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Zoning the suitability of the western Mekong Delta for paddy rice cultivation and aquaculture under current and future environmental conditions

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Highlights

- The suitability of the western Mekong Delta for paddy rice cultivation and shrimp farming was assessed for current and future environmental conditions
- The assessment used a GIS-based AHP approach, considering spatial variations in soils and changes in salinity, water resource availability and growing season length
- The 1D Hydrodynamic MIKE 11 model simulated four salinity intrusion scenarios
- Paddy rice cultivation will become more suitable in Kien Giang province in the future
- Shrimp farming will become more suitable to Ca Mau province under future environmental conditions

Zoning the suitability of the western Mekong Delta for paddy rice cultivation and aquaculture under current and future environmental conditions

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Abstract

Ca Mau and Kien Giang, the two provinces of the Mekong Delta bordering the Gulf of Thailand, are facing major environmental challenges affecting the agriculture and aquaculture sectors upon which many livelihoods in this region depend on. This study maps the suitability of these two provinces for paddy rice cultivation and shrimp farming according to soil characteristics and current and future environmental conditions for variables found to significantly influence the yield of those two sectors, i.e., the level of saltwater intrusion, water availability for rainfed agriculture, and the length of the growing period. Future environmental conditions were simulated using the MIKE 11 hydrodynamic model forced by four hydrodynamic scenarios, each one representing different extents of saltwater intrusion during both the dry and rainy seasons, while also considering the availability of water resources for rainfed agriculture. The suitability zoning was performed using a GIS-based Analytic Hierarchy Process (AHP) approach, resulting in the categorisation of the land according to four suitability levels for each sector. The analysis reveals that paddy rice cultivation will become more suitable to Kien Giang province while shrimp farming will be more suitable to Ca Mau province if the simulated future environmental conditions materialise. A suitability analysis is essential for optimal utilisation of the land. The approach presented in this study will inform the regional economic development master plan and provide guidance to other delta regions experiencing severe environmental changes and wishing to consider potential future climatic and sea level changes, and their associated impacts, in their land use planning.

Keywords: Suitability zoning; GIS; saltwater intrusion; agriculture; shrimp farming; Mekong Delta

1. Introduction

The Mekong Delta and in particular the two western provinces bordering the Gulf of Thailand, i.e., Ca Mau; Kien Giang, are facing major environmental challenges, including land subsidence and sea level rise (Wassmann et al., 2004; Toan, 2014; Erban et al 2014; Smajgl et al., 2015), leading to saltwater intrusion (Deb et al., 2016; Nhung et al., 2019; Poelma et al., 2021) and coastal erosion, with the latter enhanced by the reduced sediment supply from rivers flowing into the delta (Anthony et al., 2015; Darby et al., 2016; Le Xuan et al., 2019; Tamura et al., 2020), as well as the degradation of mangrove forests (Nguyen et al., 2014; Son et al., 2015; Hauser et al., 2020). These environmental issues are causing severe socio-economic impacts, impeding regional development, and even challenging the sustainability of communities (Drogoul et al, 2016; Tran et al., 2019).

The economy of the two provinces of the Ca Mau Peninsula is mainly based on agriculture and aquaculture. In 2019, for instance, agriculture accounted for more than 88% of the total area of Ca Mau province, while it was approximately 62% for Kien Gian province (DARD Ca Mau and Kien Giang). Of the total surface area under agriculture, the total area used for rice cultivation in Ca Mau and Kien Giang province were 31.5% and 49.1%, respectively (Van et al., 2015; Nguyen Thanh et al., 2020; GSO, 2019).

Given the importance of both agriculture and aquaculture to the two provinces of the Ca Mau Peninsula and the environmental changes that the region has been experiencing, the development of an effective master plan on regional economic development requires assessing the resilience of these two key sectors of the economy to environmental impacts (Garschagen et al., 2012; ADB, 2013; Groenewold et al., 2015). Many studies have investigated the impacts of climate change, sea level rise and coastal erosion on the Ca Mau Peninsula, as well as examining trends in degradation - and loss - of mangrove forests and biodiversity (Safford et al., 1998; Campbell, 2012; Nguyen, 2014; Van Cuong et al., 2015; Nhung et al., 2019). However, no study has yet assessed the suitability of land use in the region to those two key economic sectors in view of a continuation of changes in environmental conditions, notably, saltwater intrusion, water resource availability and growing season length.

The Food and Agriculture Organization (FAO) recommends that adaptation to climate change in the agricultural sector should be based on nature-based solutions and the sustainable use of natural resources (FAO, 2016a, b; Wiebe et al., 2019). Hence, the development of farming systems and the assessment of their adaptability should be based on ecological and environmental conditions. Moreover, there has been poor implementation of Resolution No. 120/NQ-CP of the Vietnamese Government on sustainable development of the Mekong Delta on adaptation to climate change, because of a lack of both skilled human resources and awareness of climate change impacts (Nguyen, 2019; Thi & Trong, 2019).

The suitability of the land to the primary sectors of the economy depends on the climatic and soil conditions, and water resource availability, while also considering the environmental issues that the region is facing and affecting its sustainability, i.e., climate change, sea level rise, coastal erosion, and saltwater intrusion (Nguyen & Woodroffe, 2016; Tinh et al, 2019; Bui et al., 2019). It has previously been noted that current land-use planning in the Vietnamese Mekong Delta is not appropriate to the environmental conditions that the region is facing and that it will likely need to be modified in the future in view of changing salinity conditions, water resource availability and growing season length (Tran, 2019; Nguyen et al., 2020; Tran et al., 2021). Land use planning needs to consider the full benefits that it can provide, particularly its contribution to regional economic development and the sustainability of local livelihoods. Hence, this study aims to categorise the suitability of the land of the provinces of Ca Mau and Kien Giang in southern Vietnam for paddy rice cultivation and shrimp farming into four suitability levels for both current and potential scenarios of change in environmental conditions. This land suitability analysis uses a GIS-based Analytic Hierarchy Process (AHP) approach, and is based on soil characteristics, the level of saltwater intrusion, the availability of water for rainfed agriculture, and the growing season length.

2. Study area

This study area focuses on the Ca Mau and Kien Giang provinces of the Ca Mau Peninsula in southern Vietnam. Ca Mau province is divided into nine districts, including the city district of Ca Mau, the capital and only city of the province, while Kien Giang province comprises 12 districts and three cities (Figure 1). The Ca Mau Peninsula is relatively flat and low-lying with typical elevation of approximately 0.3-2 m only above sea level, excluding the hills and mountains located in the Northwest of Kien Giang province.

The region experiences a tropical monsoon climate with two distinct seasons, the rainy season lasting from May to October and a dry season during the remaining months of the year (Le et al., 2021). The flow of the Mekong River system does not contribute to the water resources of the region; nonetheless, the Ca Mau Peninsula receives approximately 2400 mm of rain per year (Binh et al., 2005; Tue et al., 2014), of which 90% is the result of the southwest monsoon (Figure 2) (Nhung et al., 2019; Lee & Dang, 2020; Dang et al., 2020). Moreover, in October, when the monsoon weakens, heavy rain may occur due to storms associated with the movement of the Inter Tropical Convergence Zone (ITCZ) (Delgado et al., 2012; Dang et al., 2020).

Figure 1. The study area consisting of the provinces of Ca Mau and Kien Giang

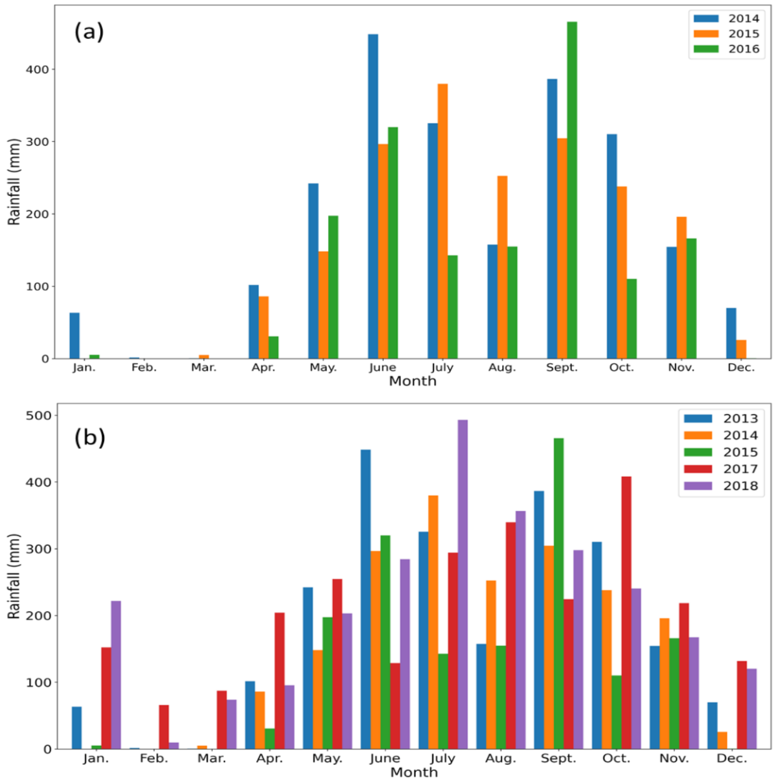

Figure 2. Monthly average rainfall at Ca Mau (a) and Kien Giang (b) provinces for different years

In the past decade, the 300 km long coastline of the provinces of Ca Mau and Kien Giang (Nguyen & Woodroffe, 2016; Luom et al., 2021) has suffered severe erosion and significant loss of land, as a result of the degradation of the mangrove forests and their loss due to their conversation to agriculture and aquaculture (Van et al., 2015; Truong & Do, 2018; Veettil et al., 2019), and a reduction in alluvium originating from the Mekong River (Nguyen et al., 2013; Karlsrud et al 2017, 2020; Li et al., 2017; Nguyen et al 2020). The economic benefit of aquaculture is the driver to the clearance of the mangrove forests, which potentially threatens the sea dikes protecting the low-lying areas from coastal flooding (Bosma et al., 2016; Danh et al., 2014; Albers & Schmitt, 2015; Phan et al., 2015; Besset et al., 2019). Moreover, unplanned development, notably for agriculture, has led to excessive groundwater extraction, causing land subsidence, and hence further enhancing the impact of sea level rise and reduced river sediment supply on coastal erosion, in addition to impacting the quality of surface and groundwater supplies (Chau et al., 2015; Stoop et al., 2015; Dao et al., 2016; Le et al., 2021). These anthropogenic stressors and unbalanced development are thus causing unintended consequences and impacting on the sustainability of the region (Alongi 200, 2012; Van Nguyen et al., 2020; Loc et al. 2021).

Current farming systems in the region include the mangrove-black tiger shrimp (or tiger prawn) and the shrimp-rice farming models. The former is the result of measures aimed at restoring the mangrove forest ecosystem, while the latter consists of shrimp farming during the dry season and cultivating rice during the rainy season (Figure 3). Along with the application of technical advances and development towards organic aquaculture, these farming models have proven to be environmentally friendly and economically sustainable.

Figure 3. The rice-shrimp farming system in Ca Mau Province

3. Materials and Methods

This study consisted of collecting data from previous projects and publicly available datasets, as listed in Table 1. Information on the soil characteristics of the region was collected from two sources to generate the soil map presented in section 3.1. A hydrodynamic model was used to estimate the extent of salinity intrusion under different scenarios of change, as presented in section 3.2. The rainfall map was produced by calculating the average rainfall over a number of years. The suitability of the study area for rice crop cultivation and shrimp farming was then assessed using a map overlay analysis with the weight of each variable estimated using the AHP methodology. Figure 4 illustrated the methodological framework.

Table 1. Data used in this study

Data types	Sources	Period of data
Soil type	FAO (2006a,b); Vu et al. (2011)	2011 - 2019
Salinity intrusion map	Derived from hydrological model MIKE 11	2017 - 2019
Rainfall distribution map	Southern Regional Hydro-meteorological Center	2015 - 2019
Farming period	Khang et al. (2010)	2000 - 2099
Land use/land cover	Ca Mau and Kien Giang Department of Agriculture and Rural Development (DARD)	2017 - 2019

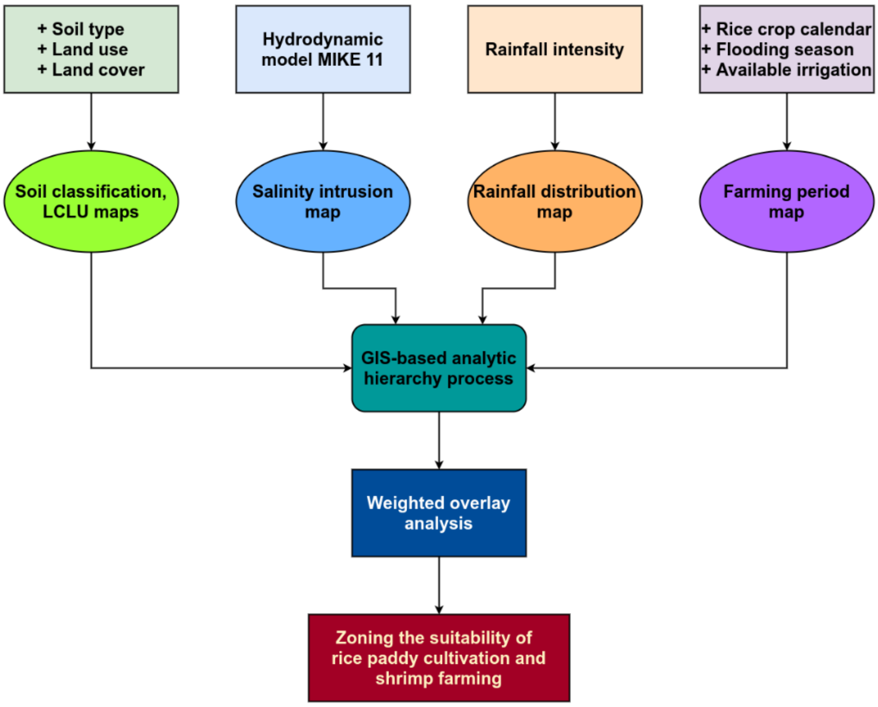

Figure 4. The methodological framework

3.1. MIKE 11 Hydrodynamic model

MIKE 11 is a one-dimensional unsteady flow hydraulic model solving the vertically integrated equations of conservation of continuity and momentum. The solutions to the equations of continuity and momentum are employed as an implicit finite difference scheme with a 6-point Abbott scheme (Abbott and Ionescu, 1967). The main governing equations are known as the Saint-Venant equations (Shooshtari, 2008). Boundary types include water level (h), flow discharge (Q) and Q/h relation. The water level must be specified at either the upstream or the downstream boundary of the model. In this study, MIKE 11 was used to obtain the salinity intrusion maps for different scenarios. The model setup, its boundary conditions and its calibration are described in Khang (2010) and Tran Anh et al. (2019).

3.2. Analytic hierarchy process

The AHP is the most effective multi-criteria decision-making technique and, for this reason, is used in many fields (Chandio et al. 2013; Guler & omralıoglu, 2017; Ali & Ahmad, 2018). The objective of the AHP is to build a matrix describing the relative significance of every variable against potential alternatives. It does so by deriving weights for different variables according to the degree of influence they have (Ali et al. 2019). In this study, the AHP technique was applied to rank the influence of four environmental variables affecting the suitability of the land for rice crop cultivation and shrimp farming. The application of the AHP technique involved interviewing local people and experts, as well as field observations with the numerical scale of of Saaty (1980) and Ali et al. (2019) used to rank each variable from one to nine (one representing the least important variable and nine the most important).

The AHP involves calculating the Consistency Ratio (CR), Consistency Index (CI), and Random consistency Index (RI), which are described in Saaty (1980, 1990); Saaty and Vargas (2000); Ali et al. (2019), and calculated as follow:

$$CR = \frac{CI}{RI} \tag{1}$$

These two indexes represent the consistency index of a randomly generated pair-wise comparison matrix and depends on the number of factors being compared (Saaty, 1980). Table 3 presents the pair-wise comparison matrix of the current study. The CI was calculated using Equation (2):

$$CI = \frac{\lambda - n}{n-1} \tag{2}$$

where n is the number of factors and λ is the average value of the consistency vector.

The AHP-based map, $F_{(AHP)}$, was created as the weighted sum of the reclassified conditioning factors, which were multiplied by their weights according to Equation (3):

$$F_{(AHP)} = \sum w_i x_i \tag{3}$$

where the AHP-based map, w_i is the weight of factor i, and x_i is the reclassified classes of each factor i.

Table 2. Environmental factors and their reclassification.

Factor	**Interval**	**Reclassification**	**Percentage of basin area (%)**	**Relative importance for rice**
Soil type				**3**
Salic Fluvisols,	Moderate suitability	1	26.2	
Protothionic Fluvisols	Low suitability	2	23.4	
OrthiThionic Fluvisols	High suitability	3	37.3	
Fluvisols	Very suitability	4	8.0	
Others	Very low suitability	5	5.1	
Salinity level (‰)				**1**

	< 4	1	47.1	
	3 - 45	2	64.2	
	15 - 20	3	3.9	
	2 - 40	4	65.6	
	10 - 25	5	11.6	
Rainfall amount (mm)				**2**
	< 1400	1	0.0	
	1401-1800	2	10.5	
	1801-2200	3	32.8	
	2201-2600	4	44.0	
	>2600	5	12.7	
Farming period (days)				**4**
	< 220	1	63.1	
	220 - 330	2	30.1	
	> 330	3	6.8	

Table 3. Pair-wise comparison matrix, normalized and calculated weights of factors (wi)

Pair-wise comparison matrix

Factor	Salinity intrusion level	Soil type	Rainfall distribution	Farming period
Salinity intrusion level	1	3	5	7
Soil type	1/3	1	3	5
Rainfall distribution	1/5	1/3	1	3
Farming period	1/7	1/5	1/3	1

Normalized weights

Factor	Salinity intrusion level	Soil type	Rainfall distribution	Farming period	Weight for rice, w_i
Salinity intrusion level	0.60	0.66	0.54	0.44	0.56
Soil type	0.20	0.22	0.32	0.31	0.26
Rainfall distribution	0.12	0.07	0.11	0.19	0.12
Farming period	0.09	0.04	0.04	0.06	0.06

(i) CR=0.07; CI=0.065; RI=0.9

(ii) A CR value of 0.1 or < 0.1 is considered as acceptable for decision making

3.3 Soil type map

Figure 5 shows that the main soil types on the west coast of the Mekong Delta, including the Salic Fluvisols, Protothionic Fluvisols, OrthiThionic Fluvisols, and Fluvisols group of soils (FAO, 2006a,b; Vu et al., 2011). Thus, saline and acidic soils prevail in both Ca Mau and Kien Giang provinces (Vu et al., 2011). Medium and lightly saline soils are the largest category of Ca Mau province, covering 191,110 ha, which corresponds to 36.2% of the area of the province. In Kien Giang province, deep saline acid sulphate active soils, deep acid sulphate active soils, and dystric plinthosols soils account for 15.8%, 18.2% and 12.8% of the area of the province, respectively. Most of the area is used for two to three rice crops per year, a small percentage is dedicated to the rice-shrimp and rice-fish farming systems, with some land used for growing pineapple and sugarcane and shrimp farming on its own.

Field surveys were conducted in 2019 in Ca Mau and Kien Giang provinces to determine the suitable levels of soils for rice cultivation, which was classified on a scale from 1 to 4 based on FAO (2006a) and Vu et al. (2011) (Table 4).

Table 4. Suitable levels for soil classification

Level		Suitable level	Description
1	N	Not suitability	Soil cannot support the land use for rice crop on a sustained basic, or soil which benefits do not justify neecessary inputs.
2	S3	Low suitability	Soil with limitations so severe that benefits are reduce and/or the inputs needed to sustain production are increased
3	S2	Moderate suitability	Soil is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity.

4	S1	High suitability	Soil without significant limitations and high suitable for rice crop

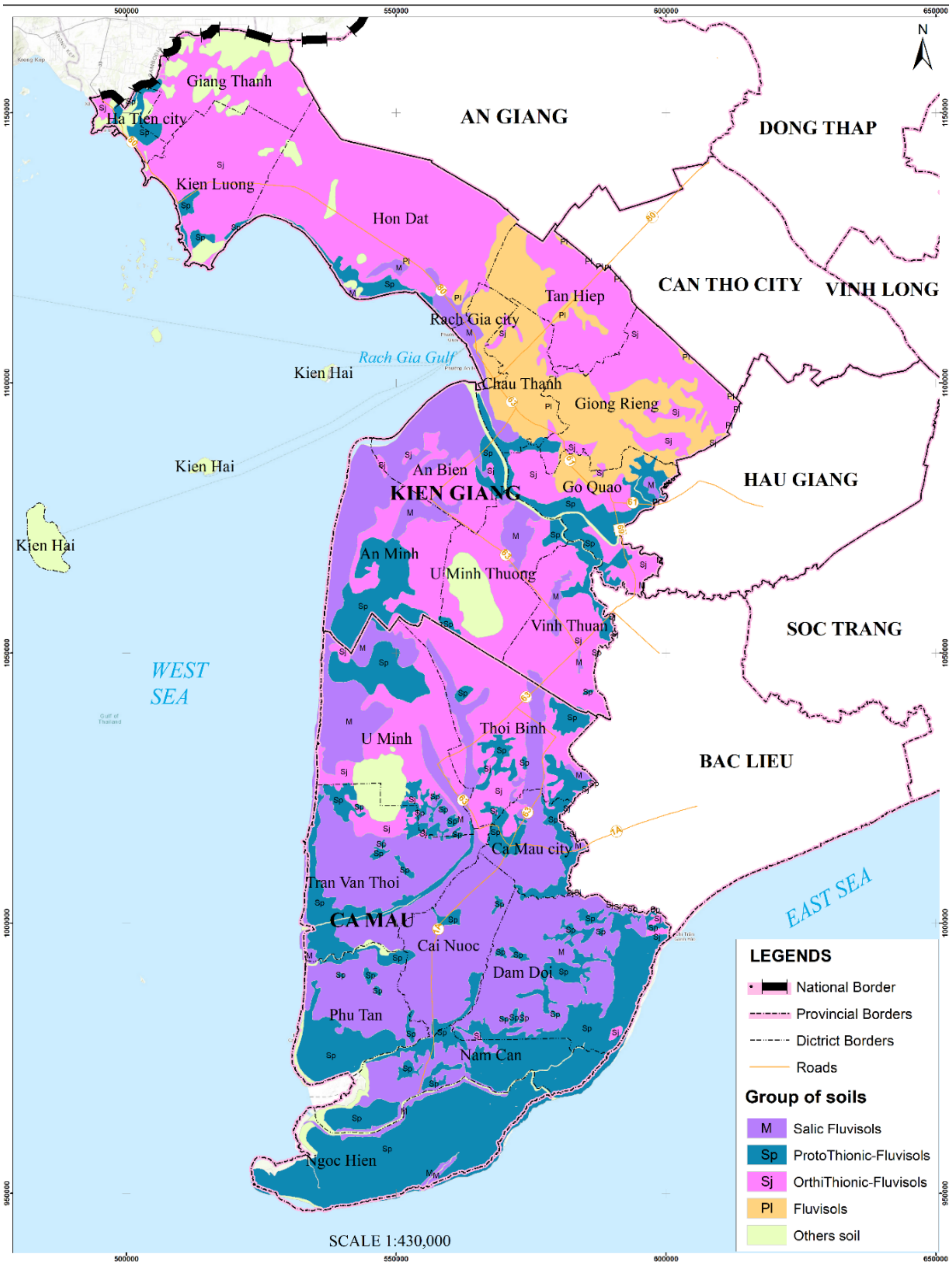

Figure 5. Soil types in the provinces of Ca Mau and Kien Giang

3.4 Salinity intrusion map

The hydrodynamic MIKE 11 model was calibrated by adjusting the Manning coefficient and used to simulate the salinity concentration for all rivers and floodplains of the entire study area. The model setup, its boundary conditions, as well as calibration and validation followed the approach presented in in Khang (2010) and Tran Anh et al. (2019). The model domain covered the Mekong delta from Kratie and Tonle Sap Lake, Cambodia, to the southern tip of the Cau Mau peninsula, including east sea and west sea coastline. The model calibration and validation were performed using water level and discharge data for main stations such as Chau Doc, Tan Chau, Can Tho, My Thuan, as shown in Tran Anh et al. (2019). The calibrated Manning coefficient for main rivers and channels, floodplain is show in Table 5.

Table 5. The calibrated Manning coefficients in the distinct parts of the river system

Components	Manning coefficient range
1. Main Tien and Hau river	n = 0.017- 0.030
- Upstream river	n = 0.028-0.030
- Middle delta	n = 0.022-0.026
- Near the sea	n = 0.017-0.022
2. Primary channels	n = 0.022-0.030
3. Field channels	n = 0.028-0.032
4. Floodplain	n = 0.028-0.032

The model was forced using three scenarios of extreme conditions of salinity intrusion together with a water resource deficit during the dry season that is unfavourable to both agriculture and aquaculture. Only scenario 4 consisted of conditions favourable to agriculture and aquaculture, in terms of water supply availability and operational hydraulic works (sluices, sea dykes, culverts, canals, and outlet gates) (Table 6). The results of model simulations are provided in Appendix 1.

Table 6. Hydrodynamic simulation scenarios for MIKE 11 model

Scenarios	**Salinity intrusion**	**Hydraulic works**	**Season**	**Water resources**
Scenario 1	Maximum	Current status	Dry	Deficit
Scenario 2	Maximum	Current status	Rainy	Deficit
Scenario 3	Minimum	Current status	Rainy	Deficit
Scenario 4	Maximum	Planned	Dry	Adequate

4. Results and discussion

4.1 Mapping suitable zones for the agriculture and aquaculture according to individual variables

The mapping of the suitability of the land of the region to rice crop cultivation and shrimp farming was done separately. Then, suitable levels for rice cultivation each input factor is discussed in following sub-sections.

4.1.1 Areas suitable for agriculture and aquaculture in relation to soil properties

Figure 6 depicts the suitable levels over the study region on the basis of the soil conditions. The salinity and alkaline levels are suitable for rice cultivation. Therefore, the intensive cultivation of rice or the combination of shrimp-rice intercropping depends on the salinity of the water in the agricultural production area. Based on the soil map individually, one can see that the high suitability of soil for rice cultivation are found in Kien Giang province, specifically in the districts of Tan Hiep, Chau Thanh, Giong Rieng, and Go Quao as well as in Rach Gia city. Moderate suitable level of soil for rice cultivation was found in both Ca Mau (Tran Van Thoi, Cai Nuoc, Dam Doi, and Phu Tan districts) and Kien Giang (Hon Dat, Giang Thanh, Tan

Hiep and some part of Giong Rieng). The remaining area is not suitable for rice crop cultivation.

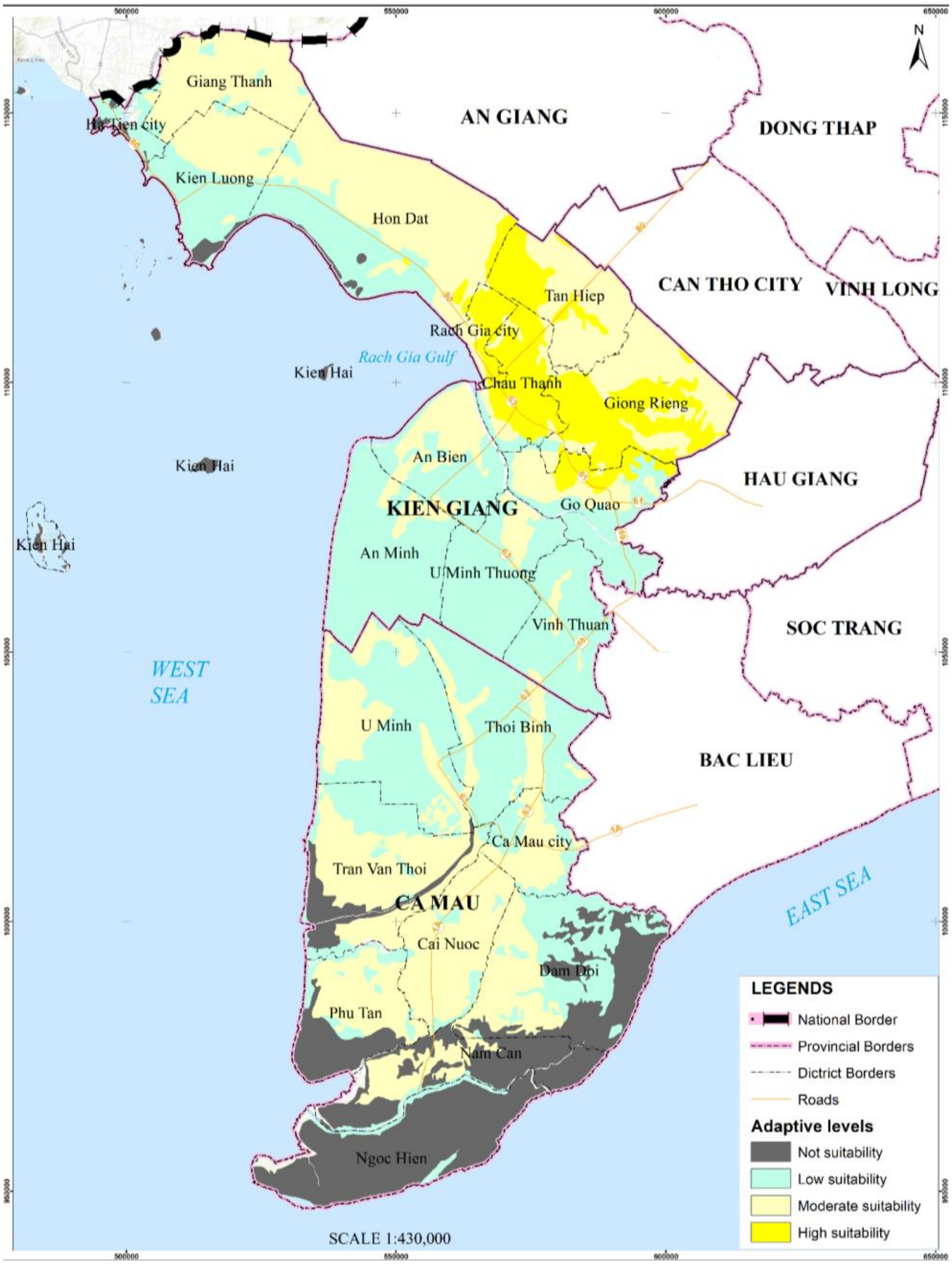

Figure 6. Suitable levels of soil map for cultivation in Ca Mau and Kien Giang provinces

4.1.2 Areas suitable for agriculture and aquaculture in relation to salinity levels

The range of salinity suitable for rice and shrimp cultivation were obtained from the handbook of technical process of rotating black tiger shrimp - rice, intercropping with giant river shrimp (*Macrobrachium rosenbergii*) published by Ca Mau DARD (Table 7).

Table 7. Suitable salinity level for rice crop and aquaculture species (Source: Ca Mau DARD)

Objects	**Suitable level of salinity**	**Remarks**
Rice varieties with high tolerance to saline conditions	< 4‰	According to the Vietnam Academy of Agriculture Sciences (VAAS)
Black tiger shrimp or Giant tiger prawn	3‰ - 45‰	Extreme range for tiger shrimp
	15‰ - 20‰	The best salinity range
Whiteleg shrimp or King prawn	2‰ - 40‰	Extreme range for whiteleg shrimp
	10‰ - 25‰	The best salinity range

The salinity intrusion maps for four scenarios are shown in Figure 7. The detail zoning of suitability for rice cultivation and shrimp farming is shown in Table 8. From Figure 7a can be seen that, the salinity intrusion with concentration more than 25 ppt in scenario 1 cover almost Ca Mau province except Tran Van Thoi district due to higher elevation. For scenario 2 and 3, the salinity level is still high (10 – 25 ppt) and spreading almost Ca Mau province and few parts of Kien Giang province such as An Minh and Vinh Thuan districts (Figure 7b, c). When all hydraulic construction will be built in the future and fully operation in scenario 4, all parts of Kien Giang province and half area of Ca Mau province are protected from saline water by sluices and other constructions (Figure 7d).

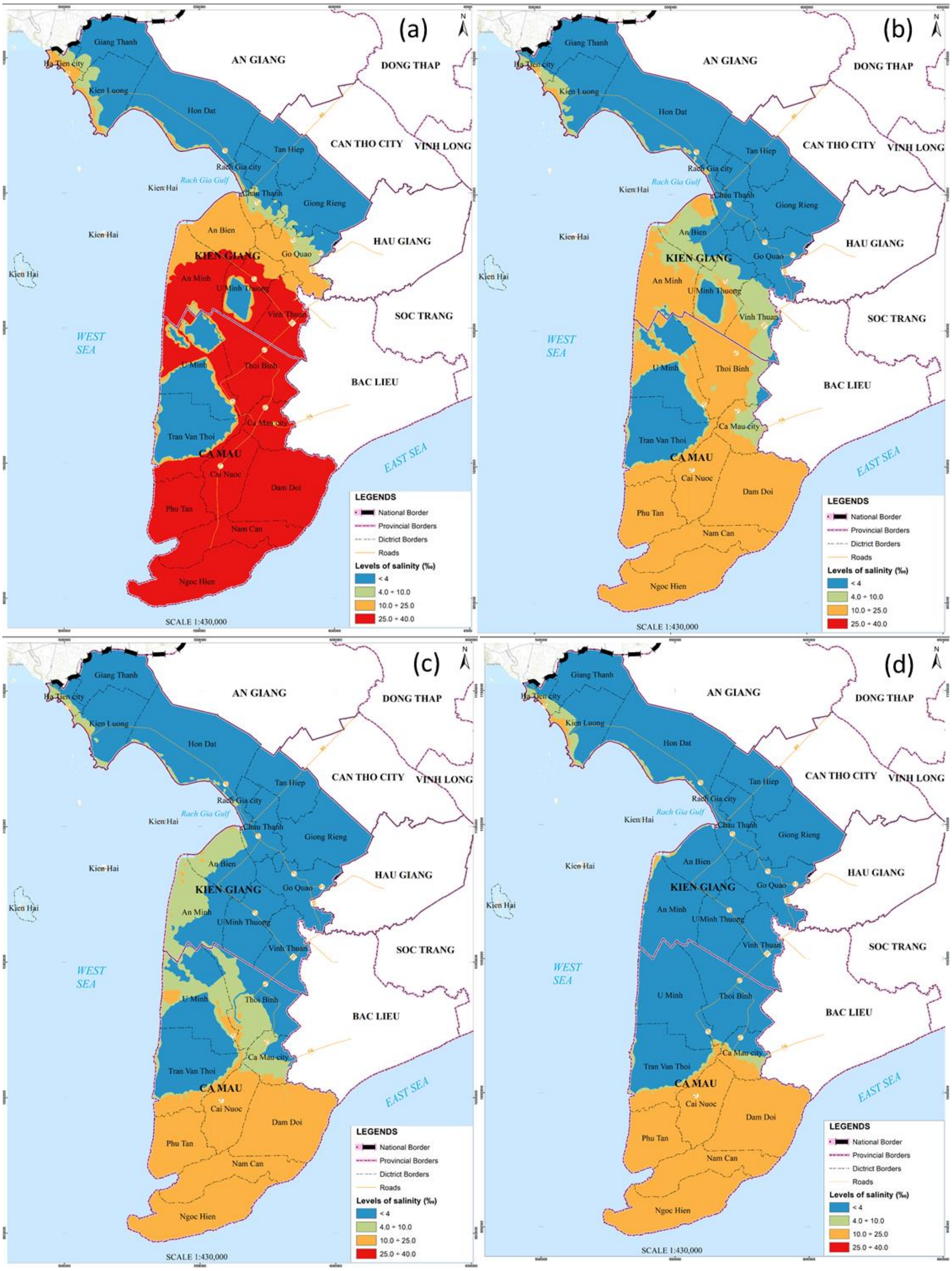

Figure 7. Salinity intrusion over the study area according to four different scenarios

Table 8. Categorisation of the suitability of the land to rice crop cultivation and shrimp farming under different saltwater intrusion scenarios

Salinity (‰)	**Capacity of adaptation**	**Scenarios of saltwater intrusion**			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
< 4	Suitable for rice cultivation	- Area bounded by Bo Bao canal, Doc River and Tieu Dua canal, Cai Tau river. - Area between Rach Tieu Dua, Bo Bao canal, canal 11 and Trem river. - U Minh Thuong forest area; - About ½ of Kien Giang province is north of National Highway 61.	- Area bounded by Bo Bao canal, Doc River and Tieu Dua canal, Cai Tau river. - Area between Tieu Dua Rach, Bo Bao canal, 11th canal and Trem river; - U Minh Thuong forest area; - North of Cai Lon river.	- Area bounded by Bo Bao canal, Doc River and Tieu Dua canal, Cai Tau river; - Area between Tieu Dua Rach, Bo Bao canal, canal 11 and Trem river; - The North-East region of Ca Mau province; - Most of Kien Giang province, east of Xeo Ro canal.	The area of Kien Giang and Ca Mau north of Doc River
4 - 10	- Less suitable for rice cultivation, low yield - Not suitable for aquaculture	- To the west of Giang Thanh and Kien Luong districts; - Roadside Highway 61.	- To the west of Giang Thanh and Kien Luong districts; - Along the National Highway 63; - West of Vinh Thuan district, Thoi Binh district, Ca Mau city.	- Coastal area of Ha Tien city, Kien Luong district, Hon Dat, Rach Gia city; - West of Xeo Ro canal; - North of Ganh Hao river (except for areas with salinity < 4.0‰).	The area along the west coast of Kien Giang province
10 - 25	- Not suitable for rice cultivation - Suitable for aquaculture	- Coastal area of Ha Tien city, Kien Luong district, Hon Dat, Rach Gia city; - Area between National Highway 61 and Highway 63.	- The remaining area.	The remaining area (south of Doc River).	The remaining area (south of Doc River).
25 - 40	Not suitable for rice and aquaculture	North of National Highway 63 (except for areas with salinity <4.0‰)	No area has this salinity range	No area has this salinity range.	No area has this salinity range.

4.1.3 Farming period

The farming or growing period refers to the time-period during which rice cultivation is possible considering the season during which the land is flooded and also saltwater level. Based on the results of Khang et al. (2010), we used the potential farming period for current status and future crop period to adapt to climate change and sea level rise including forecasted flooding. Three levels of suitability for rice crop with different rice farming periods are ranging from 220 days to 330 days as described in Table 9.

Table 9. Mapping the suitability of the land according to the farming period

Suitable level	Adaptability for production	Rice farming period
Level 1	Low suitability (S3)	< 220 days (1 crop)
Level 2	Moderate suitability (S2)	220 - 330 days (2 crops)
Level 3	High suitability (S1)	> 330 days (3 crops)

Figure 8 depicts the possible duration of rice cultivation considering flooding duration, salinity intrusion, and irrigation water availability (Khang et al., 2010). It can be seen that the rice cultivation with 1 crop to use short-term rice varieties under 220 days that is suitable for most area of Ca Mau province during current state from 2000-2020 (Figure 8a). The longer-term rice cultivation more than 220 days and to 330 days may apply in most area of Kien Giang province. However, short-term rice cultivation under 220 days should be mainly sowed in both Ca Mau province and most area of Kien Giang province due to flooding, climate change and sea level rise (Figure 8b).

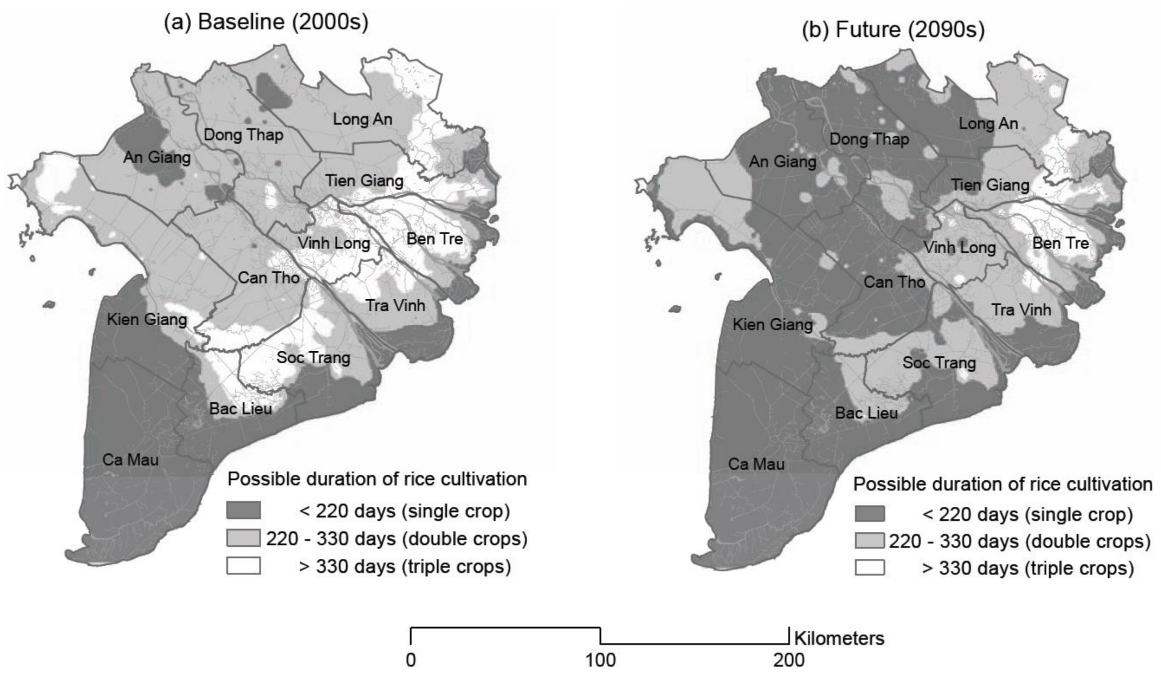

Figure 8. Farming period for rice cultivation under current and future conditions (adapted from Khang et al., 2010).

The results of zoning suitability for rice cultivation based on farming periods are shown in Figure 9. It can be seen from the figure that almost area of Ca Mau province has low suitability for rice cultivation based on the farming periods due to flooding and salinity intrusion by sea level rise because Ca Mau province is low-lying area (Wassmann et al., 2005; Groenewold et al., 2015; Quach, 2018). Only few parts of Kien Giang are zoned with high suitability for rice cultivation due to their high elevation and not affected by salinity intrusion and flooding.

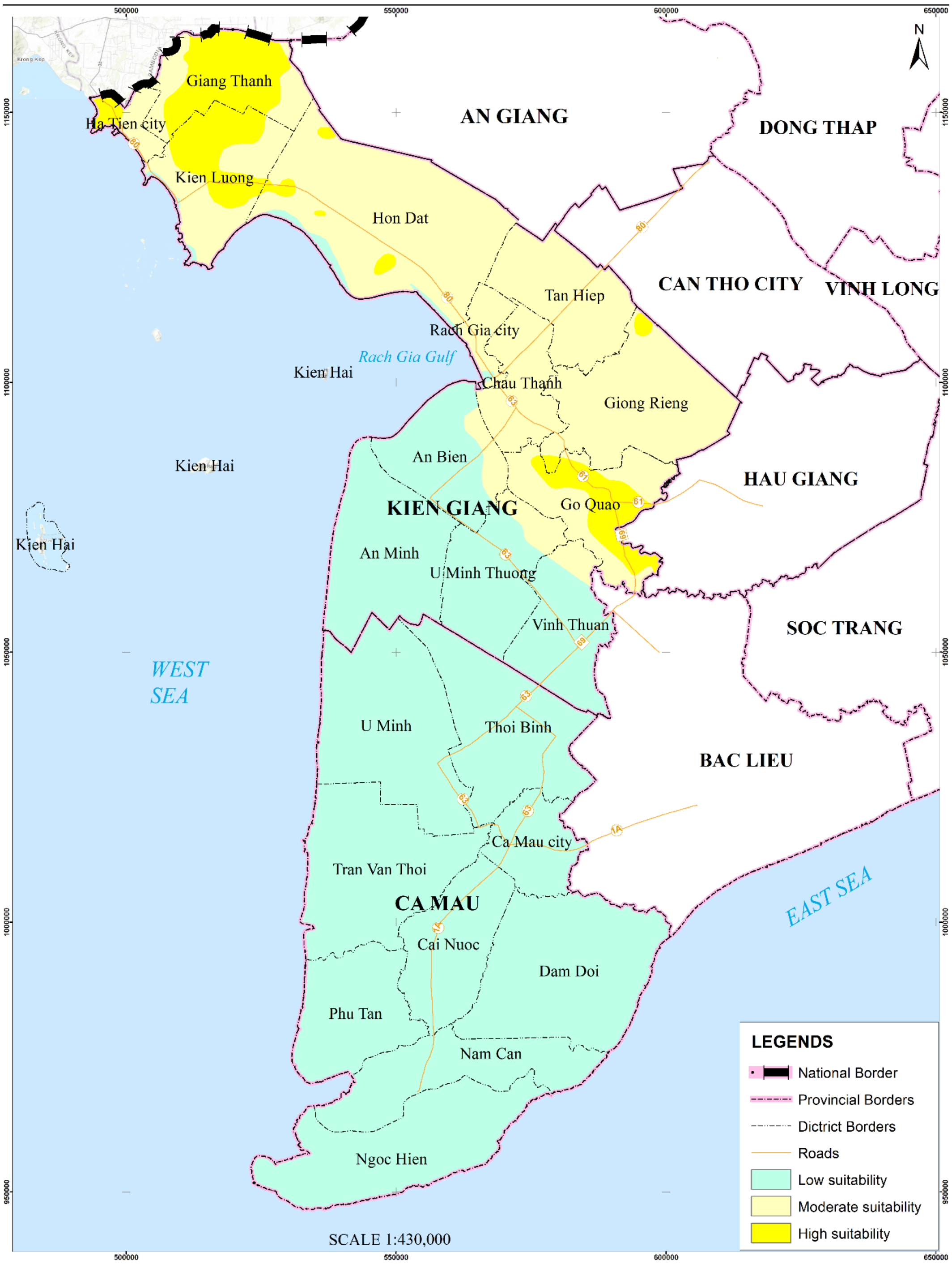

Figure 9. Suitability level for paddy rice cultivation based on the farming periods

4.1.4 Rainfall distribution

Rainwater and groundwater are the two main source of water in the provinces of Ca Mau and Kien Giang (Dao et al., 2014; Deb et al., 2016; Tinh et al., 2019). The two provinces receive a large amount of precipitation during the rainy season, with total annual rainfall averaging 1900-2400 mm. Figure 10 shows the spatial distribution of annual rainfall for the period 2015-2019 over Mekong Delta. Total rainfall amount is highest in Ca Mau with 2400 mm, and in Kien Giang varies from 1900-2300 in rainy season. Moreover, it can be seen that the rainfall intensity during rainy season (May to October) reached maximum value of 300 - 350 mm per month in Ca Mau and Rach Gia stations (Figure 10).

Figure 11 show the spatial rainfall distribution in the study area in 2019 with very high rainfall intensity in U Minh, Thoi Binh - Ca Mau; An Minh, U Minh Thuong and An Bien in Kien Giang. This mean the water available in the study area is contributed mainly from rainwater.

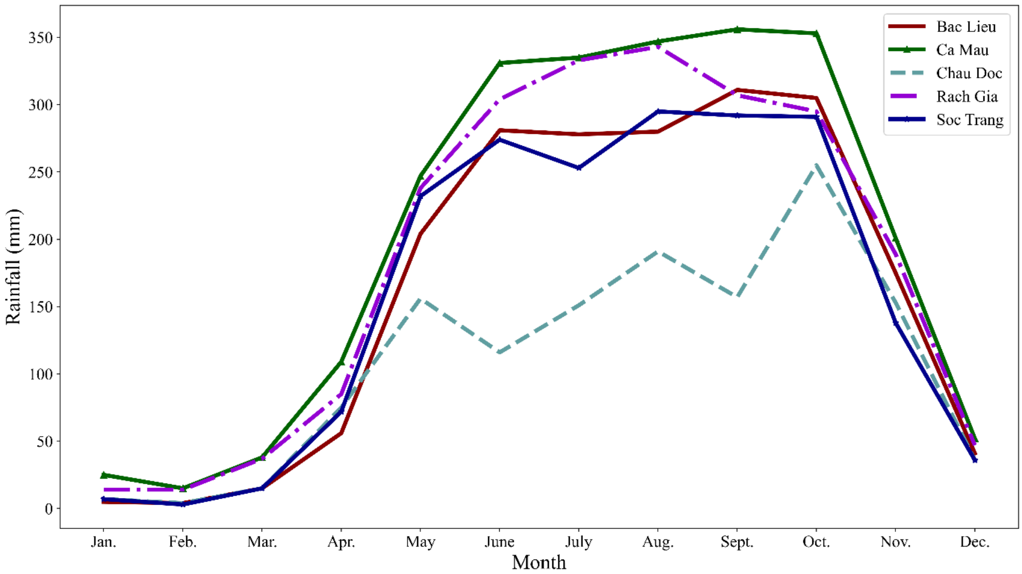

Figure 10. Season cycle of precipitation at five weather stations in study region during 2015-2019 *(Source: Southern Regional Hydro-Meteorological Center)*

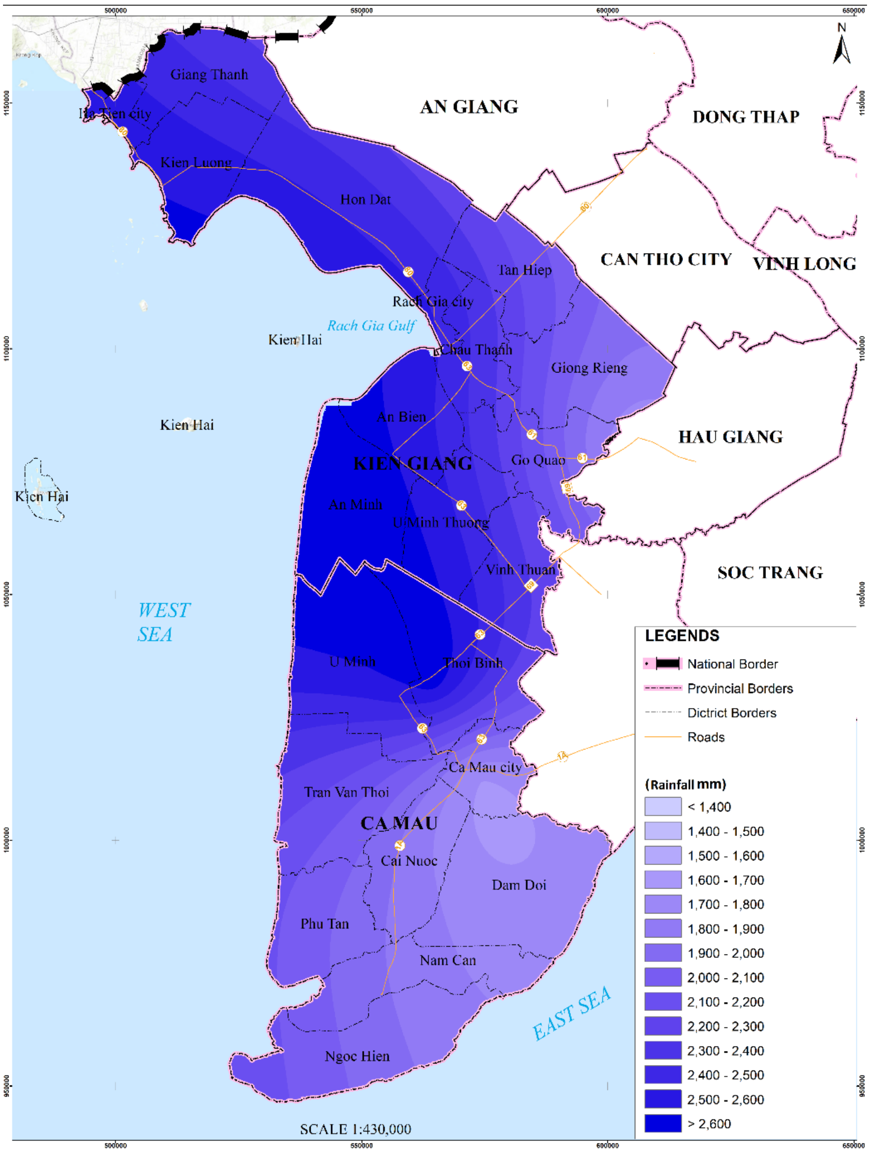

Figure 11. Spatial distribution of rainfall for the year 2019 over the study area

(Source: Southern Regional Hydro-Meteorological Center)

4.2 Assessment of current zoning condition

The current land use in western Mekong Delta including Ca Mau and Kien Giang show in Figure 12. For the agricultural and fishery production of Ca Mau province, according to the policy of agricultural restructuring, economic restructuring in the direction that the proportion of fishery, agriculture and forestry sectors decreases gradually, but on contrary progressively increase the proportion of service sector. Therefore, the total area of rice cultivation tends to decrease (from 125,581 hectares in 2010 to 115,585 hectares in 2019) in the period 2010 - 2019.

However, rice productivity increased by about 15% compared to 2010 (rice yield in 2010 was 3968 kg/ha, in 2019 was 4556 kg/ha). In contrast, aquaculture area increased significantly from 296,300 hectares in 2010 to 305,021 hectares in 2019 with fish production increasing from 387,070 tons in 2010 to 565,650 tons in 2019. Currently, Ca Mau province is developing new aquaculture methods such as ecological shrimp farming, shrimp farming combined with rice, shrimp farming in rotation, intercropping with other aquatic species (e.g., crabs, blood cockles, mussels).

For the period 2001-2014 in Kien Giang, rice land area has always expanded that focused on intensive farming to increase number of crops to effectively exploit the land resources. However, from 2015 to 2020, the ability to expand the rice area is not much, the pressure on improving the efficiency of land use to create high value, sustainable development, in order to bring high income for farmers is very high. Therefore, it is necessary to start conversion to aquaculture with concentrating in 3 main areas: Long Xuyen Quadrangle, that focuses on developing industrial and semi-industrial shrimp farming; developing shrimp - rice rotation, extensive shrimp farming, improved extensive shrimp farming in the U Minh Thuong region; Phu Quoc - Kien Hai island and island communes of Kien Luong district and Ha Tien town to develop cage farming of fish and bivalve molluscs (clams, oysters, mussels, scallops).

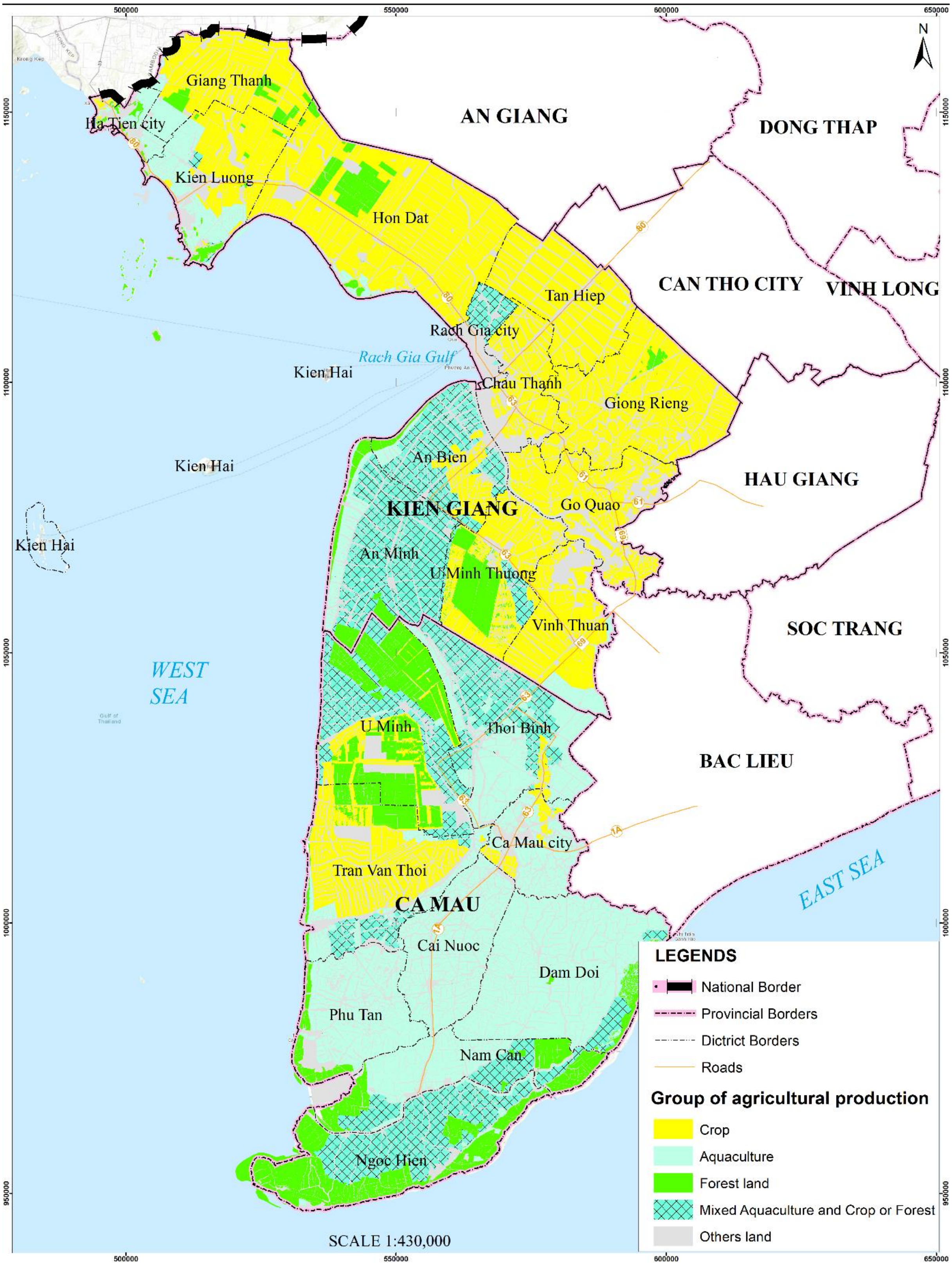

Figure 12. Land use in the study region

4.3 Overall assessment of the suitability of the land to the two primary sectors of the economy

The mapping of the suitability of the land to rice crop cultivation and shrimp farming was produced using AHP and overlaying the soil classification map (Figure 6), scenarios of saltwater intrusion (Figure 7), growing season length (Figure 8), and the annual rainfall distribution (Figure 11). The results of map overlaying process are four maps of zoning suitability of paddy rice cultivation corresponding to four scenarios as shown in Figure 13. It can be seen that there is very small area in Go Quao, Kien Giang with high suitability of rice cultivation under scenarios 2, 3, 4. Meanwhile, the area of the moderate suitability for rice cultivation is spreading out over large area of northern Kien Giang and some parts in Tran Van Thoi district of Ca Mau province (Figure 13 b, c, d). Currently, the agriculture (paddy rice) in Kien Giang account for 49.1% of total agricultural land (see Table 3S. Appendix 2) and this rate is planned to increase in the future as described in the master plan of Kien Giang (Decision No. 405/QD-UBND dated February 24, 2016, and Decision No. 41/QD-UBND dated January 9, 2017 by the Chairman of Kien Giang).

There is a large area with low suitability for rice cultivation in Ca Mau. However, these areas are more suitable for aquaculture (shrimp farming), currently accounting for 43.8% of total agricultural land instead of paddy rice cultivation (see Table 3S. Appendix 2). This rate will increase to 60.5% in 2030. This is completely in line with the development orientation of Ca Mau province on promoting the aquaculture industry to become the top income from aquaculture and the province's strengths that contribute a large proportion to the province's GDP (Decision No. 537/QD-TTg dated April 4, 2016, by the Prime Minister and Decision No. 1116/QD-UBND dated June 30, 2016, by Ca Mau Chairman).

Figure 13a also shows an extensive area of no suitability for rice crop in Ca Mau province, corresponding to scenario 1 is due to maximum salinity intrusion, a very dry season and water deficit and current hydraulic works (sluice, sea dykes, intakes, culvert, canal, tidal, and outlet gate) without effectively preventing saline water intruded to farmland. In addition, the strip of land along the East Sea in Ca Mau province will be more severely affected by sea level rise because the tide magnitude in the East Sea is higher than those in the West Sea about 0.8 - 1.2 m. This is similar for scenarios 2, 3, 4 but less area than those in scenario 1. For scenario 4, although favourable conditions of water availability, complete hydraulic constructions and full operation to reduce salinity intrusion but the extended area of rice cultivation with moderate suitability is not significant (Figure 13d) because rice cultivation in Ca Mau only accounts for 31.5% of total agricultural land and will likely decrease in the future if the master plan of Ca Mau province materialises (Table 3S. Appendix 2)

Finally, zoning suitability of agriculture and aquaculture in Ca Mau and Kien Giang provinces conclude that Ca Mau province should focus primarily on aquaculture (shrimp farming) and that rice crop cultivation should focus mainly in Kien Giang province. The zoning for rice crop area and percentage under different suitable levels is illustrated in Table 10.

From the above collected information along with the current status of agricultural and aquaculture production, we can conclude that the zoning of suitability based on natural factors as mentioned above is reasonable and has scientific basis as well as in accordance with the actual production and the economic development orientation of two provinces. This study is useful for the decision makers of the two provinces to plan future implementation considering natural factors such as saline intrusion, climate change and coastal erosion. Furthermore, zoning for realistic planning and effective management with the participation of people and stakeholders is important with bottom-up approach by survey of farmers demand and expectation. From there, the overall development planning of the provinces for far future is grounded and feasible for implementation. Therefore, zoning the adaptability of agriculture and aquaculture in the present and in the future is important and meaningful.

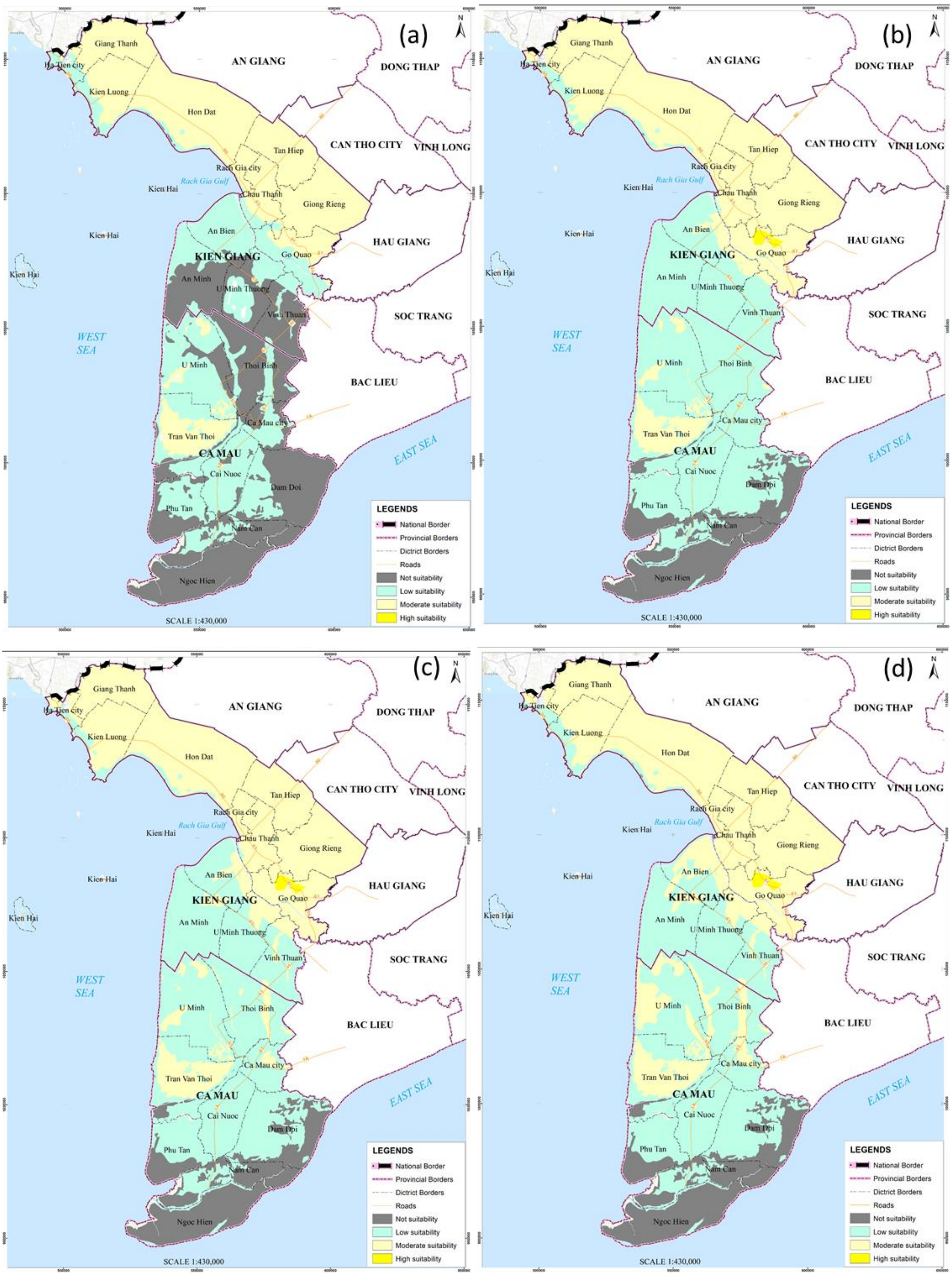

Figure 13. Zoning suitable levels of paddy rice cultivation for four scenarios

Table 10. Spatial distribution of suitable levels for paddy rice cultivation

Value	Levels	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		Estimated area (ha)	Estimated area (%)	Estimated area (ha)	Estimated area (%)	Estimated area (ha)	Estimated area (%)	Estimated area (ha)	Estimated area (%)
1	Not suitability	356233.8	32.7%	142572.0	13.1%	142594.1	13.1%	142081.4	13.1%
2	Low suitability	347377.5	31.9%	511361.6	47.0%	483446.8	44.4%	449716.4	41.3%
3	Moderate suitability	372505.7	34.2%	418194.5	38.4%	446087.2	41.0%	480330.4	44.1%
4	High suitability	5.3	0.0%	3994.3	0.4%	3994.3	0.4%	3994.3	0.4%

5. Conclusion

In this study, the suitability of the two provinces of the western Mekong Delta to rice crop cultivation and shrimp farming was mapped on the basis of four factors: soil properties, saltwater intrusion, farming period and the distribution of rainfall under current and potential scenrios of change in environmental conditions, with the latter simulated using the MIKE 11 hydrodynamic model. The suitability zoning for paddy rice cultivation and shrimp farming was performed using a GIS-based AHP approach, resulting in the categorisation of the land according to four suitability levels for each of the two sector. The results indicate that the properties of the soil and salinity intrusion are the two factors affecting the most agriculture in the region, followed by the farming period and the distribution of rainfall. During the dry season and given the current state of hydraulic works (which does not fully protect farmland from saltwater intrusion), the area on the Kien Giang side above Highway 61 has favourable conditions for rice cultivation, while the northern region of Ca Mau province is only suitable for brackish water aquaculture. Moreover, under ideal conditions, when the irrigation system and hydraulic works are completed and the sluices fully control saline intrusion into the farmland, the entire area of the Western Mekong Delta will be capable of cultivating three rice crops or applying different shrimp-rice models. These models are sustainable for agricultural and aquaculture production that bring high economic efficiency and ensure high income for local people. Finally, to zone the suitability of the land for agricultural and aquaculture production in accordance with practice and with higher accuracy, it is necessary to further study the impact of other factors such as topographical conditions, water demand and water use for each cultivar or plant and aquatic species.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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