

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

3 **Highlights**

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

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

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36 **Abstract**

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

56

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

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60

61 **1. Introduction**

62 The Mekong Delta and in particular the two western provinces bordering the Gulf of Thailand,
63 i.e., Ca Mau; Kien Giang, are facing major environmental challenges, including land
64 subsidence and sea level rise (Wassmann et al., 2004; Toan, 2014; Erban et al 2014; Smajgl et
65 al., 2015), leading to saltwater intrusion (Deb et al., 2016; Nhung et al., 2019; Poelma et al.,
66 2021) and coastal erosion, with the latter enhanced by the reduced sediment supply from rivers
67 flowing into the delta (Anthony et al., 2015; Darby et al., 2016; Le Xuan et al., 2019; Tamura
68 et al., 2020), as well as the degradation of mangrove forests (Nguyen et al., 2014; Son et al.,
69 2015; Hauser et al., 2020). These environmental issues are causing severe socio-economic
70 impacts, impeding regional development, and even challenging the sustainability of
71 communities (Drogoul et al, 2016; Tran et al., 2019).

72

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

79

80 Given the importance of both agriculture and aquaculture to the two provinces of the Ca Mau
81 Peninsula and the environmental changes that the region has been experiencing, the
82 development of an effective master plan on regional economic development requires assessing
83 the resilience of these two key sectors of the economy to environmental impacts (Garschagen
84 et al., 2012; ADB, 2013; Groenewold et al., 2015). Many studies have investigated the impacts
85 of climate change, sea level rise and coastal erosion on the Ca Mau Peninsula, as well as

86 examining trends in degradation - and loss - of mangrove forests and biodiversity ([Safford et](#)
87 [al., 1998](#); [Campbell, 2012](#); [Nguyen, 2014](#); [Van Cuong et al., 2015](#); [Nhung et al., 2019](#)).
88 However, no study has yet assessed the suitability of land use in the region to those two key
89 economic sectors in view of a continuation of changes in environmental conditions, notably,
90 saltwater intrusion, water resource availability and growing season length.

91

92 The Food and Agriculture Organization (FAO) recommends that adaptation to climate change
93 in the agricultural sector should be based on nature-based solutions and the sustainable use of
94 natural resources ([FAO, 2016a, b](#); [Wiebe et al., 2019](#)). Hence, the development of farming
95 systems and the assessment of their adaptability should be based on ecological and
96 environmental conditions. Moreover, there has been poor implementation of Resolution No.
97 120/NQ-CP of the Vietnamese Government on sustainable development of the Mekong Delta
98 on adaptation to climate change, because of a lack of both skilled human resources and
99 awareness of climate change impacts ([Nguyen, 2019](#); [Thi & Trong, 2019](#)).

100

101 The suitability of the land to the primary sectors of the economy depends on the climatic and
102 soil conditions, and water resource availability, while also considering the environmental issues
103 that the region is facing and affecting its sustainability, i.e., climate change, sea level rise,
104 coastal erosion, and saltwater intrusion ([Nguyen & Woodroffe, 2016](#); [Tinh et al, 2019](#); [Bui et](#)
105 [al., 2019](#)). It has previously been noted that current land-use planning in the Vietnamese
106 Mekong Delta is not appropriate to the environmental conditions that the region is facing and
107 that it will likely need to be modified in the future in view of changing salinity conditions,
108 water resource availability and growing season length ([Tran, 2019](#); [Nguyen et al., 2020](#); [Tran](#)
109 [et al., 2021](#)). Land use planning needs to consider the full benefits that it can provide,
110 particularly its contribution to regional economic development and the sustainability of local

111 livelihoods. Hence, this study aims to categorise the suitability of the land of the provinces of
112 Ca Mau and Kien Giang in southern Vietnam for paddy rice cultivation and shrimp farming
113 into four suitability levels for both current and potential scenarios of change in environmental
114 conditions. This land suitability analysis uses a GIS-based Analytic Hierarchy Process (AHP)
115 approach, and is based on soil characteristics, the level of saltwater intrusion, the availability
116 of water for rainfed agriculture, and the growing season length.

117

118 **2. Study area**

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

125

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

134

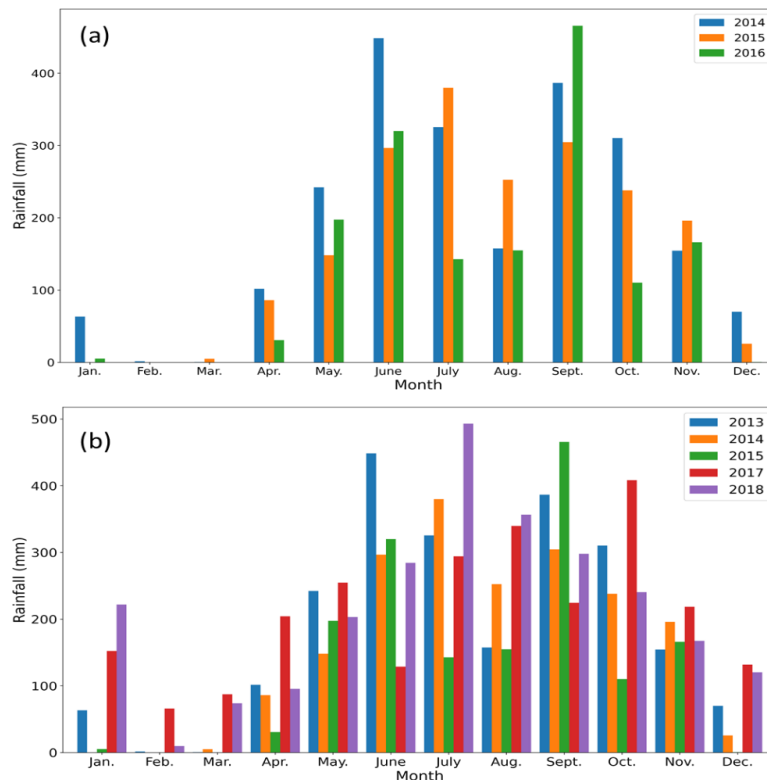


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136

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

137



138

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

141

142 In the past decade, the 300 km long coastline of the provinces of Ca Mau and Kien Giang
 143 (Nguyen & Woodroffe, 2016; Luom et al., 2021) has suffered severe erosion and significant
 144 loss of land, as a result of the degradation of the mangrove forests and their loss due to their
 145 conversation to agriculture and aquaculture (Van et al., 2015; Truong & Do, 2018; Veettil et
 146 al., 2019), and a reduction in alluvium originating from the Mekong River (Nguyen et al., 2013;
 147 Karlsrud et al 2017, 2020; Li et al., 2017; Nguyen et al 2020). The economic benefit of
 148 aquaculture is the driver to the clearance of the mangrove forests, which potentially threatens
 149 the sea dikes protecting the low-lying areas from coastal flooding (Bosma et al., 2016; Danh et
 150 al., 2014; Albers & Schmitt, 2015; Phan et al., 2015; Besset et al., 2019). Moreover, unplanned
 151 development, notably for agriculture, has led to excessive groundwater extraction, causing land
 152 subsidence, and hence further enhancing the impact of sea level rise and reduced river sediment

153 supply on coastal erosion, in addition to impacting the quality of surface and groundwater
154 supplies (Chau et al., 2015; Stoop et al., 2015; Dao et al., 2016; Le et al., 2021). These
155 anthropogenic stressors and unbalanced development are thus causing unintended
156 consequences and impacting on the sustainability of the region (Alongi 200, 2012; Van Nguyen
157 et al., 2020; Loc et al. 2021).

158

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

165



166

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

168

169 **3. Materials and Methods**

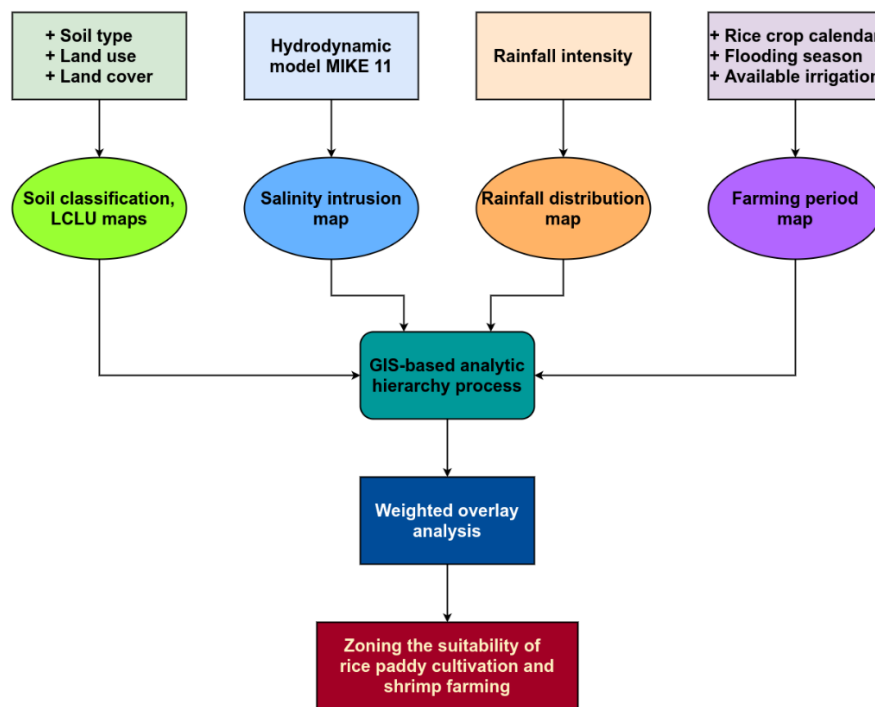
170 This study consisted of collecting data from previous projects and publicly available datasets,
171 as listed in Table 1. Information on the soil characteristics of the region was collected from two

172 sources to generate the soil map presented in section 3.1. A hydrodynamic model was used to
 173 estimate the extent of salinity intrusion under different scenarios of change, as presented in
 174 section 3.2. The rainfall map was produced by calculating the average rainfall over a number
 175 of years. The suitability of the study area for rice crop cultivation and shrimp farming was then
 176 assessed using a map overlay analysis with the weight of each variable estimated using the
 177 AHP methodology. [Figure 4](#) illustrated the methodological framework.

178 **Table 1.** Data used in this study
 179

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

180



181

182 **Figure 4.** The methodological framework

183 **3.1. MIKE 11 Hydrodynamic model**

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

193

194 **3.2. Analytic hierarchy process**

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

205

206 The AHP involves calculating the Consistency Ratio (CR), Consistency Index (CI), and
 207 Random consistency Index (RI), which are described in Saaty (1980, 1990); Saaty and Vargas
 208 (2000); Ali et al. (2019), and calculated as follow:

$$209 \quad CR = \frac{CI}{RI} \quad (1)$$

210 These two indexes represent the consistency index of a randomly generated pair-wise
 211 comparison matrix and depends on the number of factors being compared (Saaty, 1980). Table
 212 3 presents the pair-wise comparison matrix of the current study. The CI was calculated using
 213 Equation (2):

$$214 \quad CI = \frac{\lambda - n}{n - 1} \quad (2)$$

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

216

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

$$219 \quad F_{(AHP)} = \sum w_i x_i \quad (3)$$

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

222

223 **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	

224

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

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

226

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

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

229

230 3.3 Soil type map

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

241
242 Field surveys were conducted in 2019 in Ca Mau and Kien Giang provinces to determine the
243 suitable levels of soils for rice cultivation, which was classified on a scale from 1 to 4 based on
244 [FAO \(2006a\)](#) and [Vu et al. \(2011\)](#) ([Table 4](#)).

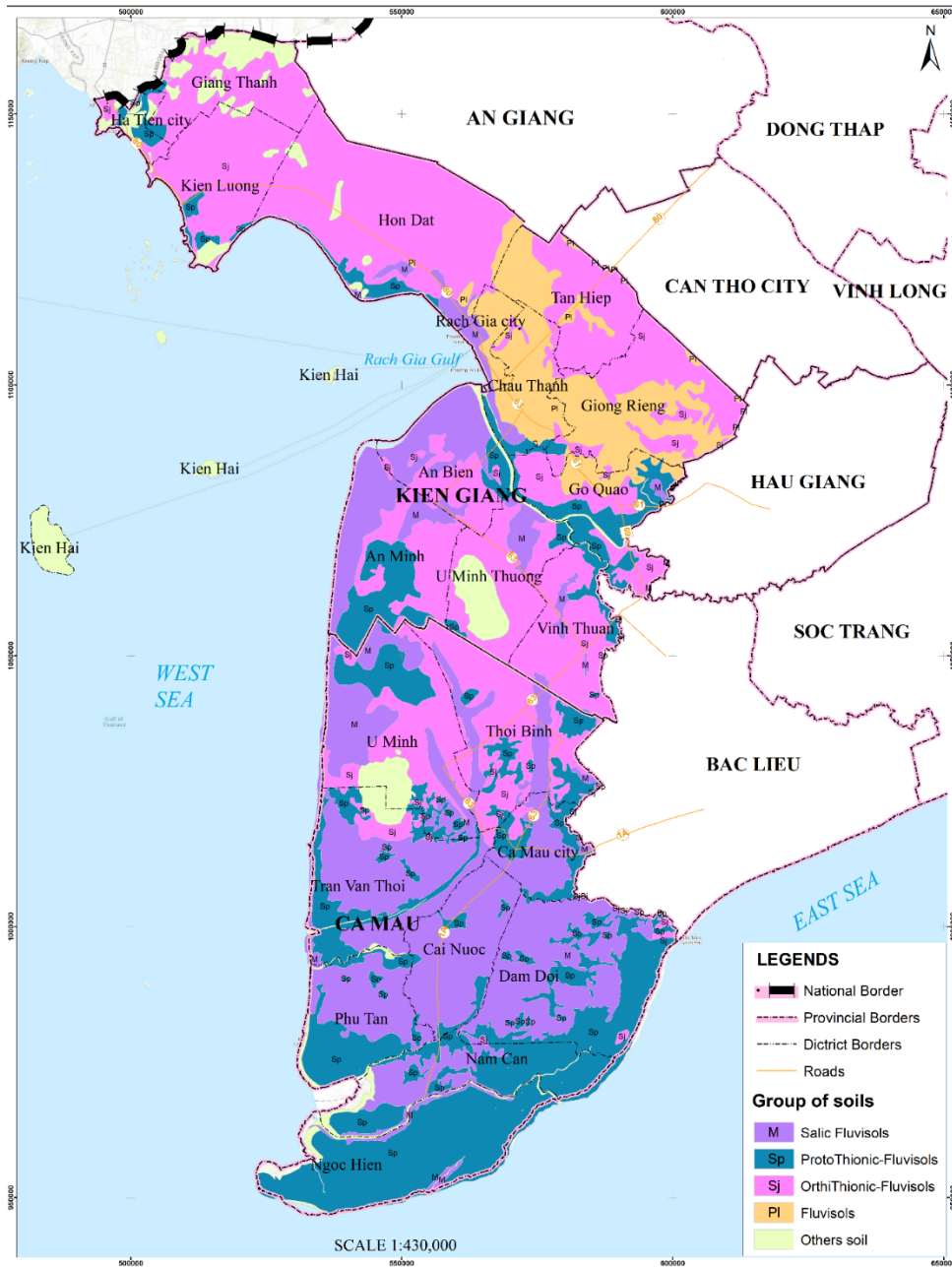
245

246 [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 necessary 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
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247



248

249

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

250

251 **3.4 Salinity intrusion map**

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

261 [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

262
 263 The model was forced using three scenarios of extreme conditions of salinity intrusion together
 264 with a water resource deficit during the dry season that is unfavourable to both agriculture and
 265 aquaculture. Only scenario 4 consisted of conditions favourable to agriculture and aquaculture,
 266 in terms of water supply availability and operational hydraulic works (sluices, sea dykes,

267 culverts, canals, and outlet gates) (Table 6). The results of model simulations are provided in
268 Appendix 1.

269 **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

270

271

272 **4. Results and discussion**

273 **4.1 Mapping suitable zones for the agriculture and aquaculture according to individual** 274 **variables**

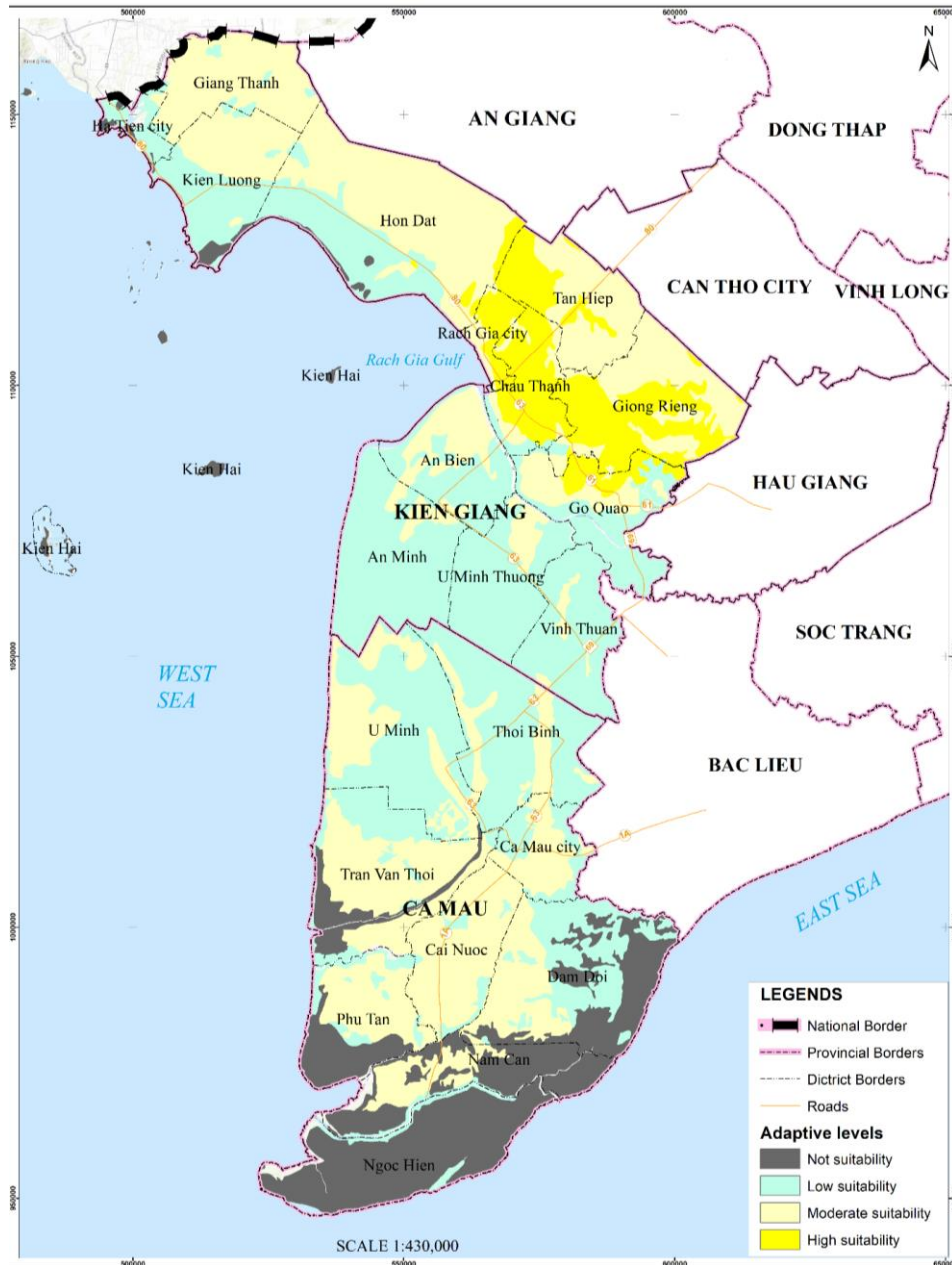
275 The mapping of the suitability of the land of the region to rice crop cultivation and shrimp
276 farming was done separately. Then, suitable levels for rice cultivation each input factor is
277 discussed in following sub-sections.

278 **4.1.1 Areas suitable for agriculture and aquaculture in relation to soil properties**

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

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

289



290

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

292

293 4.1.2 Areas suitable for agriculture and aquaculture in relation to salinity levels
 294 The range of salinity suitable for rice and shrimp cultivation were obtained from the handbook
 295 of technical process of rotating black tiger shrimp - rice, intercropping with giant river shrimp
 296 (*Macrobrachium rosenbergii*) published by Ca Mau DARD (Table 7).

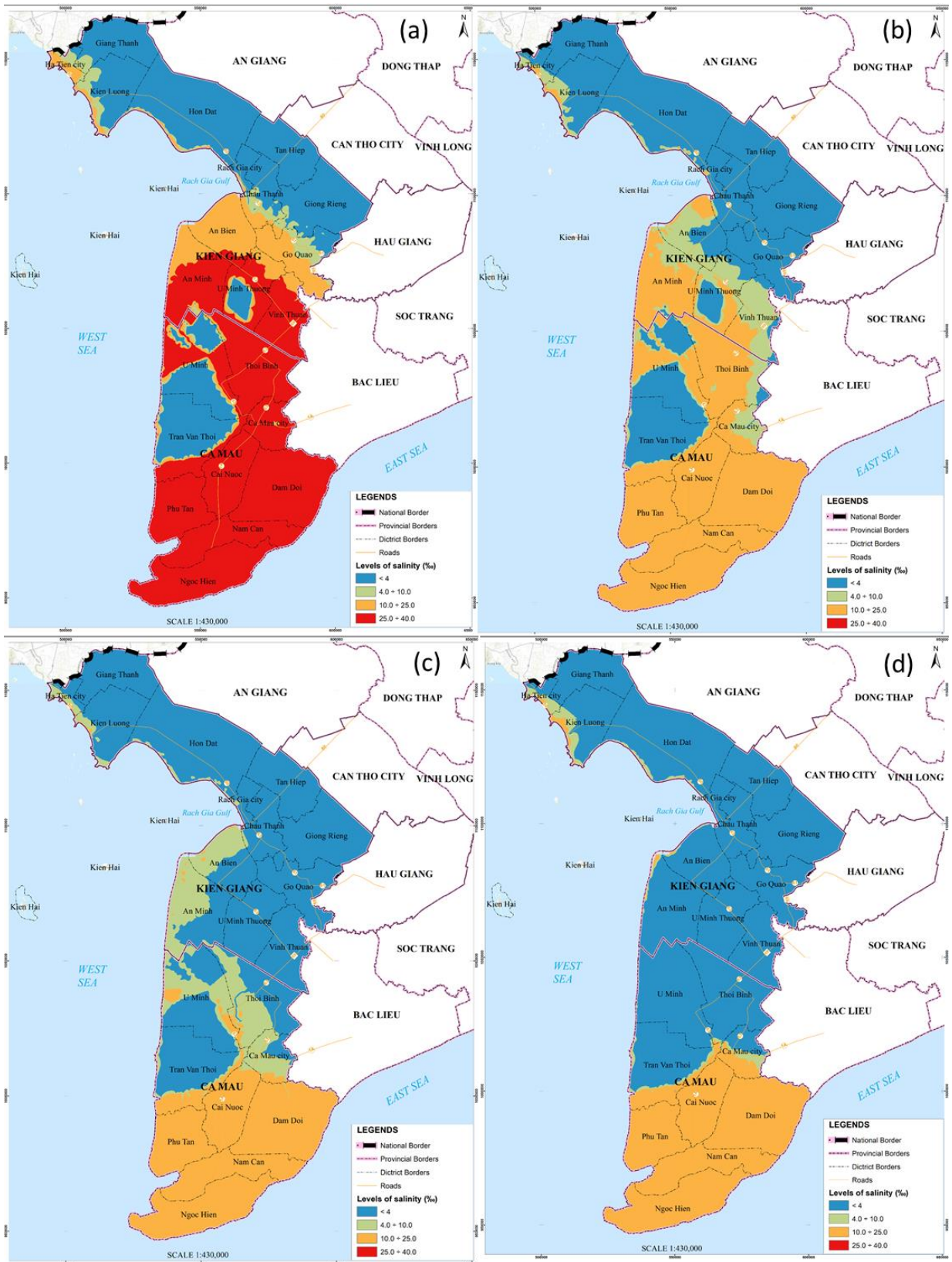
297

298 **Table 7.** Suitable salinity level for rice crop and aquaculture species (Source: Ca Mau
 299 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

300

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



310

311

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

312

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	<ul style="list-style-type: none"> - 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. 	<ul style="list-style-type: none"> - 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. 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Less suitable for rice cultivation, low yield - Not suitable for aquaculture 	<ul style="list-style-type: none"> - To the west of Giang Thanh and Kien Luong districts; - Roadside Highway 61. 	<ul style="list-style-type: none"> - 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. 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Not suitable for rice cultivation - Suitable for aquaculture 	<ul style="list-style-type: none"> - Coastal area of Ha Tien city, Kien Luong district, Hon Dat, Rach Gia city; - Area between National Highway 61 and Highway 63. 	<ul style="list-style-type: none"> - 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.

315 4.1.3 Farming period

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

322

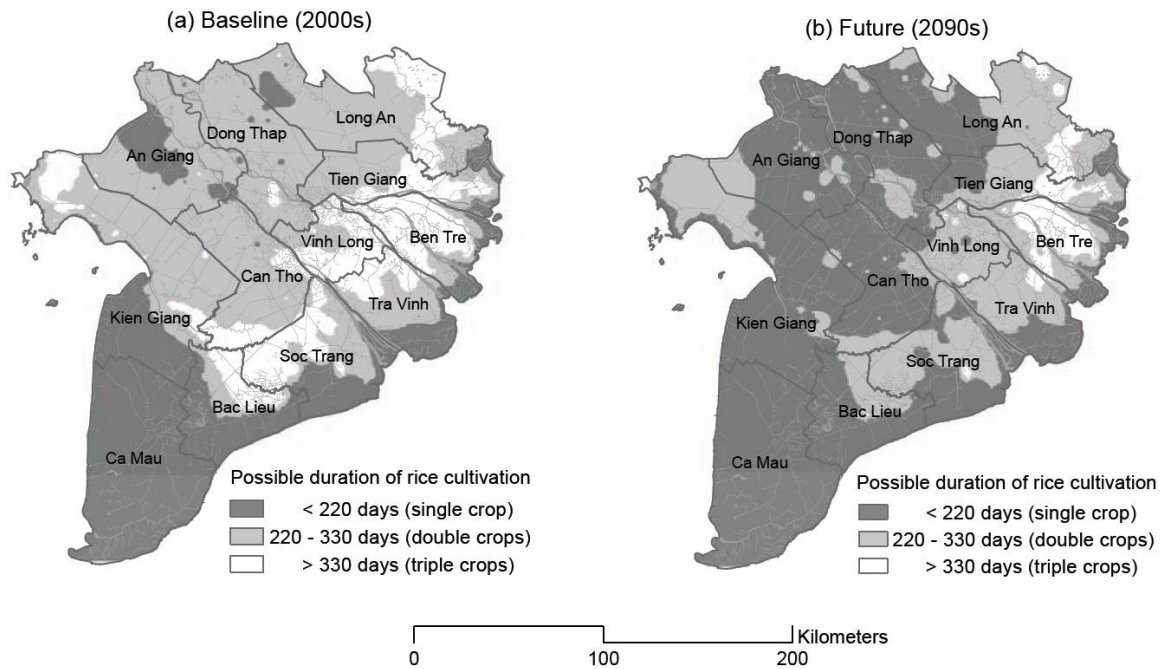
323 [Table 9](#). Mapping the suitability of the land according to the farming period

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)

324

325

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



335

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

338

339 The results of zoning suitability for rice cultivation based on farming periods are shown in

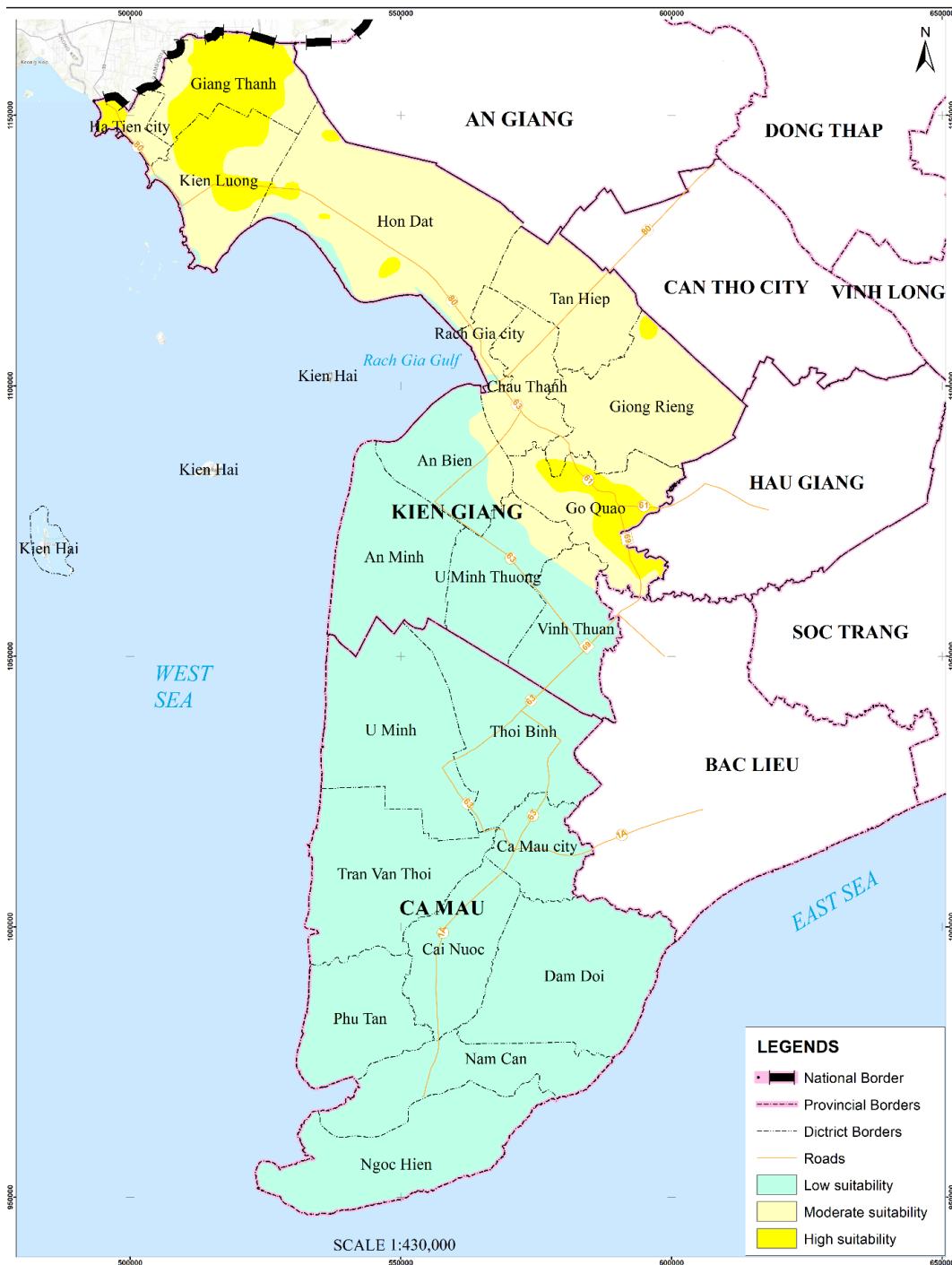
340 [Figure 9](#). It can be seen from the figure that almost area of Ca Mau province has low suitability

341 for rice cultivation based on the farming periods due to flooding and salinity intrusion by sea

342 level rise because Ca Mau province is low-lying area ([Wassmann et al., 2005](#); [Groenewold et](#)

343 [al., 2015](#); [Quach, 2018](#)). Only few parts of Kien Giang are zoned with high suitability for rice

344 cultivation due to their high elevation and not affected by salinity intrusion and flooding.



345

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

347

348

349 4.1.4 Rainfall distribution

350 Rainwater and groundwater are the two main source of water in the provinces of Ca Mau and

351 Kien Giang (Dao et al., 2014; Deb et al., 2016; Tinh et al., 2019). The two provinces receive a

352 large amount of precipitation during the rainy season, with total annual rainfall averaging 1900-

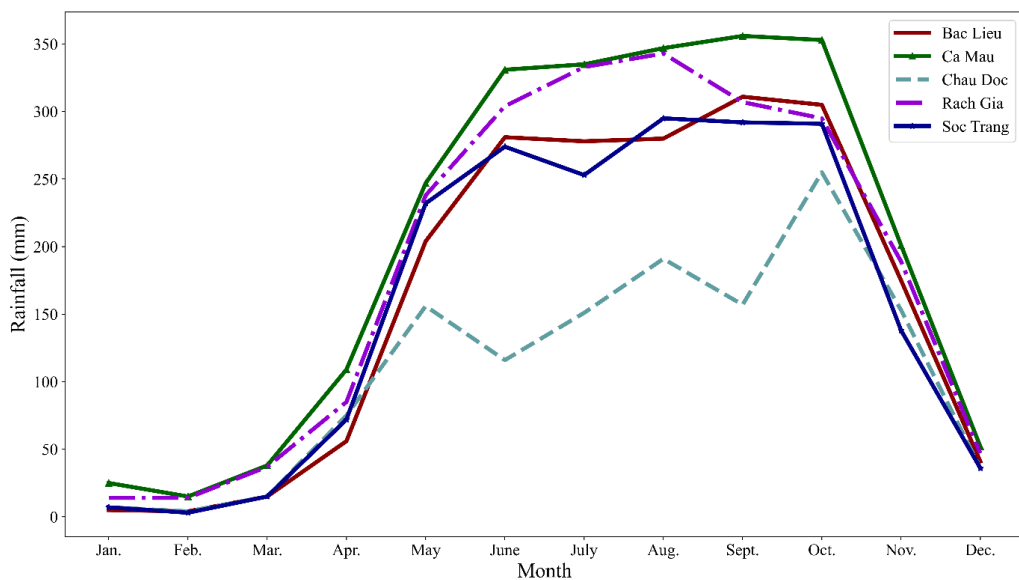
353 2400 mm. Figure 10 shows the spatial distribution of annual rainfall for the period 2015-2019

354 over Mekong Delta. Total rainfall amount is highest in Ca Mau with 2400 mm, and in Kien
 355 Giang varies from 1900-2300 in rainy season. Moreover, it can be seen that the rainfall intensity
 356 during rainy season (May to October) reached maximum value of 300 - 350 mm per month in
 357 Ca Mau and Rach Gia stations (Figure 10).

358

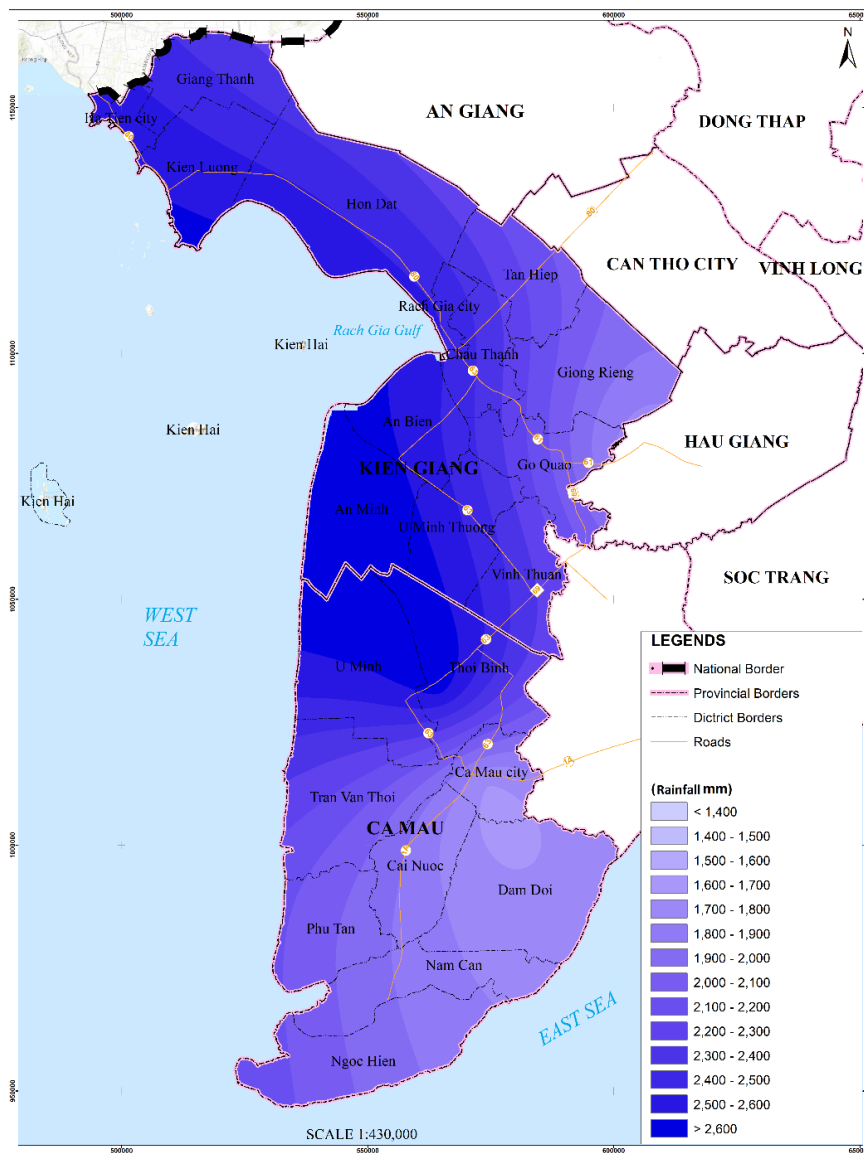
359 Figure 11 show the spatial rainfall distribution in the study area in 2019 with very high rainfall
 360 intensity in U Minh, Thoi Binh - Ca Mau; An Minh, U Minh Thuong and An Bien in Kien
 361 Giang. This mean the water available in the study area is contributed mainly from rainwater.

362



363

364 Figure 10. Season cycle of precipitation at five weather stations in study region during 2015-
 365 2019 (Source: Southern Regional Hydro-Meteorological Center)



366

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

368

(Source: Southern Regional Hydro-Meteorological Center)

369

370 **4.2 Assessment of current zoning condition**

371

The current land use in western Mekong Delta including Ca Mau and Kien Giang show in

372

Figure 12. For the agricultural and fishery production of Ca Mau province, according to the

373

policy of agricultural restructuring, economic restructuring in the direction that the proportion

374

of fishery, agriculture and forestry sectors decreases gradually, but on contrary progressively

375

increase the proportion of service sector. Therefore, the total area of rice cultivation tends to

376

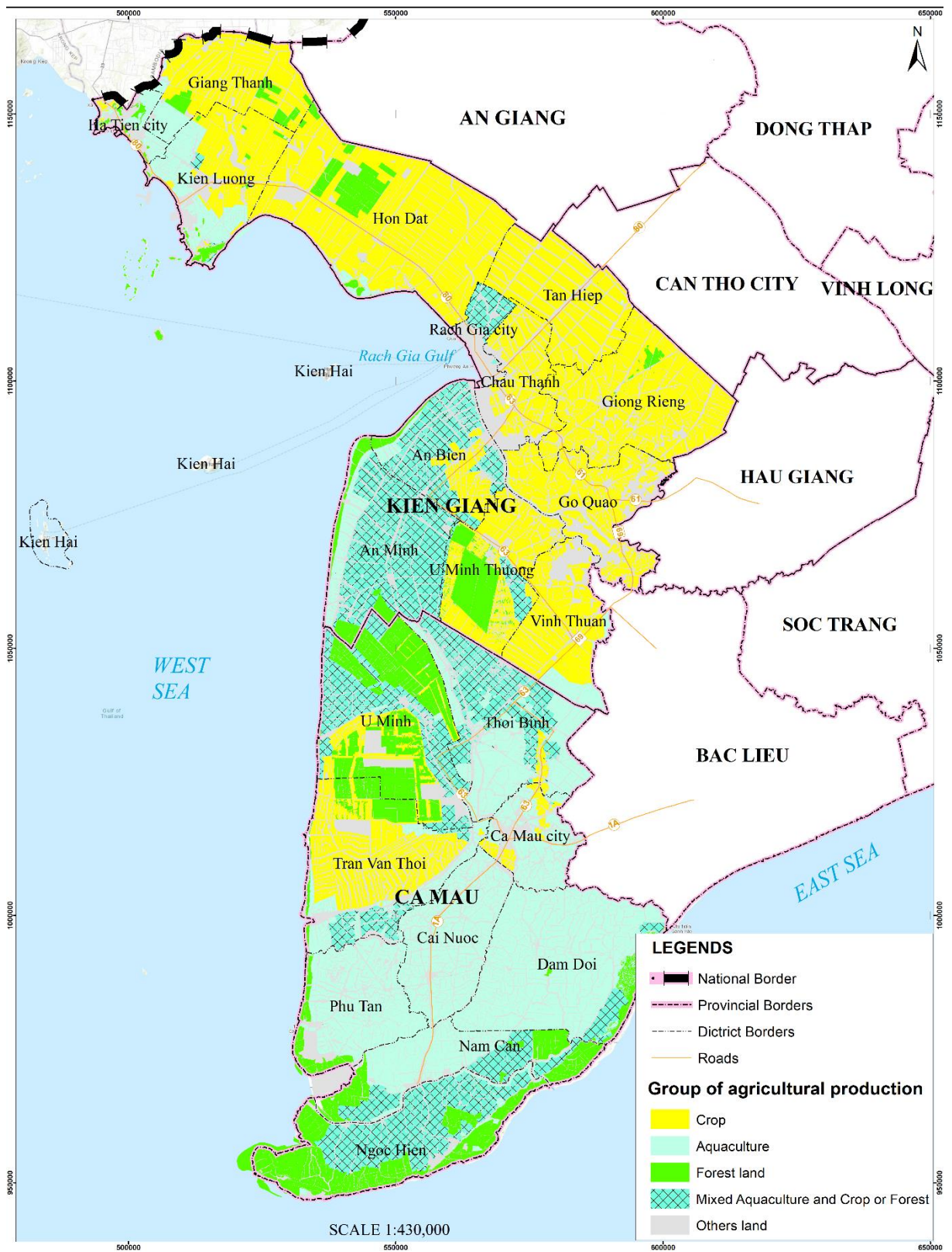
decrease (from 125,581 hectares in 2010 to 115,585 hectares in 2019) in the period 2010 - 2019.

377 However, rice productivity increased by about 15% compared to 2010 (rice yield in 2010 was
378 3968 kg/ha, in 2019 was 4556 kg/ha). In contrast, aquaculture area increased significantly from
379 296,300 hectares in 2010 to 305,021 hectares in 2019 with fish production increasing from
380 387,070 tons in 2010 to 565,650 tons in 2019. Currently, Ca Mau province is developing new
381 aquaculture methods such as ecological shrimp farming, shrimp farming combined with rice,
382 shrimp farming in rotation, intercropping with other aquatic species (e.g., crabs, blood cockles,
383 mussels).

384

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

395



396

397

398

Figure 12. Land use in the study region

399 **4.3 Overall assessment of the suitability of the land to the two primary sectors of the**
400 **economy**

401 The mapping of the suitability of the land to rice crop cultivation and shrimp farming was
402 produced using AHP and overlaying the soil classification map (Figure 6), scenarios of
403 saltwater intrusion (Figure 7), growing season length (Figure 8), and the annual rainfall
404 distribution (Figure 11). The results of map overlaying process are four maps of zoning
405 suitability of paddy rice cultivation corresponding to four scenarios as shown in Figure 13.

406 It can be seen that there is very small area in Go Quao, Kien Giang with high suitability of rice
407 cultivation under scenarios 2, 3, 4. Meanwhile, the area of the moderate suitability for rice
408 cultivation is spreading out over large area of northern Kien Giang and some parts in Tran Van
409 Thoi district of Ca Mau province (Figure 13 b, c, d). Currently, the agriculture (paddy rice) in
410 Kien Giang account for 49.1% of total agricultural land (see Table 3S. Appendix 2) and this
411 rate is planned to increase in the future as described in the master plan of Kien Giang (Decision
412 No. 405/QD-UBND dated February 24, 2016, and Decision No. 41/QD-UBND dated January
413 9, 2017 by the Chairman of Kien Giang).

414

415 There is a large area with low suitability for rice cultivation in Ca Mau. However, these areas
416 are more suitable for aquaculture (shrimp farming), currently accounting for 43.8% of total
417 agricultural land instead of paddy rice cultivation (see Table 3S. Appendix 2). This rate will
418 increase to 60.5% in 2030. This is completely in line with the development orientation of Ca
419 Mau province on promoting the aquaculture industry to become the top income from
420 aquaculture and the province's strengths that contribute a large proportion to the province's GDP
421 (Decision No. 537/QD-TTg dated April 4, 2016, by the Prime Minister and Decision No.
422 1116/QD-UBND dated June 30, 2016, by Ca Mau Chairman).

423

424 [Figure 13a](#) also shows an extensive area of no suitability for rice crop in Ca Mau province,
425 corresponding to scenario 1 is due to maximum salinity intrusion, a very dry season and water
426 deficit and current hydraulic works (sluice, sea dykes, intakes, culvert, canal, tidal, and outlet
427 gate) without effectively preventing saline water intruded to farmland. In addition, the strip of
428 land along the East Sea in Ca Mau province will be more severely affected by sea level rise
429 because the tide magnitude in the East Sea is higher than those in the West Sea about 0.8 - 1.2
430 m. This is similar for scenarios 2, 3, 4 but less area than those in scenario 1. For scenario 4,
431 although favourable conditions of water availability, complete hydraulic constructions and full
432 operation to reduce salinity intrusion but the extended area of rice cultivation with moderate
433 suitability is not significant ([Figure 13d](#)) because rice cultivation in Ca Mau only accounts for
434 31.5% of total agricultural land and will likely decrease in the future if the master plan of Ca
435 Mau province materialises ([Table 3S. Appendix 2](#))

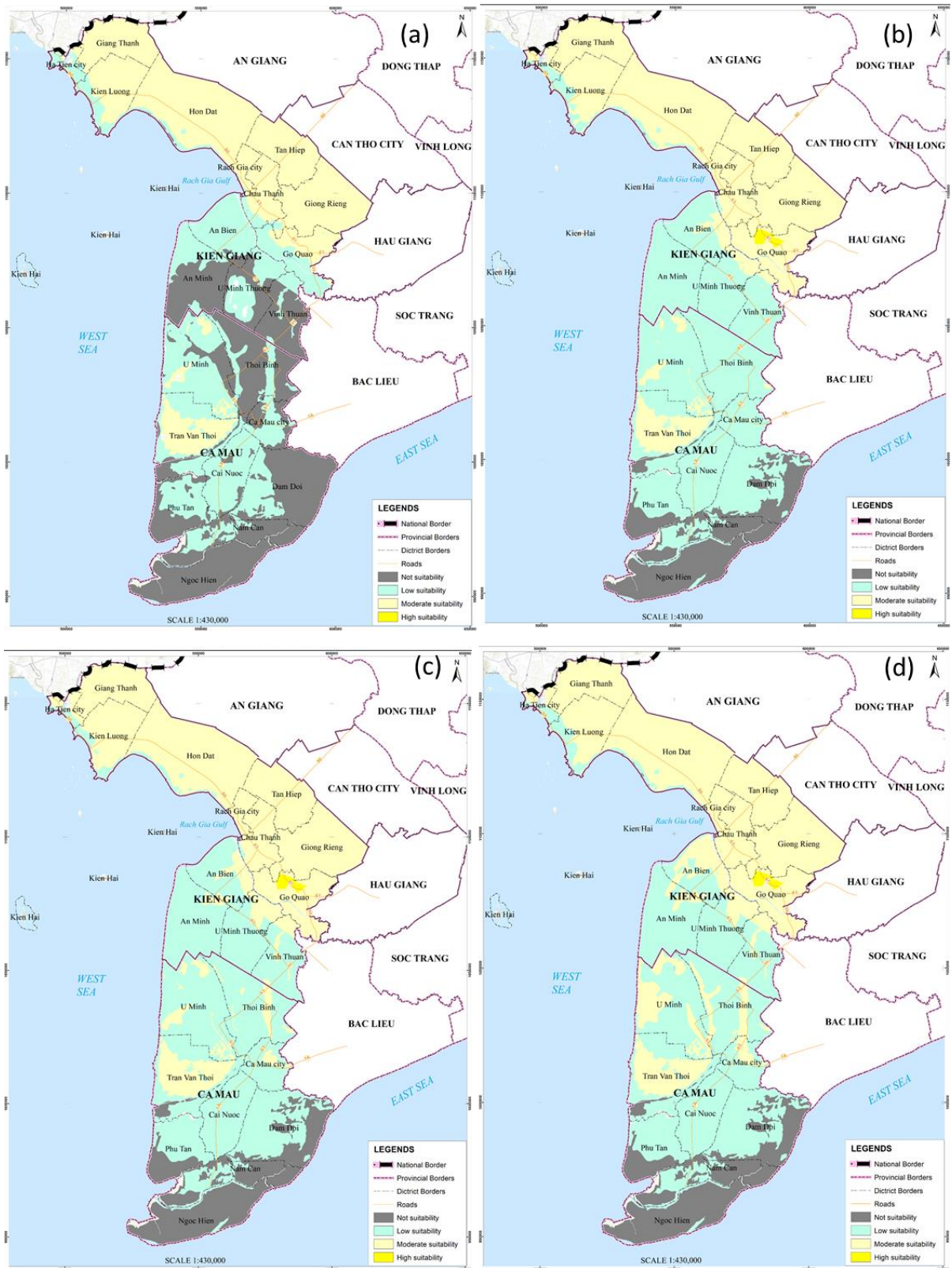
436

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

441

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

450 expectation. From there, the overall development planning of the provinces for far future is
 451 grounded and feasible for implementation. Therefore, zoning the adaptability of agriculture and
 452 aquaculture in the present and in the future suitability is important and meaningful.



453

454

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

455

456

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

Value	Levels	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
		area (ha)	area (%)	area (ha)	area (%)	area (ha)	area (%)	area (ha)	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%

457

458 **5. Conclusion**

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

480

481

482 **Disclosure statement**

483 The authors declare that they have no known competing financial interests or personal

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485

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494

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