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An integrated approach of GIS-AHP-MCE methods for the selection of suitable sites for the shrimp farming and mangrove development- A case study of the coastal area of Vietnam

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ABSTRACT

This study was conducted to identify suitable sites for shrimp farming combined with the mangrove development (SFM) in the coastal area of central Vietnam. An integrated approach using GIS with weighted Multi-Criteria Evaluation (MCE) by Analytic Hierarchy Process (AHP) was adopted for the selection of sites. In this study, fifteen sub-criteria belonging to three main criteria (geographical conditions, water quality and infrastructure availability) were selected as evaluation parameters in the GIS model. The study indicated that the geographical factors are the most important for the SFM development with 0.44 weight. However, the availability of such areas is limited. Results of the integrated study indicated that SFM area for development is highly suitable: 1127.82 ha (15.57%), moderately suitable: 2056.87 ha (28.4%), marginally suitable: 2835.52 ha (39.16 %) and not suitable: 3204.36 ha (17.0 %) in the Hau basin, Vietnam. In this study, we have also used GIS-AHP-MCE methods for developing organic shrimp farming and mangrove rehabilitation.

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1. INTRODUCTION

Aquaculture is one of the most important economic sectors in Vietnam (Hai et al., 2020). It contributes 4-5% of the Gross Domestic Product (GDP) and employs about 4 million people. Shrimp trade is the highest proportion of GDP in the coastal and estuary areas of many countries around the world (Fierro-Sañudo et al., 2020; Khiem et al., 2020). In Vietnam, shrimp farming began in the early 1960 and increased rapidly in the last two decades (Phuong et al., 2010). Despite its economic importance, shrimp farming is risky due to its heavy dependence on the natural ecosystem and vulnerability to diseases. In fact, the shrimp epidemic diseases are widespread mainly due to the effect of environmental pollution. Therefore, natural environmental factors are to be carefully considered in shrimp farming (Yang et al., 2018). Worsening environmental conditions are believed to be the main cause of the failure of shrimp farms in Ecuador, Taiwan, Thailand, Bangladesh, and Vietnam (Hossain et al., 2009). In some cases, aquaculture development is accelerated in areas which are inconsistent with the favorable climatic conditions, water quality, soil, and infrastructure facilities, thus results in losses in shrimp farming, especially in developing countries such as China, Thailand, India, Indonesia, Vietnam (Nguyen et al., 2020). In these countries adverse conditions are being created by the destruction of landscape diversity and encroachment of area by other species, thus reducing the area and biodiversity of mangrove ecosystems. Untreated waste water from cities and industries leads to water and soil pollution of shrimp habitats and mangrove farming (Van Hue & Scott, 2008). Also, shrimp farming has been a cause of mangrove destruction in different regions of the world, especially tropical Asian regions such as India and Thailand, which otherwise act as a "green wall" to prevent and mitigate natural disasters such as storms and sea waves (Vandergeest et al., 1999). In addition, the livelihoods for communities associated with mangroves and shrimp farming are affected due to infrastructure development in these areas. The conflict between economic interests and environmental protection as well as livelihoods are the major concern in some mangrove areas of Vietnam (Phuong & Oanh, 2010; Van Hue & Scott, 2008). Thus, the intensive shrimp farming in the areas create conflicts with the other uses such as development of mangrove forests, agricultural cultivation, and development activities are posing challenges to land use planners.

Since the year 1990s, forestry integrated aquaculture has appeared as an optimal solution for the economic development in Southeast Asian countries, including Vietnam (Dang et al., 2021; Luom et al., 2021). Some studies have also analyzed the impact of shrimp farming development on the environment and mangrove degradation. Some other studies have raised the problem of environmental management and protection in shrimp farming areas, including ecological models (Hossain et al., 2013; Sohel & Ullah, 2012). These models are developed to grow more mangroves along with developing aquatic resources for local people. In some cases, Shrimp Farming in Mangroves (SFM) area have been designed and implemented with different proportions of mangroves and distributed trees on a central platform or buffer zone around the pond. The SFM practices have been applied in Southern Vietnam for better management of the shrimp aquaculture in coastal areas considering socio-economic and environmental aspects (Clough et al., 2000). Currently, in the Mekong Delta (Vietnam), organic shrimps are produced considering these models. Therefore, the selection of suitable sites for SFM should be based on an integrated assessment and consideration of land use factors (Luom et al., 2021). However, up to now, building an ecological model that combines components of the wetland ecosystem (including mangroves, brackish water organisms, plants) and shrimp and crab farming, suitable site selection methods have not been mentioned much in previous studies. In the Central region of Vietnam, there is no plan to deploy such models, even though it is one of the strategies (NASO, 2018). It is important to make a site analysis to select a suitable area for SFM. The formidable and complex task to evaluate suitable sites is that the model requires many factors for the growth of mangroves and shrimp. They can be assessed based on land, environmental, social, and economic physical databases (Calle Yunis et al., 2020; Meaden & Aguilar-Manjarrez, 2013).

The suitable site selection for the aquaculture development and mangrove rehabilitation can be implemented by land assessment approach (Aguilar-Manjarrez et al., 2010; Calle Yunis et al., 2020; Hasim et al., 2017; Mandal et al., 2020). Integrating GIS, Multi-criteria Evaluation (MCE), and AHP method is a powerful tool for land-use integration assessment and decision-making for the sustainable development of agriculture, forestry and aquaculture (Falconer et al., 2020; Mandal et al., 2020; Sari et al., 2020; Teixeira et al., 2018). This approach was also applied effectively to evaluate the water and soil quality, topography, infrastructure, and socio-economic factors for aquaculture development and fish farming (Hasim et al., 2017). In this study, GIS-based Multi-Criteria Evaluation (MCE) modeling and the AHP method were used to determine the suitable sites for building the mangrove-shrimp farming in the central coast of Vietnam. The specific objectives of this study include (i) Identifying suitable criteria for mangrove restoration and shrimp farming based on analysis of theoretical, practical and expert opinion approach; (ii) Establishing evaluation models and select experimental design; (iii) Building component (thematic) maps that are corresponding to the selected criteria; and (iv) Generation of suitable site maps for developing the mangrove-shrimp farming by overlaying the component (thematic) maps with the participation of weights generated from the model. It deals with the selection of multiple criteria for mangrove shrimp farming, which satisfies both the conditions for mangrove rehabilitation and creating good conditions for shrimp farming for sustainable development of the coastal areas.

2. MATERIAL AND METHODS

2.1. Study Area

The study area is located in the Hau river basin of Nghe An Province, Vietnam, which is having tropical climate with hot and humid summer (Fig. 1). The rainfall is concentrated during the rainy season between September and November. The mean annual precipitation is 1143 mm. The average annual temperature is 22°C, the highest is 41°C, lowest is 5.3°C. Morphology of the study area comprises mainly flood and coastal plains, and hills adjacent to the West coast. Hau River originates from the western region and flows through the midlands and plains into the sea at Hau estuary. The river mouth is narrow, due to the existence of the mountains on both sides. As a result, less sediment flows back into the river from the sea, thus forming narrow alluvial flats. Mangroves develop mostly along riverbanks and rarely in coastal areas. Brackish water shrimp farming is developing along tributaries that flow into the Hau estuary, including Mo and Thai rivers.

The tidal regime is an irregular semi-diurnal tide with nearly half the number of high-water days in a month in the area. During the period of low tide, there are two low tides per day. The mangrove vegetation is quite diverse, distributed in the area depending on the salinity, topography, and soil type. On the alluvial flats in the creeks such as Con, Quen, Thoi, the soil texture is sandy, the Avicennia plant population grows pure because the salinity here is quite high (0.25-0.30%). In the medium-flooded, humus-rich, clay-rich intertidal flats with a lot of organic humus, the tree species composition is more complicated forming a complex community such as: *Rhizophora stylosa*, *Bruguiera gymnorhiza*, *Kandelia candel*, occasionally some individuals of the *Aegiceras corniculatum*, *Acanthus ilicifolius*. The dominant tree in higher lands is *Acrosstichum aureum*, *Clerodendron inerme*, *Pandanus tectorius*, *Pluchea indica*, *Caesalpinia bonduc* and other herbaceous vegetation. On the flooded tidal flats with high tide, the *Bruguiera gymnorhiza* population dominates and develops well. In the very high tidal flooding area, mangrove communities with species composition are *Excoecaria agallocha*, *Cynodon dactylon*, *Cyperus malaccensis*.

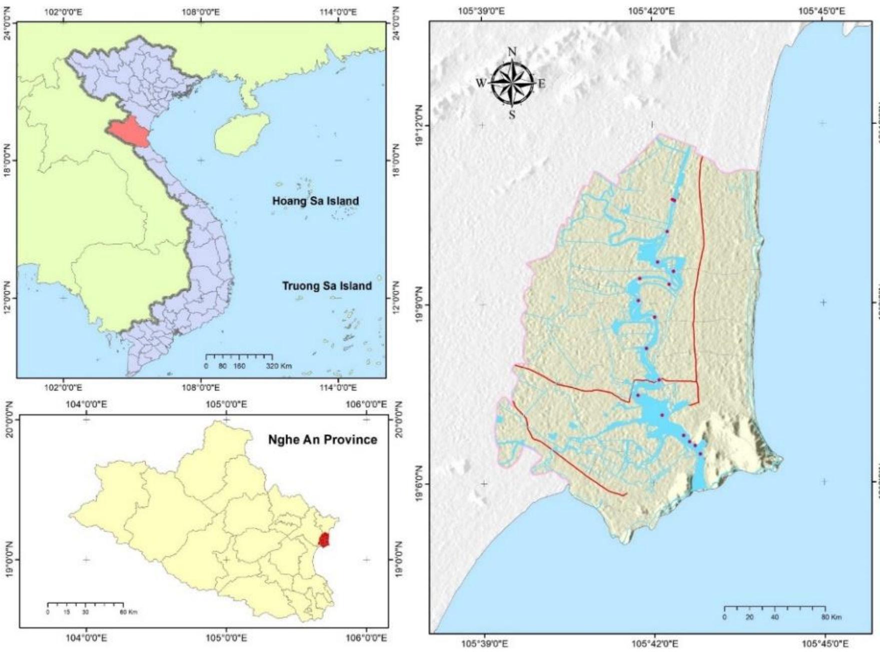

Figure 1. The location of Hau river area

Aquaculture plays an important role in the economic development of this area. Its employees 67% of the workforce and contributes 72% of the GDP (NASO, 2018). In the study area, aquaculture occupies more than 2500 ha, mainly for shrimp farming (PCQL, 2020). However, the waste from shrimp farming has made sedimentation in the creeks contaminated with chemical residues, containing pathogens in shrimp (DNRRNA, 2020). In addition, the development of intensive shrimp farming has destroyed a significant area of mangroves in the study area in the past few years. The area of mangroves in Nghe An Province has decreased by 176.28 ha which is 28.5% from 2009 to 2018, due to conversion to shrimp farming (DARDNA, 2013). Therefore, the combination of mangrove rehabilitation and fisheries development promises the potential to increase income and protection of the ecological environment balance in this area.

2.2. Materials

The data used in this study include both spatial and non-spatial data obtained from the available records, satellites, and Google Earth Images. Topographical features such as slope was extracted from the Digital Elevation Model (DEM) of 10 m resolution. The map of hydrology and transport was extracted from the cadastral maps (Scale 1:10.000) of the communes, obtained from the Department of Natural Resources and Environment of Nghe An Province and combined with the satellite image data. Land-use/land-cover map was developed from a Landsat image of 15th July acquired from the United States Geological Survey (USGS) Earth Explorer platform and verified from the data of the People's Committee of Quynh Luu district, Nghe An Province (DNRRNA, 2020).

The soil and water data were obtained from the field survey. To assess the parameters associated with the water environment and soil, 17 monitoring stations were established in the Hau river basin. Water sampling points were set up on the mainstream of Hau river, shrimp ponds and estuaries. The soil sampling points were established in the estuary and coastal areas within mangrove forests. The clay contents in the soil were determined from the 34 soil samples collected from two layers at each location with the depth ranging from 0 (surface) to 40cm. Water quality including salinity, pH, and dissolved oxygen of water was measured directly at each monitoring station. The data of water and soil were collected and analyzed two times a year (2020) in January and July. Inundation of the tidal water in the study area was measured at 21 measuring sites at Cua Hoi measuring stations in Nghe An Province using GPS (Tran et al., 2021). The texture and other properties of soil were analyzed in the laboratory of Vinh University. Thematic layers of soil and water data analysis were generated for the spatial analysis in the GIS environment. IDW method was used for the interpolation of point data. The ArcGIS software was used for the data analysis and visualization.

2.3. Criteria Selection

It is crucial to select criteria that affect mangrove rehabilitation and shrimp farming for the model development. The criteria for SFM are determined by a combination of the mangrove rehabilitation conditions and affected factors of shrimp growth. Based on a literature survey (Assefa & Abebe, 2018; Calle Yunis et al., 2020; Falconer et al., 2020; Falconer et al., 2016; Francisco et al., 2019; Khiem et al., 2020), three criteria and 19 sub-criteria are selected for the assessment of conditions. These conditions include geographical locations, water quality, soil characteristics, tide and climate, soil salinity, land use-land cover and social factors (Hossain et al., 2009). However, sites of shrimp farming in the mangrove forest require multiple criteria analysis based on practical knowledge of the area. Therefore, the Delphi method with two round stakeholder consultations process is used to obtain an expert opinion. There are twenty-one expert systems with in-depth knowledge in shrimp farming and mangrove forests as well as ecosystem restoration.

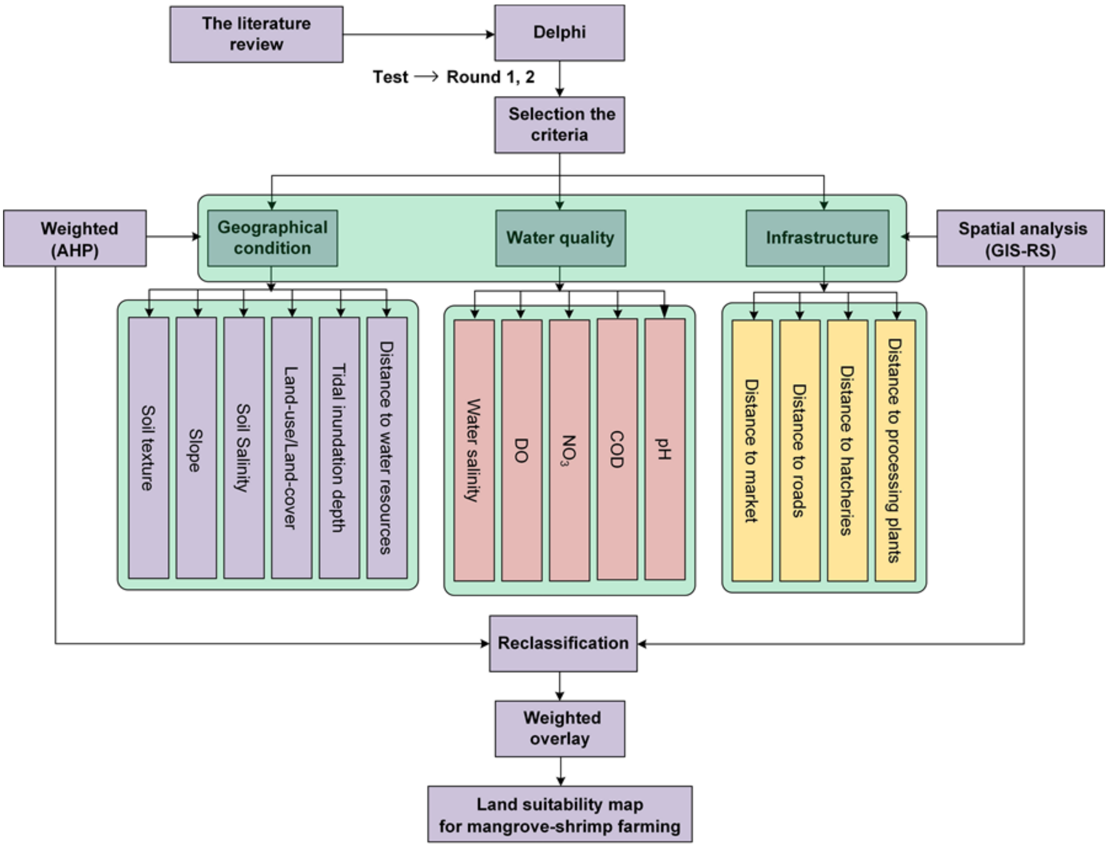

Figure 2. Flowchart of the methodology of the model study

To determine the obtained evaluation results, the first round Delphi survey was carried out based on an expert system with 19 sub-criteria. The Kamet principle was used to analyze in first-round survey and as a result, the expert system showed a high consensus with 17 criteria, excluding soil maturity and topographic elevation. In the second round, the Delphi investigation was performed similarly as the first round. The results showed that 15 sub-criteria of three main criteria were considered necessary, whereas two indicators were excluded namely P_3O_4 and NO_3. The sub-criteria in the present study included soil texture (ST), slope, distance to water resource (DWR), tidal inundation depth (TD), land use/land cover (LULC), pH, chemical Oxygen demand (COD), dissolved Oxygen (DO), water salinity (WS), total Nitrogen (NO_3), distance to processing plants (DPP), distance to hatchery (DH), distance to roads (DR), and distance to market (DM).

2.4. Analytical processing

The suitability of the criteria is classified as per FAO method in four levels: highly suitable, moderately suitable, marginally suitable, and not suitable with the score of 4, 3, 2, 1, respectively (Aguilar-Manjarrez et al., 2010; Assefa & Abebe, 2018; Ross et al., 2013; Tuyen et al., 2019). Independent evaluations of each criterion/sub-criterion contribution that has been applied and developed have been done in many studies by researchers (Calle Yunis et al., 2020; Falconer et al., 2013; Falconer et al., 2016; Sari et al., 2020; Teixeira et al., 2018). In this study, two hierarchies and a pair of criteria were compared, and sub-criteria were implemented. In the first hierarchy, three main criteria were paired and weighted, including geographical conditions, water quality and available infrastructure. In the second hierarchy, 15 sub-criteria belonging to the above main criteria were calculated (Fig.2).

The weight assignment of the multiple layers was performed by Saaty's AHP method (Assefa & Abebe, 2018). This method allows comparing a pair of criteria and independent evaluations of each criterion/sub-criterion contribution that has been applied and developed in many studies (Calle Yunis et al., 2020; Francisco et al., 2019; Sari et al., 2020; Tuyen et al., 2019). In this study, two hierarchies were implemented. In the first hierarchy, three main criteria for mangrove-shrimp farming are paired and weighted, including geographical conditions, water quality and infrastructure availability (Table 1).

In the second hierarchy, 15 sub-criteria belonging to the above main criteria are calculated. Results of pair comparison and weight calculation are shown in Table 2, Table 3, Table 4, and Table 5. Each reclassified factor/layer on the thematic maps was weighted and combined according to Eq. 1 (Calle Yunis et al., 2020; Cheng & Hsu, 2022; Nayak et al., 2018).

$$Ai = \sum Vi \times Wi \quad [1]$$

$$Cl_s = \frac{H-L}{4} \quad [2]$$

where (H) is the highest score and (L) is the lowest score of classification value.

The equal interval method was applied in this study to define the four levels of classification (highly suitable, moderately suitable, marginally suitable, and not suitable) (Calle Yunis et al., 2020; Francisco et al., 2019). The Eq. 2 is used to define the classification of intervals (Cl) between four levels.

Table 1. Threshold hierarchy of suitability sub-criteria

1.1. Geographical conditions

Criteria	Sub-criteria	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Geographical conditions	Soil texture (ST)	Silty clay loam	Silty loam	Sandy clay loam	Sandy; Rocky
	Slope/Terrain (°)	< 5	5-10	10-15	> 15
	Soil salinity (SS) (%)	0.80-0.16	5.0-8.0 16.0-32.0	3.0-5.0 32.0-37.0	> 37
	Distance to river (DWR)(km)	<0.5	0.5-1.0	1.0-1.5	>1.5
	Tide inundation depth (TD) (m)	1.0-2.0	0.5-1.0	<0.5	0.00
				4.0-5.0	>5.0
	LULC	Mangroves; Shrimp farm	Poor agricultural crop	Intensive rice and crop	Water bodies; Settlement

1.2. Water quality

Criteria	Sub-criteria	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Water quality	pH	7.5-8.5	6.5-7.5	4.5-6.5	<4.5; >8,5
	COD (mg l^{-1})	<20	20-40	40-60	>60.0
	DO (mg l^{-1}))	4-6	3-4; 6-9	2-3; 9-12	<2; >12
	Water salinity (WS)	8-16	5-8; 16-32	3-5; 32-37	<3; >37
	NO_3	<50	50-60	60-70	>70

1.3. Infrastructure availability

Criteria	Sub-criteria	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Infrastructure availability	Distance to processing plant (DPP) (Km)	3	3-5	5-10	>10
	Distance to populations (DP) (Km)	<2	2-4	4-6	>6
	Distance to road (DR) (Km)	<1	1-2	2-3	>3
	Distance to market (DM)(Km)	<1	1-3	3-5	>5

3. RESULTS

3.1. The importance of the factors/Criteria

Results of the AHP method indicated that the most important factor for the SFM is geographical conditions with 0.42 weight, followed by water quality (0.34), and the available infrastructure (0.24) (Table 2 and Fig. 3). In the geographical conditions: soil texture, tidal inundation depth, and terrain slope were weighting 2.3, 1.9, and 1.7, respectively. In fact, these are the main factors affecting mangrove rehabilitation and shrimp pond design. The results show that soil texture and tide inundation depth plays a vital role in shrimp farming combined with mangrove rehabilitation by weight value of 0.31 and 0.25, respectively (Table 3).

Regarding water quality, water salinity was the most important factor with a weight of 0.44, followed by pH (0.23) (Table 4). However, the weighting difference between the first and the third factor is quite large, more than twice.

Table 2. Matrix results compared pairwise parameters of main criteria

Criteria	Geo-Condition	Water quality	Infrastructure	Weight
Geographical Conditions	1	4	1/2	0.42
Water quality	1/4	1	2	0.34
Infrastructure	2	1/2	1	0.24

Table 3. Matrix compared pairwise parameters of geographical condition

Criteria	ST	Slope	SS	DR	TD	LULC	Weight
ST	1	3	2	4	3/2	3	0.31
Slope/ Terrain (°)	1/3	1	1/2	2/3	1/3	1/3	0.07
Soil salinity (SS)	1/2	2	1	2/3	1/2	4	0.15
Distance to River (DWR)(km)	1/4	3/2	3/2	1	2/3	3/2	0.13
Tide inundation depth (TD) (m)	2/3	3	2	3/2	1	5	0.25
LULC	1/3	3	1/4	2/3	1/5	1	0.09

Table 4. Matrix results compared pairwise parameters of Water quality

Criteria	pH	DO	NO_3	COD	Weight
Water salinity (WS)	2	4	3	5	0.44
pH	1	2	3/2	3	0.23
DO	1/2	1	2/3	3/2	0.11
NO_3	2/3	3/2	1	3/2	0.15
COD	1/3	3/4	2/3	1	0.08

Table 5. Matrix results compared with pairwise parameters of Available Infrastructure

Criteria	DPP	DH	DR	DM	Weight
Distance to processing plant (DPP) (Km)	1	2/3	1/3	1/2	0.13
Distance to populations (DP) (Km)	3/2	1	1/2	3/4	0.19
Distance to road (DR) (Km)	3	2	1	3	0.46
Distance to market (DM)(Km)	2	3/2	1/3	1	0.22

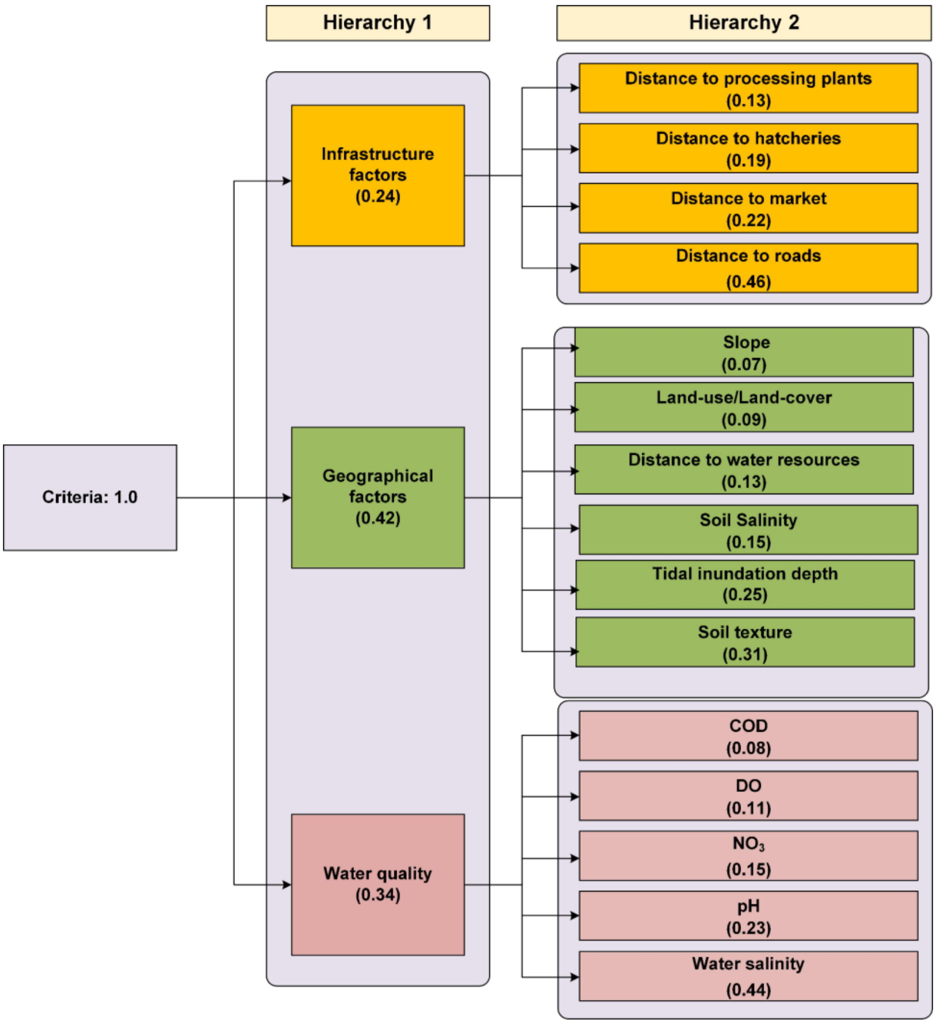

Figure 3. Weighted results of the criteria of AHP method

This shows the importance of water salinity for shrimp farming and mangrove rehabilitation. In terms of the available infrastructure, the distance to road was the most important factor with a weight 0.32, followed by the distance to market (0.28) and distance to hatcheries (0.26) (Table 5).

3.2. Suitability classification

The suitability of the sub-criteria in four levels of suitability level is shown in Table 6 and Fig. 4. In geographical factors, suitable terrain slope area and rivers flowing area comprise the largest area within the study area of the "highly suitable" class for shrimp farming with 6403.54 ha (88.43%) and 3564.68 ha (49.23%), respectively. On the contrary, other factors such as tidal fluctuation, soil texture, and soil salinity have a limited area as shown in Fig. 5. In this area, coastal sandy soils account for the largest proportion and are assessed as unsuitable for mangroves, although they may be suitable for shrimp farming. Silt and clay loam soil has a significant efficiency in mangrove rehabilitation, but it is a limited area of 785.73 ha (10.8%). Soil salinity fluctuates within the most appropriate range (0.8-1.6 %) that occupies a small area, concentrating mainly in the estuary and coastal areas with 787.34 ha (10.87%). Tidal inundation was higher in the estuary (1.0 to 1.5 m), while it was lower in the beach area (0.5 to 1.0 m) and the upstream (<0.5 m). Results show that the "suitable area" of tidal inundation depth for shrimp farming and mangrove forests is only 296.75 ha, accounting for 4.1% of the study area. This area also has easy access to brackish water and sea water. In the study area, the crop cultivation is dominated by the land use/land cover pattern with vegetables, and paddy fields accounting for more than 70%. Meanwhile, shrimp farms and mangrove forest areas have significant contributions to the selected sites. Mangroves are distributed along the river, in the estuary, and in tidal flats. However, the "suitable area" for shrimp farming is the mangrove area next to the river, where the tidal range is suitable. Figure 6 shows obviously that the water quality parameters including pH, water salinity, NO_3 and DO have high compatibility with SFM. The very adaptable area accounts for a high proportion: 70.6%, 70.69%, 88.9% and 98.23%, respectively. The DO values are highly suitable and suitable, at 15/17 measuring stations, reaching from 4.0 to 6.0, only one station measured 3.9 and the other 6.1. On the contrariwise, COD is the factor with the smallest adaptive area of 6.29 ha (1.49%) at only one station that measures 16.3 mg l^{-1}. The higher COD, the richer the water with organic compounds, thus more polluted for the shrimp pond. The COD concentrations in successful shrimp ponds of the Mekong Delta ranged from 2.64 to 35.21 mg l^{-1}, averaging 17.31 mg l^{-1}. The measured COD content in this area was too high with concentrations (greater than 40 mg l^{-1}) at 15/17 monitoring points.

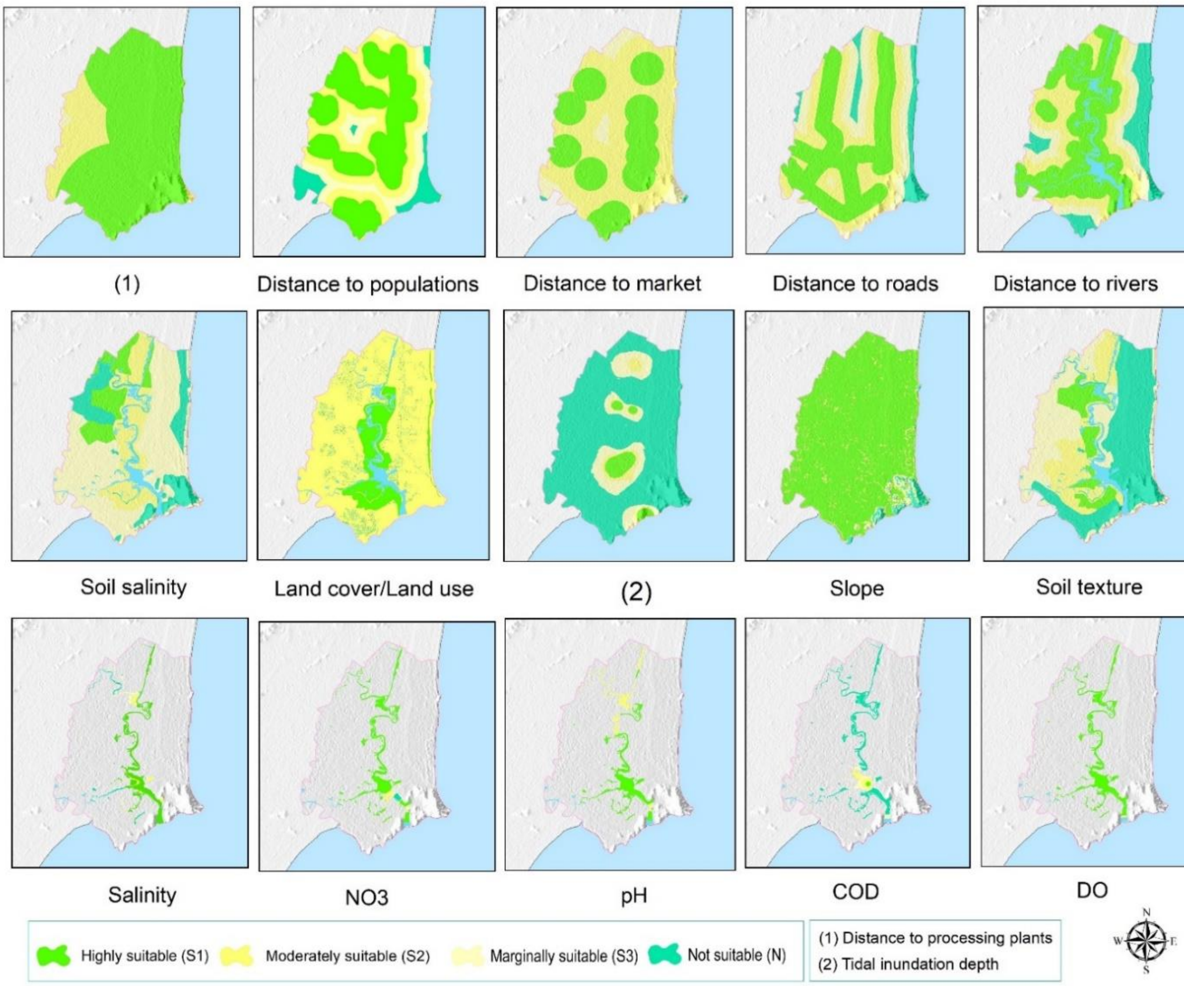

Figure 4. The maps of the adaptability levels of the sub-criteria

Table 6. The suitability of areas based on sub-criteria

Sub-Criteria	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	ha	%	ha	%	ha	%	ha	%
Soil texture (ST)	785.73	10.85	1453.34	20.07	1798.03	24.83	3204.37	44.25
Slope/ Terrain (°)	6403.54	88.43	484.04	6.68	127.27	1.76	226.62	3.13
Soil salinity (SS) (%)	787.34	10.87	1508.92	20.84	3318.37	45.82	1626.84	22.47
Distance to river (DWR) (km)	3564.68	49.23	1675.83	23.14	941.67	13.00	1059.29	14.63
Tide inundation depth (TD) (m)	296.75	4.10	222.40	3.07	928.41	12.82	5793.91	80.01
LULC	1457.60	20.13	435.88	6.02	5152.85	71.16	195.14	2.69
pH	296.50	70.16	126.09	29.84	0	0	0	0
COD	6.29	1.49	48.14	11.39	56.32	13.33	311.84	73.79
DO	415.11	98.23	7.48	1.77	0	0	0	0
Water salinity (WS)	298.71	70.69	60.54	14.33	43.58	10.31	19.76	4.68
NO_3	372.27	88.09	28.51	6.75	9.45	2.24	12.36	2.93
Distance to processing plant (DPP) (Km)	5276.86	72.87	1195.57	16.51	769.04	10.62	0	0
Distance to populations (DP) (Km)	3132.62	43.26	1891.86	26.13	1241.64	17.15	975.35	13.47
Distance to road (DR) (Km)	3055.04	42.19	2207.74	30.49	1368.21	18.89	610.48	13.47
Distance to market (DM) (Km)	2940.72	40.61	3699.47	51.09	584.52	8.07	16.76	0.23

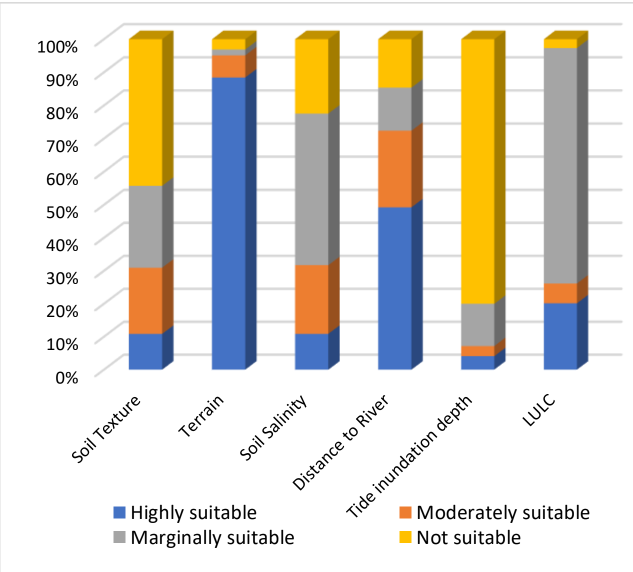

Figure 5. The suitable levels of the geographical factor

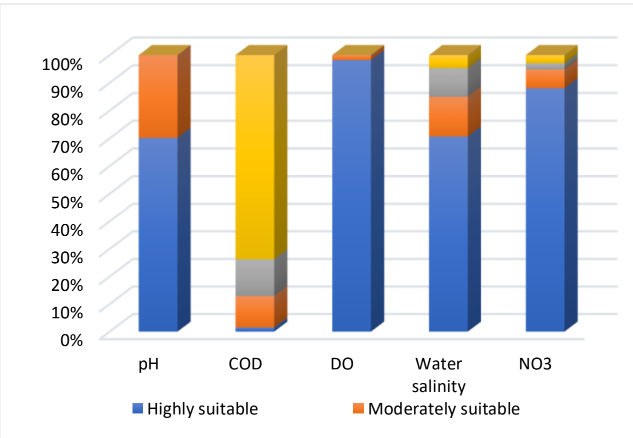

Figure 6. The suitable levels of the water quality factor

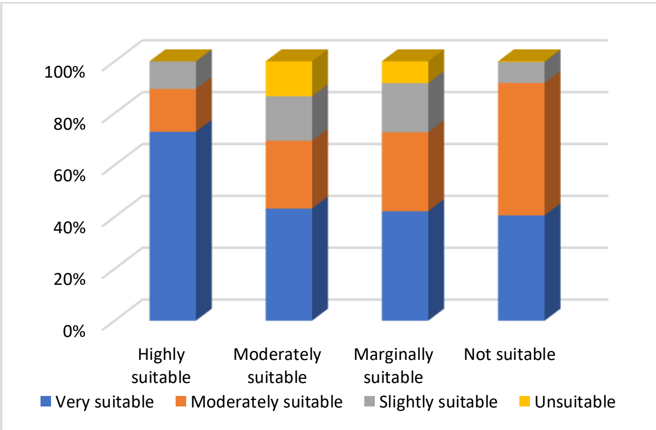

Figure 7. The suitable levels of the infrastructure factors

Similar to water quality, infrastructure criteria are favorable for shrimp farming and mangrove development. The advantages of distance to processing plants, roads, populations, and markets in this area are shown in a highly suitable area with 5276.86 ha, 3055.04 ha, 3132.62 ha and 2940.72 ha, respectively. This range of all sub-criteria accounts for over 40%, especially distance to processing plants is 72.87% that is shown in Fig. 7. These factors do not restrict the growth of shrimp farming, which is also the result of investment for shrimp culture in the past decades in this area. However, the close distance to residents and factories is one of the factors that harm the development of mangroves if they are not managed well.

Fig. 8 and Fig. 9 show the suitable area for the SFM in this study. The highly suitable regions in the Hau basin concentrate in the central area with 1127.82 ha, accounting for 15.57 %. This area is most favorable in terms of the depth of tidal flooding, soil texture, and factors that have high impact on shrimp farming.

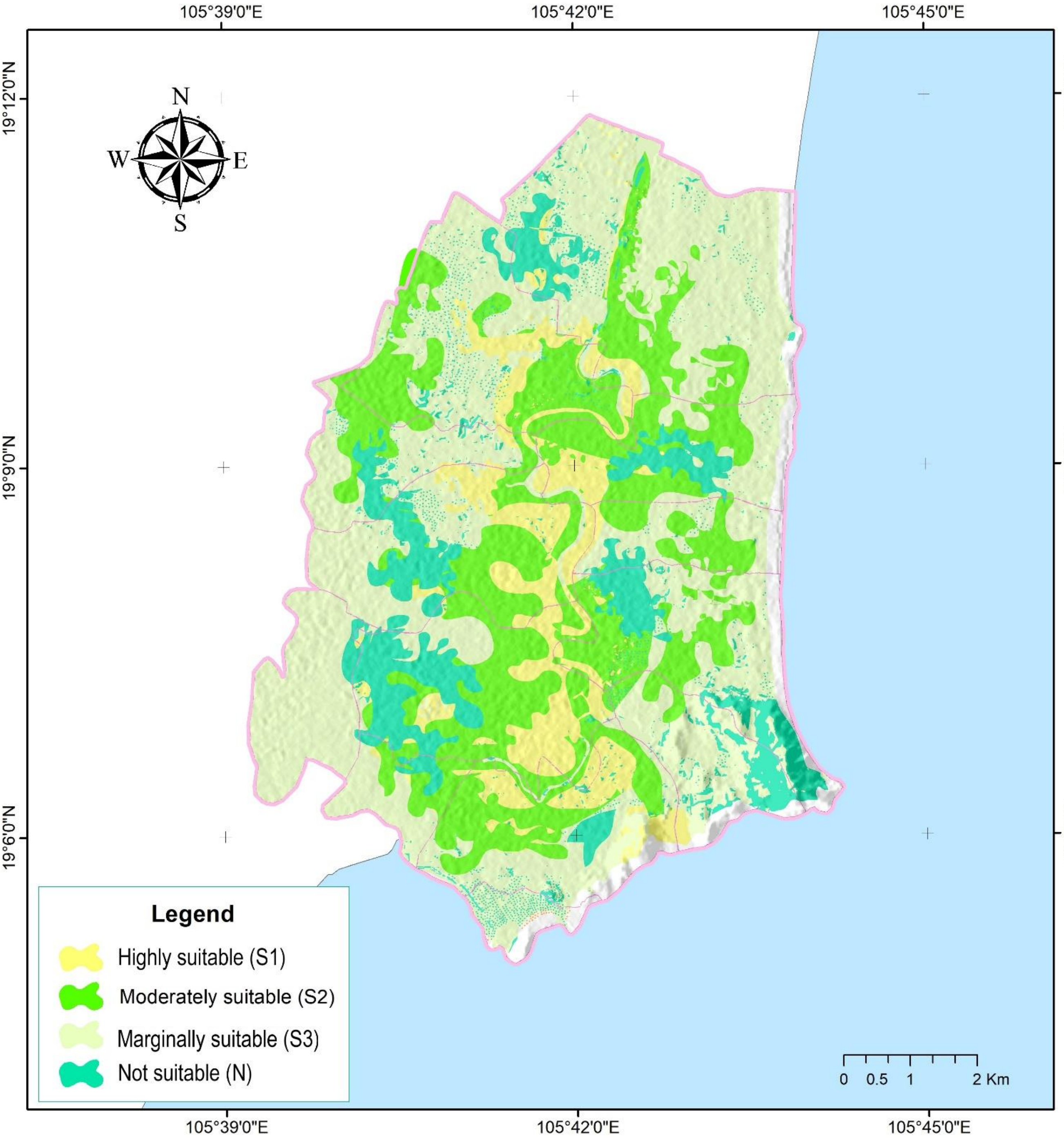

Figure 8. The suitability map for shrimp farming and mangrove forest development

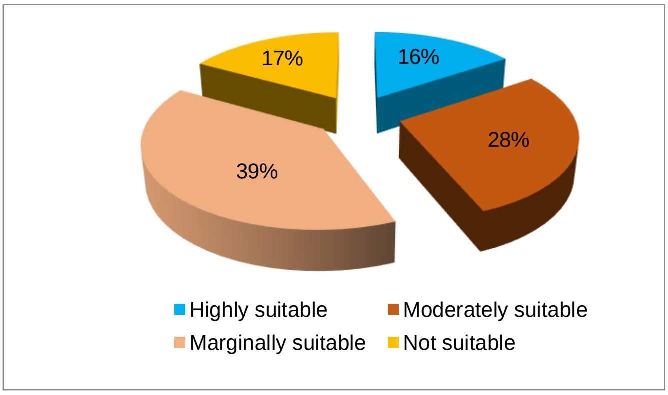

Figure 9. The percentage areas of the suitability levels

Moderately suitable areas accounted for 2056.87 ha (28.4%), which is distributed close to the river. Marginally suitable level occupies the largest area, 2835.52 ha (39.16%) and the part of it is not suitable (17%). These areas are located along the coast, including existing aquaculture, cropland, and salt farms in Quynh Luong, Quynh Thuan, Quynh Bang commune.

4. DISCUSSION

There has been little doubt that aquaculture combined with mangrove conservation plays a crucial role in economic development and environmental protection. The interaction between mangroves and aquaculture systems requires quite complex selection criteria for farming sites. The present study addressed the suitable areas for the development of shrimp farms combined with mangrove rehabilitation on the coast of Vietnam by using the combined GIS - MCE – AHP method.

This study has revealed that geographical conditions such as tidal inundation depth, quality of water, infrastructure and soil characteristics have the greatest impact on the decision of shrimp farming location and mangrove plantation. These results can be corroborated by previous studies related to aquaculture and mangrove development (Francisco et al., 2019; Hossain et al., 2009). Another study carried out in Peru by Calle Yunis et al. (2020) noted that the highest to lowest importance of the criteria is the economic sub-model (9.20%), followed by social (6.35%), and the environment (3.92%). However, in some other studies, mangroves are believed to be the most suitable land cover (Francisco et al., 2019; Hossain et al., 2009). This indicated that the standards in our study must be satisfied both for shrimps and mangroves. Our study also confirms the potential to develop mangrove-integrated shrimp farming in the research area with 1127.82 ha (15.57%) which is coming under very suitable criteria (Fig. 9). Our findings corroborate the studies carried out in other parts of the world (Islam et al., 2009).

Mapping suitable shrimp farming and mangrove forest development are crucial to understanding the result of interactions between geographical factor - water quality – infrastructure (Fig. 5, Fig. 6 & Fig. 7). Soil is another important factor which affects the filtration and infiltration capacity of shrimp ponds and helps in the development of mangrove roots (Table 1).

5. CONCLUSION

Generation of the suitability maps based on GIS-AHP-MCE model helped in identifying suitable sites for the development of SFM on the coastal area of Nghe An Province Vietnam. Based on the model study 1127.82 ha (15.57%) area has been identified as highly suitable for shrimp farming and mangrove development. This area is also having the advantage of water, road, and high agglomeration potential of market outlets. In particular, the availability of mangroves and their rehabilitation are appropriate conditions for proper farming of organic shrimps. The results from this study have demonstrated the effectiveness of an integrated approach in finding the appropriate area for aquaculture and mangrove development to improve the livelihood of local people while conserving the ecosystem. This study has also demonstrated that geographic factors play a crucial role in SFM followed by water quality and infrastructure availability in the coastal area.

It is important to note that, to develop the SFM, the highly suitable area (15.57%) should be priorities for the development. Areas rated as moderately suitable (28.4%) need to overcome the limiting factor when being included in the development planning. Marginally suitable areas (39.16%) and not suitable areas (17.0%) should be carefully considered when incorporating development plans for other purposes. It is also suggested that marginally suitable areas besides not suitable areas should be considered for other uses as the shrimp ponds this area may have many risk factors and thus are not suitable for shrimp farming.

One of the limitations of the study is the application of the model in one of the provinces of Vietnam which has to be applied in other coastal areas also for further improvement in the selection of more appropriate parameters in the model depending on the different geo-environmental conditions. It is proposed to further refine the study by incorporating other factors in the model such as the spreading of disease from other species and also migration of pathogens with sediments from land into the ponds affecting the quality of shrimp production and even death. Similarly, climate change factors may also affect the health of shrimps and mangrove forests needed to be considered.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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