence of sulfuric horizon (cm)	Depth of occurrence of sulfidic horizon (cm)	Area (ha)	Ratio (%)
1	AR	0	0	None	None	2,999.8	2.88
2	FL	0	0	None	50-100	306.3	0.29
3	FL	0	0	50-100	>100	3,318.2	3.18
4	FL	0-≤16	6	None	50-100	754.0	0.72
5	FL	0-≤16	6	50-100	>100	979.2	0.94
6	FL	>16	12	50-100	>100	255.7	0.25
7	GL	0	0	None	None	13,524.5	12.96
8	GL	0-≤16	6	None	None	10,035.7	9.62
9	GL	>16	12	None	None	2,941.7	2.82
10	GL	0	0	None	None	10,956.0	10.50
11	GL	0	0	100-150	>150	10,291.6	9.86
12	GL	0-≤16	6	None	None	1,099.9	1.05
13	GL	0-≤16	6	100-150	>150	1,894.7	1.82
14	GL	>16	12	None	None	89.3	0.09
15	GL	>16	12	100-150	>150	440.3	0.42
16	SC	0	0	None	None	13.4	0.01
17	SC	0-≤16	6	None	None	7,673.5	7.36
18	SC	0-≤16	6	100-150	>150	280.9	0.27
19	SC	>16	12	None	None	36,451.3	34.94
20	SC	>16	12	100-150	>150	19.1	0.02

Notes: Land Map Units (LMUs), Arenosol (AR), Fluvisol (FL), Gleysol (GL), Solonchak (SC).

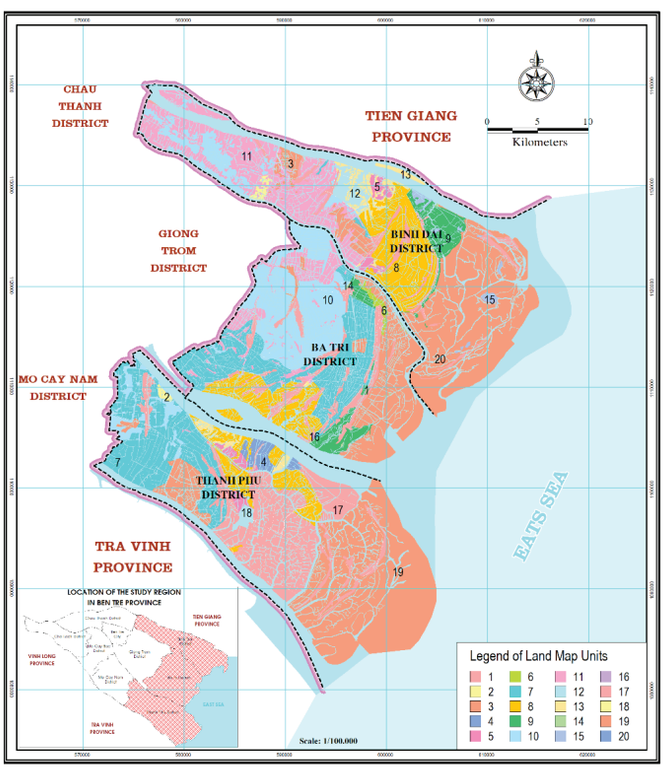

Fig. 3. Map of land units in three districts of the coastal zone of the Ben Tre province.

Physical land suitability evaluation

Eleven major land use types with cultivation calendar (Fig. 4) were considered to identify as potential development in study area via a data collection process allocated in three agro-ecological zones such as the freshwater zone, brackish water zone, and salt water zone. The identification and description of the land use types (Table 2) is considered an essential part of the evaluation procedure. In particular, the conversion of agricultural land use by farmers is often affected by physical conditions such as saline intrusion, erratic weather, and economic conditions such as consumption markets, product selling prices, and labour resources for different land use types.

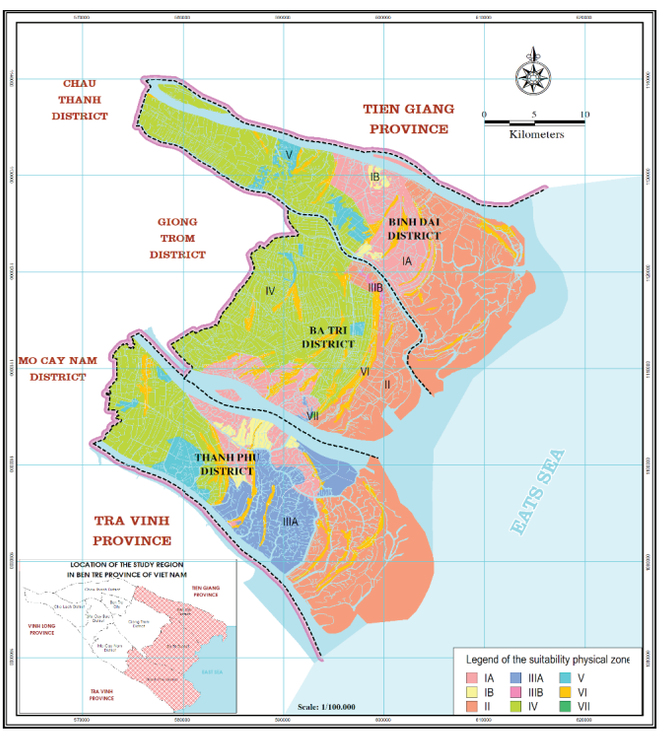

Fig. 4. Map of the suitability of physical zones for land use types in three coastal districts of the Ben Tre province.

Table 2. Cultivation calendar of land use types.

Month (dl)/Land use types	1	2	3	4	5	6	7	8	9	10	11	12
Triple rice	→			↔				↔				←
Double rice				↔				↔				
Double rice - Cash crops	→			↔				↔				←
Rice - Shrimp	↔							↔				←
Coconut - Shrimp (Crayfish)	↔											↔
Coconut	↔											↔
Cash crops	↔											↔
Fruits	↔											↔
Aquacultural	↔											↔
Salt	⇢											⇠
Shrimp - Forest	↔											↔

Source: Field survey, 2018.

Land characteristics were used to delineate Land-mapping units. The research identified three land qualities that were believed to have significant effects on the types of land use under consideration. Land qualities are described by means of the land characteristics below:

- Nutrient availability (fertilizer - soil types).

- Soil toxicity (depth of occurrence of sulfuric horizon and depth of occurrence of sulfidic horizon).

- Salinity hazards (salinity, salinity duration).

Each type of land use has different requirements, which refer to the set of land qualities that determine the production and management conditions of types of land use. Therefore, limitations are land qualities and their expression by means of diagnostic criteria adversely affect a type of land use. Land evaluation is essential in order to ensure suitability classes and show the suitability of each land mapping unit for each relevant type of land use.

The process of land suitability classification is the fitness of a given land mapping unit for a defined use. Land suitability classes reflect degrees of suitability [16, 17]. Suitability classes are recognized within the order suitable, and definitions may be appropriate in a qualitative classification: Class S1 (highly suitable): >80% maximum yield; class S2 (moderately suitable): >40-80% maximum yield; class S3 (marginally suitable): 20-40% maximum yield; and class N (not suitable): <20% maximum yield,

The result of physical land suitability evaluation showed that seven land suitability zones were determined as follows: suitability zone I occupied 14,482.50 ha (13.85%) with highly suitable (S1), moderately suitable (S2) for rice - shrimp, shrimp, salt production and shrimp - forest; suitability zone II occupied 3,490.30 ha (34.29%), the largest proportion in study area, with highly suitable for land use types in saltwater (shrimp, salt, shrimp - forest). This zone had highly salinity and constant salinity durations because it is close to East Sea; suitability zone III occupied 7,929.17 ha (7.58%) with highly suitable (S1) for shrimp, salt and moderately suitable (S2) for shrimp - forest. Allocated mainly in the Thanh Phu district, suitability zone IV occupied 34,770.71 ha (33.5%), which is in a freshwater zone. Therefore, this zone was suitable with triple rice, double rice, double rice - cash crops, cash crops, fruits, coconut - shrimp (giant freshwater shrimp). Mainly in Ba Tri district, suitability zone V occupied 3,624.50 ha, which was also suitable for freshwater land use. Allocated mainly in the Thanh Phu and Binh Dai districts, suitability zone VI was highly suitable (S1) for coconut, fruits, and cash crops. However, soil conditions were limited as this zone is not able to be developed for rice, rice - cash crop, or coconut - shrimp. Suitability zone VII was the lowest area, which occupied 0.01%. This zone was limited by salinity so that it was not suitable for any land use types.

Based on physical land suitability evaluation, the land use types that are suitable for each agro-ecological zones are identified. The results of physical land suitability evaluation for major land use types in Ben Tre's coastal zone had different suitability classes. Soil and salinity were major limitations of land characteristics, which adversely affected the type of land use.

Limitations of land qualities in suitability zones need to provide land improvements that cause beneficial changes in the qualities of the land itself. Additionally, a combination between local agricultural planning and improvement of land use are also necessary to offer suitable solutions with a choice of land use type.

Quantitative economic land suitability evaluation

Based on the results of physical land suitability evaluation, this study conducted quantitative economic land suitability evaluations for eleven major land use types, which were chosen in Ben Tre's three coastal zones. Land suitability classification of economic criteria of land use types was generated by economic interview data of farmers (Table 3.)

Table 3. Factor rating of economic land suitability classification of land use types.

Criteria	Decentralization of economic factor			
	S1	*S2*	*S3*	*N*
Revenue	>74.64	55.98-74.64	37.32-55.98	<37.32
Benefit - cost ratio (BCR)	>1.75	1.32-1.75	0.88-1.32	<0.88

Notes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), not suitable (N).

The result of economic land suitability evaluation was determined to consist of eight suitability zones such as suitability zone I (Fig. 5), which was highly suitable for cash crops and fruits occupying 6,624.25 ha, and suitability zone II, which occupies 1,733.14 ha. For revenue, this zone was highly suitable (S1) for salt production. However, regarding BCR, it was moderately suitable (S2) for shrimp - forest, marginally suitable (S3) for shrimp and salt, and was not suitable (N) for the rest of land use types. Suitability zone III occupied 255.66 ha. For the revenue, this zone was highly suitable (S1) for salt production. Regarding BCR, it was moderately suitable (S2) for salt production and shrimp - forest and marginally suitable (S3) for shrimp. Suitability zone IV occupied 34,772.10 ha. For the revenue, this zone was highly suitable (S1) for coconut - shrimp, cash crops and fruits, and marginally suitable (S3) for triple rice, double rice - cash crops, and coconut. Regarding BCR, it was highly suitable (S1) for coconut, cash crops, and fruits, and moderately suitable (S2) for coconut - shrimp and marginally suitable (S3) for triple rice, double rice. Suitability zone V occupied 13.030,3 ha. For the revenue, this zone was highly suitable (S1) for salt production and moderately suitable (S2) for rice - shrimp. Regarding BCR, it was moderately suitable (S2) for shrimp and shrimp - forest, and was marginally suitable (S3) for salt production. Suitability zone VI occupied 39,941.55 ha. In revenue, this zone was highly suitable (S1) for salt production. Regarding BCR, it was highly suitable (S1) for

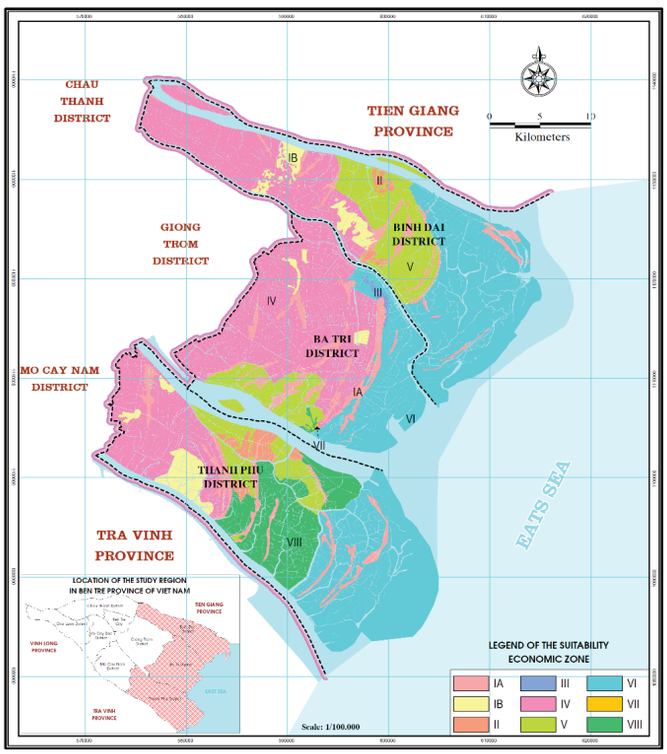

Fig. 5. Map of the suitability economic zone for land use types in the three coastal districts of the Ben Tre province.

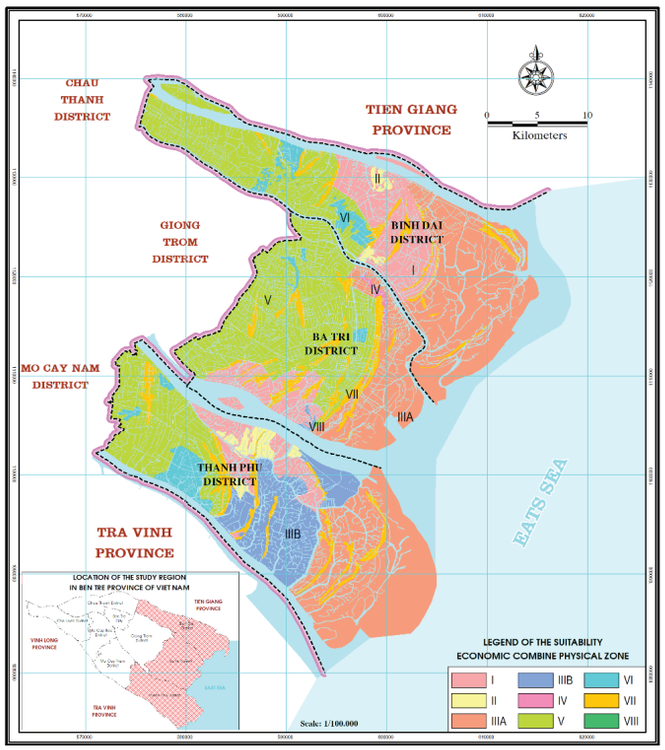

Fig 6. Map of the suitability of combined economic and physical zones for land use types in three coastal districts of the Ben Tre province.

shrimp - forest and moderately suitable (S2) for shrimp and salt. Suitability zone VII gave the lowest proportion in economic land suitability evaluation (about 13.36 ha). For the revenue, this zone was moderately suitable (S2) and was marginally suitable (S3) for cash crops, fruits, coconut - shrimp. Regarding BCR, it was highly suitable (S1) for coconut and marginally suitable (S3) for cash crops and fruits. Suitability zone VIII occupied 7,954.41 ha. For the revenue, this zone was highly suitable (S1) for salt production. Regarding BCR, it was moderately suitable (S2) for shrimp, shrimp - forest, and marginally suitable (S3) for salt.

The result of economic land suitability evaluation (revenue and BCR) for the eleven main land use types in the study area showed that most of the suitability zones were marginally suitable (S3) or not suitable (N) for triple rice, double rice, and double rice - cash crops in economic conditions. Salt production was a land use type that demonstrated high suitability (S1) in five suitability zones. However, price of salt was high at the present time, and one needs to consider economic efficiency of salt production in the future.

Integrated physical-economic land suitability evaluation

On the basis of economic land suitability and physical land suitability of land units, the results have identified eight land suitability zones integrating economic and physical condition for eleven land use types in Ben Tre's three coastal districts, and the distribution of land suitability zones is shown in Fig. 6.

The results showed that land suitability zone I was physically not suitable (N) for freshwater land use types such as: triple rice, double rice, double rice mixed cash-crop, coconut, and fruits due to the influence of saline intrusion conditions. In contrast, it was physically suitable from moderately (S2) to highly suitable (S1) for land use types such as salt production, shrimp - forest, rice - shrimp, and shrimp. However, profit suitability of land use types ranged from marginally suitable (S3) to not suitable (N) due to risks from epidemics, consumer markets, and product selling prices. Because these land use types had low initial investment capital, the efficiency of capital presented moderately suitable (S2) in suitability zone I, which occupied 13,030.3 ha. Similar to suitable zone I, suitable zone II has the potential for development of land use types in brackish and saline ecological zones, and the suitability was physically moderately suitable (S2) or not suitable (N) for profit. The efficiency of capital had suitability ranging from moderately (S2) to highly (S1) suitable for land use types such as salt production and shrimp - forest. The area of suitability zone II was about 1,733.1 ha. Suitability zone III has been divided into two ecological sub-zones (IIIA and IIIB) and because of this it was physically marginally suitable (S3) for land use type of rice-shrimp, and it was highly suitable (S1) for shrimp, salt production, and shrimp-forest (IIIA) and moderately suitable (S2) to ecological sub-zone IIIB.

In addition, the benefit over cost of both sub-zones had suitability from moderately (S2) to highly suitable (S1) for the above land use types, and profit suitability was marginal (S3)

to not suitable (N). The area of zone III was about 47,896.0 ha. Suitability zone IV was an area that was physically marginally suitable (S3) for rice - shrimp, and moderately suitable (S2) for land use types such as shrimp, salt production, and shrimp - forest. However, the profitability was not suitable (N) for all land use types, the capital efficiency was highly suitable (S1) for the land use type of salt production, and shrimp-forest had moderate suitability (S2). Suitability zone IV had a low area of suitable zones occupying only 225.7 ha. Meanwhile, suitability zone V occupied 34,772.1 ha and this area was highly suitable (S1) for land use types of the freshwater ecological sub-zone such as triple rice, double rice, double rice - cash crops, coconut, and coconut mixed crayfish, cash crops, and fruits. The remaining land use types were not suitable (N). However, the economic indicators of profit and efficiency of capital in this region were of a well-developed ability for land use types like coconut mixed crayfish, coconuts, cash crops, and fruits. Suitability zone VI was an area that had a developed ability for land use types like the suitability zone V. However, the physical suitability of land use types were reduced to moderately suitable (S2), and the economic suitability was the development suitability for land use types of cash crops and fruits. Suitability zone VI occupied 3,624.5 ha. The suitability zone VII was a zone that was physically marginally suitable (S3) for land use types such as triple rice, double rice, double rice - cash crop, and was economically not suitable (N). However, the area was moderately (S2) to highly suitable (S1) for land use types of coconut mixed crayfish, coconut, cash crops, and fruits in regards to both physical and economic factors. Suitability zone VII occupied 2,999.8 ha. Suitability zone VIII was physically marginally suitable (S3) for land use types of the freshwater ecoregion and not suitable (N) for the remaining land use types. Economic suitability of zone VIII has profit high suitability (S1) for cash crops and fruits, marginally suitable (S3) for coconut mixed crayfish, and was not suitable for development for the remaining land use types. However, the investment efficiency for the development of use types was not suitable (N) for land use types. The distribution area of suitability zone VIII occupied the least among the suitability zones (13.4 ha).

Based on the combined physical and economic suitability zones for land use types in Ben Tre's three coastal districts, managers could receive help to plan agricultural production zones that are suitable for physical and famer's economic conditions that are aimed at bringing the highest production efficiency, to build concentrated production areas with homogeneous quality, and bring into play the potential and available advantages of the zones. In addition, the land use types chosen to be suitable for each soil, water, and climate conditions will support the sustainable and effective structural transformation of the agricultural sector in Ben Tre's coastal districts.

Conclusions

Twenty land mapping units were identified by five single maps by their physical conditions. Seven and eight suitability zones, respectively, for eleven major land use types in Ben Tre's three coastal districts were identified by physical land suitability evaluations and economic land suitability evaluations. In addition, the results identified eight land suitability zones combining quantitative economic and physical conditions for land use types in Ben Tre's three coastal districts.

The results contribute to the basic of knowledge that supports agricultural managers in land use planning in the future and offers solutions (infrastructure and non-infrastructure) for adaptation to complex salinization.

COMPETING INTERESTS

The author declares that there is no conflict of interest regarding the publication of this article.

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