# GIS–BASED PLANNING FOR SUSTAINABLE SHRIMP FARMING IN THANH PHU, BEN TRE PROVINCE, VIET NAM

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## Abstract

This study was conducted to develop a GIS-based approach to identify and quantify the suitable areas for shrimp farming in Thanhphu district, Bentre province, Vietnam. The data used were Landsat 5 TM image, thematic maps, related reports and field survey data. Nine raster data layers were prepared and put in two groups namely: natural physical condition (soil types, salinity, water pH, proximity to mangroves, distance to water sources) and socio-economic condition (distance to roads, population density, experience in shrimp farming and land-use). Different criteria usually have different levels of importance. It is necessary to incorporate some criteria giving weight to indicate relative importance. Criteria weighting is done using analytic hierarchy process (AHP), which translates pair wise comparison matrix for different land-use into vectors of relative weights. Ammonia-N was used as criteria for calculating the carrying capacity of water bodies for shrimp farming with the assumption that $NH_3$ in the study area was only produced from shrimp farming activities.

Hamluong and Cochien rivers system have provided the good existing conditions on carrying capacity to develop shrimp farming activities in Thanhphu district. These rivers can carry the intensive shrimp farming areas equivalent to 3 times the total areas of Thanhphu district. The overall assessment has revealed that 21.17% of the total area is moderately suitable for shrimp culture and can be used for improved-extensive culture, 23.9% is suitable and can be used for semi-intensive culture and 14.3% is highly suitable and can be used for intensive culture. The present study has shown that 21,621.45 ha can be used for shrimp farming development while the current shrimp farms area is 15,871.74 ha. It means that the area for shrimp farming can be expanded to include rangeland and bare land. This study demonstrates the use of GIS in aquaculture planning which can be applied in other places and the results from this study can be very useful for decision makers to make shrimp culture sustainable through proper consideration of socio–economic and environmental issues.

*Key words:* GIS, land evaluation, shrimp farming.

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## 1. Introduction

Zoning involves an integration analysis of various spatial factors of features that are complex and relatively relevant each other, and it requires a combination of these factors to identify suitable zones as expected. Spatial factors including physical, biological and others such as land-use have complex relationships and they have certain effects on zoning objectives. Zoning also is considered to be relevant to process of multiple-criteria and multiple-objectives evaluation in which factors or map layers are superimposed together to create a new layer that presents a spatial distribution of zones. Therefore, to deal with this complexity, overlaying-mapping method is used for spatial analysis and simple mathematical models are employed in zoning to facilitate the process (Unwin, 1996 cited in Pham, 1999). A large number of land evaluations for aquaculture using GIS have been studied at different scales for various cultured species and environments, for example, hard clam aquaculture in Florida, USA: GIS applications to lease site selection (Arnold et al., 2000); zoning and management of razor clam in the muddy coastal zone between the Mae Klong and Tha Chin rivers, Thailand (Benjarat, 2002); analysis of sustainability of the shrimp farming systems in Haiphong, Vietnam (Dao, 2005); planning for coastal aquaculture development using remote sensing and GIS in Nghean, Vietnam (Nguyen, 2002); GIS modeling for aquaculture in South-western Bangladesh: comparative production scenarios for brackish and freshwater shrimp and fish (Salam et al., 2003); planning of coastal aquaculture in Lampung province, Indonesia (Setiato, 1993).

In Vietnam, aquaculture has become a highly profitable business, and will continue to grow to meet domestic and export demands. Shrimp farming in particular has expanded rapidly in recent years, and contributed about 50% of the total export earning of Vietnamese fisheries products with 324,680 tons of farmed shrimp in the year 2005 (MOFI, 2006). It has been so difficult to control the development of brackish water shrimp culture. Due to the potentially high income from shrimp culture, rice farmers have converted their farms to shrimp farms but most of these rice farms are not suitable for shrimp culture only. In other areas, mangrove forests have been cleared to acquire areas for shrimp culture. A major cause of the farmers' problem is the unsuitable site used for shrimp culture. It is therefore necessary to identify which areas are suitable for shrimp culture and models position of shrimp farming as well.

This paper presents results of the application of GIS techniques to develop a land evaluation method for identifying and quantifying appropriate sites and farming operations of shrimp farming development in Thanhphu district, Bentre province, Vietnam.

## 2. Methodology

### *2.1 Study area*

Thanhphu is one of the coastal districts of Bentre province, in the Mekong delta, Vietnam. It is located at the end of Minh island, between two rivers: Hamluong and

Cochien and contiguous with East Sea. It covers from $9^0 47'95''$N to $10^0 03'52''$N and $106^0 24'41''$E to $106^0 41'47''$E (Figure 1).

Except some high sand dunes (height about 2 – 5 m), topography is quite flat, the differential between highest and lowest areas just about 50 – 60 cm. Thanhphu's climate has been affected by tropical climate. It has two seasons: dry season (from Dec to April), rainy season (from May to Nov). Temperature is high and stable. Annual average temperature is about 26 – 27$^o$C. With the position near by East Sea, Thanhphu is one of the lowest rainfall areas in the Mekong delta. Average rainfall is 1,279 mm yearly. The rainy season and dry season rainfall of 1,218 mm and 61 mm represents 95% and 5% of total annual rainfall.

It's affected directly from East sea's tide, the major rivers flow toward North East – South West. The study area locates between two major rivers: Hamluong and Cochien. Rivers and canals in Thanhphu district are affected from semi – daily tidal regime of East sea.

There are about 7.87% of populations living in urbanization and 22, 52% in non-agriculture areas. Almost land areas in study area are used for agriculture and aquaculture. On the aspect of shrimp farming, there are two alternatives: rice –shrimp and shrimp only in study area. There was a rapid change in shrimp farming development. It reached the areas of 7843.74 ha for shrimp only and 7572.11 ha for rice – shrimp by the year 2006 of which mostly converted from aquaculture pond, rangeland, paddy field, and agriculture land.

*2.2 Data and software used*

The used data were Landsat 5 TM image, thematic maps, related reports and field survey data.

Water quality (NH3), water depth, and water flow velocity at each hour in one tidal cycle (24 hours) were collected from the filed survey. These data were used for calculating the carrying capacity of water bodies for shrimp farming in the study area.

Nine raster layers were prepared and put in two groups namely: natural physical condition (soil types, salinity, water pH, Proximity to mangroves, distance to water sources) and socio-economic condition (distance to roads, population density, experience in shrimp farming and land-use).

Salinity, water pH, population density, experience in shrimp farming were derived from related reports which getting from Research Institute for Aquaculture No.2, Bentre Statistical Office and Thanhphu Statistical Office. Soil types, distance to water sources, distance to roads were got from related thematic maps. proximity to mangroves and land-use map were extracted from Landsat 5 TM image of the year 2006 (p125r053_20060304 FCC 542).

ENVI 4.2 (The Environment for Visualizing Images, Research Systems Inc., USA), ArcView 3.2 (The Environmental Systems Research Institute, USA) and MS Office 2003 (The Microsoft Corporation, USA) softwares were used for analyzing remote sensing image, GIS and statistic, respectively.

*2.3 Analysis procedure*

The method to calculate the remaining carrying capacity of water bodies for shrimp farming was also adopted from Kanokporn (1997). Ammonia-N was used as criteria for calculating the remaining carrying capacity of shrimp farming with the assumption that $NH_3$ in the study area is only produced from shrimp farming activities. We also assumed that the study area had been affected by $NH_3$ through Hamluong and Cochien river systems. We considered ammonia-N within 1 tidal cycle (24 hours) in the dry season. The following equations were used:

Remaining carrying capacity (C) = ((R x MAI) – AO)/AL    Equation 1

Removal rate (R) = AO/AI    Equation 2

Ammonia loading (AL) = (AO – AI)/ Area    Equation 3

**Where**
C = Remaining carrying capacity (ha)
R = Removal rate
MAI = Maximum ammonia inflow (kg/day)
AO = Ammonia outflow (kg/day)
AL = Ammonia loading (kg/day/ha)
Area = Current shrimp farm area = 4,716.96 hectares

$$\text{Ammonia outflow (AO)} = \sum_{j=1}^{n} 3.6\, A_j V_j C_j \qquad \text{Equation 4}$$

**Where**
j = Low tide level at 1st to nth hour
$A_j$ = Cross section area of the river entrance at j hour ($m^2$)
$V_j$ = Current velocity at j hour (m/s)
$C_j$ = Concentration of ammonia at j hour (mg/L)

$$\text{Ammonia inflow (AI)} = \sum_{i=1}^{n} 3.6\, A_i V_i C_i \qquad \text{Equation 5}$$

**Where**
i = High tide level at 1st to nth hour
$A_i$ = Cross section area of the river entrance at i hour ($m^2$)
$V_i$ = Current velocity at i hour (m/s)
$C_i$ = Concentration of ammonia at i hour (mg/L)

$$\text{Maximum Ammonia Inflow (MAI)} = \sum_{i_m=1}^{n} 3.6\, A_{im} V_{im} C_{im} \qquad \text{Equation 6}$$

**Where** $i_m$ = High tide level at $1^{st}$ to $n^{th}$ hour
$A_{im}$ = $A_i$ ($m^2$)
$V_{im}$ = $V_i$ (m/s)
$C_{im}$ = Concentration of ammonia at optimum safe level (mg/L) (e.g. 0.1 mg/L)

Suitability ratings were established according to FAO classification (Hajek and Boyd, 1994; FAO, 1977 cited in Dao, 2005) on the appropriateness of land for defined uses. Weighing and suitability rating were based on the level of importance of a particular factor that influences aquaculture. Each factor was ranked and classified according to the following procedure (Table 1).

+ Highly suitable (3): provides a situation in which a minimum time and investment are required to develop shrimp farming
+ Suitable (2): requires modest investment and time period
+ Moderately suitable (1): requires significant intervention before shrimp farming can be operated.
+ Unsuitable (0): requires considerable time and cost or both. These are not worthwhile for shrimp farming.

Different criteria usually have different levels of importance. It is necessary to incorporate of some form of criteria weighting to take care of their relative importance. Criteria weighting is done using analytic hierarchy process (AHP) developed by Saaty (1980), which translates pair wise comparison matrices for different land uses into vectors of relative weights (Tables 3 and 4). The AHP is based upon the construction of a series of “pair – wise comparison” matrices, which compare criteria to one another. This is done to estimate a ranking or weighting of each of the criteria that describes the importance of each of these criteria in contributing to the overall objective.

To estimate the consistency of judgment, the steps followed are:
+ Calculate the consistency vector
+ Compute lambda ($\lambda$)
Lambda = the average value of the consistency vector
+ To compute the Consistency Index (C.I.)
C.I. = $(\lambda$-n)/(n-1)
+ To calculate the Consistency Ratio (C.R.)
C.R. = C.I./R.I.
Where: R.I., the random consistency index, is the consistency of a randomly generated pair-wise comparison matrix.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0.00 | 0.00 | 0.56 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

According to Saaty (1980), a C.R. of less than 0.10 indicates a reasonable level of consistency in the pair-wise comparison. If the CR is lager than 0.10 the ratio indicates inconsistent judgment, hence the original value need to be revised.

For shrimp farming activities, the natural conditions are more important than the socio-economic conditions, so that we assigned the weightings as 0.75 and 0.25 for map of natural physical suitability and map of socio-economic suitability respectively.

The suitability scores then were calculated by the following equation:

$$\mathbf{S} = \sum_{i=1}^{n} \mathbf{X_i * W_i} \qquad \text{Equation 7}$$

Where S = Suitability score
$X_i$ = Standardized score for value of criteria i
$W_i$ = Weight of criteria i

**Map of natural physical suitability = 0.22***Soil types + **0.27***Salinity + **0.14***Water pH + **0.09***Water sources buffer + **0.28***Mangrove area buffer

**Map of socio-economic suitability = 0.13***Population density + **0.36***Shrimp farming experiences + **0.18***Roads buffer + **0.33***Land-use

**Suitability map for brackish water shrimp farming = 0.75***Natural physical suitability + **0.25***Socio-economic suitability

The buffer map of major rivers and sea was prepared and converted to raster map. This map was multiplied with the shrimp farming final suitability map (raster map) to reach the results on land suitability for shrimp farming operations.

## 3. Results

The carrying capacity for shrimp farming of Cochien river and Hamluong river were found as 17,649.32 hectares and 92,731.69 hectares, respectively. The carrying capacity of water bodies for shrimp farming of Thanhphu district was considered as the sum of Cochien and Hamluong rivers carrying capacities. The result reached was 110,381.02 hectares. This area is equal 3 times the total area of Thanhphu district (36,438.41 hectares).

The classification of land-use types were showed in Table 2. It expressed that the dominant land-use types were shrimp ponds (21.53%), rice-shrimp farms (20.78%), and paddy field (16.54%) of total area.

The classified of related factors suitability for shrimp culture was presented in Table 5. Most of the soil types of study area can be used for shrimp farming, 40.87% and 24.06% of total area were found as suitable and highly suitable, respectively. The soil types, which considered as highly suitable and suitable, were severely saline soil, moderately and slightly saline soil.

The study area owned the profound water resources, many rivers, streams and man-made canals were connected to make a watercourses network. Cause of that, 87.5% of total area were found as highly suitable for shrimp culture on the aspect of distance to watercourses. 88% of study area were also found as highly suitable related with water pH. In the context of water salinity, 42.1% and 31.2% of total area were recognized as highly suitable and suitable for shrimp farming.

The socio-economic conditions have taken an important role in shrimp farming development. The land-use factor, which relates to the government policies, somewhere could be used for shrimp culture on the aspect of natural conditions, but cause of the reasons such as security and safe of food, those area then were not used for shrimp culture. In this study, aquaculture pond and rangeland were considered as highly suitable and suitable, respectively for shrimp farming. The suitability process was found that 16.46% and 43.86% of total area as highly suitable and suitable, respectively, for shrimp culture in terms of socio-economic conditions.

The overall assessment has revealed that 21.17%, 23.9% and 14.3% of total area can be applied for improved-extensive as moderately suitable, semi-intensive as suitable and intensive as highly suitable, respectively ( Table 7, Figure 6).

## 4. Discussions

In the context of Vietnam, the areas for shrimp farming have been decided mainly according to the expert's experiences or to considering the factors in separately or to farmer's spontaneousness. The integration of GIS with MCE (Multi-Criteria Evaluation) including Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) is so useful for land evaluation for shrimp farming and shrimp farming operations position as well. Through out this method, we can get the comprehensive and accurately results on shrimp farming areas. However, for getting more appropriate results, we should consider more importance factors such as political, socio-economic, environmental issues.

The present study has shown that 21621.45 ha can be used for shrimp farming development while the current shrimp farms area were 15871.74 ha (Fig. 2). It means the study area can expand shrimp farms to other areas based on the land suitability as proposed on Fig. 5 and Fig. 6.

On the aspect of environmental pollution, the intensive model produced the highest amount of pollution, followed by the semi-intensive and improved-extensive operations. For sustainable farming, therefore, the intensive model should take the places nearest major rivers or the sea, followed by semi-intensive and improved-extensive more inland. On the other hand, the moderately suitable area, suitable area and highly suitable area

should be employed for improved-extensive, semi-intensive and intensive respectively because of the reasons about investment risks.
In the context of GIS – based planning for sustainable shrimp farming, these are three main points that may be considered: suitable area, suitable area position for shrimp farming operations and carrying capacity of water bodies. If these three main points are satisfied and associated with the government policies, farmer's awareness and a stable market, then the sustainable development can be achieved.

## 5. Conclusions

With the conditions of a developing country as Vietnam, the Landsat 5 TM has been very appropriate for making the existing shrimp farms map and land evaluation as well.

This kind of research should be applied on the lager area such as the coastal areas of Mekong delta in order to get the comprehensive results on suitable area for shrimp farming development. This is the most importance thing in making the sustainable planning of shrimp farming.

More important factors such as soil pH, soil bearing capacity, etc. should be considered to get more specific results.

Higher resolution satellite images should be used to get more detail and accuracy, as well as better image interpretation.

The integration of AHP and WLC with the supporting of expert's opinion, government policies has been so useful to reveal the appropriate results of shrimp farming areas. To apply this method elsewhere, the authors should be reconsidered the expert's opinion, government policies of new study areas.

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**Tables:**

Table 1: Detail of Factors, Indicators and Range of Measurement in the Study Area Potential Surface Analysis

| Factor | Indicator | Range of Measurement | Score |
|---|---|---|---|
| Soil type([1]) | - Severely saline soil | | 3 |
| | - Moderately and slightly saline soil | | 2 |
| | - Saline-slightly potential acid sulphate soil, Mangrove Saline soil | | 1 |
| | - Sandy soil | | 0 |
| Salinity([2]) | - ppt | 10 – 25 | 3 |
| | | 5 - 9; 26 – 35 | 2 |
| | | < 5; > 35 | 0 |
| Water pH([2]) | | 7.5 – 8.5 | 3 |
| | | 7 – 7.5; 8.5 – 9 | 2 |
| | | < 7; > 9 | 0 |
| Proximity to mangroves([1]) | - km | 1 – 2 | 3 |
| | | >2 | 2 |
| | | <1 | 0 |
| Distance to water sources([1]) | - km | < 0.5 | 3 |
| | | 0.5 – 2 | 2 |
| | | > 2 | 1 |
| Distance to roads([1]) | - km | < 0.5 | 3 |
| | | 0.5 – 1.5 | 2 |
| | | > 1.5 | 1 |
| Population density([1]) | - People/$km^2$ | < 200 | 3 |
| | | 200 – 800 | 2 |
| | | > 800 | 1 |
| Experience in shrimp farming([1]) | - No of years | > 10 | 3 |
| | | 5 – 10 | 2 |
| | | < 5 | 1 |
| Land-use([1]) | - Aquaculture pond | | 3 |
| | - Rangeland | | 2 |
| | - Agriculture land, Rice-Shrimp land, Paddy field, Bare land | | 1 |
| | - Mangroves, Water body, Abandon pond, Sand dune | | 0 |

Note: ([1]) Field survey results and expert opinions

([2]) Vietnamese standards for shrimp farming (MOFI 2001) and expert opinions

Highly suitable (3): provides a situation in which a minimum time and investment are required to develop shrimp farming

Suitable (2): requires modest investment and time period

Moderately suitable (1): requires significant intervention before shrimp farming can be operated.

Unsuitable (0): requires considerable time and cost or both. These are not worthwhile for shrimp farming.

Table 2: Areas of Land-use kinds in 2006

| | Area (ha) | Percentage |
|---|---|---|
| Abandon pond | 89.69 | 0.25 |
| Agriculture | 3177.47 | 8.72 |
| Mangrove | 1980.79 | 5.44 |
| Paddy field | 6026.94 | 16.54 |
| Pond | 7843.74 | 21.53 |
| Rangeland | 2949.41 | 8.09 |
| Rice - Shrimp | 7572.11 | 20.78 |
| Sand dune, Bare land | 5578.51 | 15.31 |
| Water body | 1219.74 | 3.35 |
| Column total | 36438.41 | 100.00 |

Table 3: Importance Matrix for The Suitability Analysis of Natural Conditions for Shrimp Farming

| | Soil types | Salinity | Water pH | Distance to water sources | Proximity to mangroves | Weightage |
|---|---|---|---|---|---|---|
| Soil types | 1.00 | 0.33 | 2.00 | 3.00 | 1.00 | 0.22 |
| Salinity | 3.00 | 1.00 | 1.50 | 2.00 | 0.67 | 0.27 |
| Water pH | 0.50 | 0.67 | 1.00 | 1.50 | 0.50 | 0.14 |
| Distance to water sources | 0.33 | 0.50 | 0.67 | 1.00 | 0.33 | 0.09 |
| Proximity to mangroves | 1.00 | 1.50 | 2.00 | 3.00 | 1.00 | 0.28 |
| Column total | 5.83 | 4.00 | 7.17 | 10.50 | 3.50 | 1.00 |

*Consistency ratio (C.R.) = 0.06*

Table 4: Importance Matrix for Socio-Economic Conditions of Shrimp Farming

| | Population density | Experience in shrimp farming | Distance to roads | Land-use | Weightage |
|---|---|---|---|---|---|
| Population density | 1.00 | 0.33 | 0.67 | 0.50 | 0.13 |
| Experience in shrimp farming | 3.00 | 1.00 | 2.00 | 1.00 | 0.36 |
| Distance to roads | 1.50 | 0.50 | 1.00 | 0.50 | 0.18 |
| Land-use | 2.00 | 1.00 | 2.00 | 1.00 | 0.33 |
| Column total | 7.50 | 2.83 | 5.67 | 3.00 | 1.00 |

*C.R. = 0.01*

Table 5: Areas of Related Factors Suitability for Shrimp Farming (ha)

| | Unsuitable | | Moderately Suitable | | Suitable | | Highly Suitable | |
|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % |
| Natural physical suitability | 10201.83 | 28.40 | 12074.13 | 33.60 | 10890.21 | 30.30 | 2772.06 | 7.70 |
| Socio-economic suitability | 4107.26 | 11.30 | 10328.76 | 28.40 | 15957.70 | 43.86 | 5986.61 | 16.46 |
| Soil types | 4114.93 | 11.41 | 8526.32 | 23.66 | 14728.13 | 40.87 | 8670.15 | 24.06 |
| pH | - | - | - | - | 4456.77 | 12.00 | 32843.02 | 88.00 |
| Salinity | 9947.48 | 26.70 | | | 11643.40 | 31.20 | 15708.88 | 42.10 |
| Distance to watercourses | - | - | 1306.70 | 3.50 | 3356.94 | 9.00 | 32637.81 | 87.50 |
| Proximity to mangroves | 32853.35 | 88.88 | - | - | 1277.70 | 3.46 | 2832.66 | 7.66 |
| Land-use | 8834.95 | 24.20 | 16946.77 | 46.43 | 2814.36 | 7.710 | 7903.60 | 21.65 |
| Population density | - | - | 344.28 | 0.90 | 16293.20 | 43.70 | 20663.50 | 55.40 |
| Experiences in shrimp farming | - | - | 9603.77 | 25.74 | 14239.43 | 38.17 | 13457.78 | 36.08 |
| Distance to roads | 4809.35 | 13.05 | 5870.60 | 15.93 | 3436.64 | 9.32 | 22729.73 | 61.69 |

Table 6: Suitability Areas for Shrimp Farming of Each Commune (ha)

| | Highly Suitable | Suitable | Moderately Suitable | Unsuitable |
|---|---|---|---|---|
| Andien | 1026.10 | 1075.61 | 1032.07 | 38.18 |
| Myan | 192.24 | 355.42 | 1301.46 | 431.91 |
| Thanhhai | 823.00 | 440.94 | 2023.81 | 972.17 |
| Thanhphong | 608.66 | 1535.77 | 1104.07 | 631.76 |
| Giaothanh | 80.70 | 997.92 | 854.51 | - |
| Annhon | - | 1691.88 | 889.59 | - |
| Binhthanh | - | 499.83 | 1021.67 | 62.77 |
| Anthuan | - | 1276.86 | 358.83 | 17.73 |
| Thanhphu | - | 207.66 | 884.95 | 3.20 |
| Hoaloi | - | - | 49.97 | 1643.21 |
| Anqui | - | 1970.29 | 345.10 | - |
| Anthanh | - | 727.60 | 171.23 | - |
| Myhung | - | - | 473.22 | 902.34 |

| | | | | |
|---|---|---|---|---|
| Tanphong | - | - | - | 1406.71 |
| Phukhanh | - | - | - | 1034.07 |
| Quoidien | - | - | - | 1356.30 |
| Daidien | - | - | - | 891.86 |
| Thoithanh | - | - | - | 1706.90 |
| Column total | 2730.70 | 10780.76 | 10512.34 | 11120.45 |

**Table 6 continued**

Table 7: The Suitability Areas for Shrimp Farming Operations of Each Commune

| | Improved – Extensive, Moderately Suitable | Semi – Intensive, Suitable | Intensive, Highly Suitable |
|---|---|---|---|
| Andien | 370.70 | 1323.43 | 1391.42 |
| Myan | 330.95 | 1163.58 | 319.68 |
| Thanhhai | 235.15 | 1887.24 | 1016.30 |
| Thanhphong | 973.07 | 1152.61 | 982.70 |
| Giaothanh | 871.55 | 288.43 | 193.26 |
| Annhon | 917.87 | 697.26 | 227.65 |
| Binhthanh | 441.65 | 941.09 | 149.30 |
| Anthuan | 495.48 | 513.47 | 551.60 |
| Thanhphu | 1056.56 | 35.62 | - |
| Hoaloi | 11.14 | 43.34 | - |
| Anqui | 916.76 | 520.46 | 369.63 |
| Anthanh | 623.61 | 140.68 | - |
| Myhung | 468.20 | - | - |
| Column total | 7712.67 | 8707.23 | 5201.55 |

Table 8: Raw and calculated data about carrying capacity for shrimp farming of Cochien river

| Date | Time (hour) | Cross Section Area ($m^2$) | Water Flow Velocity (m/sec) | $NH_3$ Concentration (mg/L) | AI (kg/hour) | AO (kg/hour) | MAI (kg/hour) | Remark |
|---|---|---|---|---|---|---|---|---|
| 12/13/2006 | 10:00 | 14588.18 | 0.69 | 0.06 | - | 2020.61 | - | Low tide |
| 12/13/2006 | 11:00 | 14079.04 | 0.60 | 0.04 | - | 1314.85 | - | Low tide |
| 12/13/2006 | 12:00 | 13654.76 | 0.57 | 0.02 | - | 503.30 | - | Low tide |
| 12/13/2006 | 13:00 | 13298.36 | 0.92 | 0.08 | - | 3486.09 | - | Low tide |
| 12/13/2006 | 14:00 | 13128.65 | 0.56 | 0.02 | - | 501.01 | - | Low tide |
| 12/13/2006 | 15:00 | 13400.19 | 0.57 | 0.06 | - | 1639.05 | - | Low tide |
| 12/13/2006 | 16:00 | 13824.47 | 0.30 | 0.01 | - | 150.24 | - | Low tide |
| 12/13/2006 | 17:00 | 14350.58 | 0.01 | 0.08 | - | 38.10 | - | Low tide |
| 12/13/2006 | 18:00 | 15063.37 | 0.11 | 0.02 | 144.56 | - | 602.34 | High tide |
| 12/13/2006 | 19:00 | 15351.88 | 0.48 | 0.03 | 829.76 | - | 2676.63 | High tide |
| 12/13/2006 | 20:00 | 15606.45 | 0.41 | 0.00 | 0.00 | - | 2300.79 | High tide |
| 12/13/2006 | 21:00 | 15945.88 | 0.41 | 0.04 | 880.59 | - | 2379.97 | High tide |
| 12/13/2006 | 22:00 | 16200.44 | 0.07 | 0.02 | 62.95 | - | 419.68 | High tide |
| 12/13/2006 | 23:00 | 15945.88 | 0.27 | 0.08 | 1172.41 | - | 1563.22 | High tide |
| 12/14/2006 | 0:00 | 15555.54 | 0.60 | 0.02 | - | 768.11 | - | Low tide |
| 12/14/2006 | 1:00 | 15284.00 | 0.64 | 0.02 | - | 814.31 | - | Low tide |
| 12/14/2006 | 2:00 | 14944.57 | 0.59 | 0.02 | - | 731.20 | - | Low tide |
| 12/14/2006 | 3:00 | 14605.15 | 0.39 | 0.02 | - | 473.38 | - | Low tide |
| 12/14/2006 | 4:00 | 14350.58 | 0.53 | 0.02 | - | 627.80 | - | Low tide |
| 12/14/2006 | 5:00 | 14163.89 | 0.63 | 0.02 | - | 738.00 | - | Low tide |
| 12/14/2006 | 6:00 | 14028.12 | 0.82 | 0.02 | - | 947.95 | - | Low tide |
| 12/14/2006 | 7:00 | 14503.32 | 0.51 | 0.02 | - | 611.40 | - | Low tide |
| 12/14/2006 | 8:00 | 14723.95 | 0.36 | 0.02 | - | 441.01 | - | Low tide |
| 12/14/2006 | 9:00 | 14995.49 | 0.29 | 0.02 | - | 353.96 | - | Low tide |
| | | | | Column total | 3090.27 | 16160.36 | 9942.63 | |

Table 9: Raw and calculated data about carrying capacity for shrimp farming of Hamluong river

| Date | Time (hour) | Cross Section Area ($m^2$) | Water Flow Velocity (m/sec) | $NH_3$ Concentration (mg/L) | AI (kg/hour) | AO (kg/hour) | MAI (kg/hour) | Remark |
|---|---|---|---|---|---|---|---|---|
| 12/14/2006 | 16:00 | 15506.13 | 0.38 | 0.01 | 188.79 | - | 2097.65 | High tide |
| 12/14/2006 | 17:00 | 15855.94 | 0.13 | 0.01 | 50.05 | - | 714.99 | High tide |
| 12/14/2006 | 18:00 | 16621.16 | 0.17 | 0.02 | 171.46 | - | 1008.56 | High tide |
| 12/14/2006 | 19:00 | 17167.75 | 0.07 | 0.02 | 68.21 | - | 426.29 | High tide |
| 12/14/2006 | 20:00 | 17823.65 | 0.19 | 0.01 | 98.32 | - | 1229.05 | High tide |
| 12/14/2006 | 21:00 | 18370.23 | 0.11 | 0.02 | 126.89 | - | 746.42 | High tide |
| 12/14/2006 | 22:00 | 18370.23 | 0.10 | 0.02 | 148.14 | - | 673.36 | High tide |
| 12/14/2006 | 23:00 | 18282.78 | 0.13 | 0.01 | - | 74.82 | - | Low tide |
| 12/15/2006 | 0:00 | 18086.01 | 0.17 | 0.02 | - | 166.95 | - | Low tide |
| 12/15/2006 | 1:00 | 17583.15 | 0.61 | 0.03 | - | 997.81 | - | Low tide |
| 12/15/2006 | 2:00 | 17014.70 | 0.56 | 0.03 | - | 1141.44 | - | Low tide |
| 12/15/2006 | 3:00 | 16227.62 | 0.61 | 0.01 | - | 464.75 | - | Low tide |
| 12/15/2006 | 4:00 | 15877.81 | 0.69 | 0.02 | - | 744.55 | - | Low tide |
| 12/15/2006 | 5:00 | 15527.99 | 0.35 | 0.02 | - | 329.86 | - | Low tide |
| 12/15/2006 | 6:00 | 15484.27 | 0.06 | 0.02 | - | 59.53 | - | Low tide |
| 12/15/2006 | 7:00 | 15659.17 | 0.21 | 0.01 | 156.57 | - | 1204.36 | High tide |
| 12/15/2006 | 8:00 | 16140.17 | 0.02 | 0.02 | 15.93 | - | 93.69 | High tide |
| 12/15/2006 | 9:00 | 16424.39 | 0.08 | 0.03 | 129.42 | - | 479.33 | High tide |
| 12/15/2006 | 10:00 | 16839.80 | 0.53 | 0.02 | 670.36 | - | 3192.19 | High tide |
| 12/15/2006 | 11:00 | 16949.11 | 0.05 | 0.02 | 64.31 | - | 321.56 | High tide |
| 12/15/2006 | 12:00 | 16883.52 | 0.02 | 0.02 | 36.15 | - | 150.63 | High tide |
| 12/15/2006 | 13:00 | 16839.80 | 0.06 | 0.03 | 94.88 | - | 338.86 | High tide |
| 12/15/2006 | 14:00 | 16752.34 | 0.10 | 0.03 | 160.82 | - | 618.56 | High tide |
| 12/15/2006 | 15:00 | 16315.08 | 0.53 | 0.03 | 865.18 | - | 3089.92 | High tide |
| | | | | Column total | 3045.47 | 3979.71 | 16385.41 | |

**Figures:**

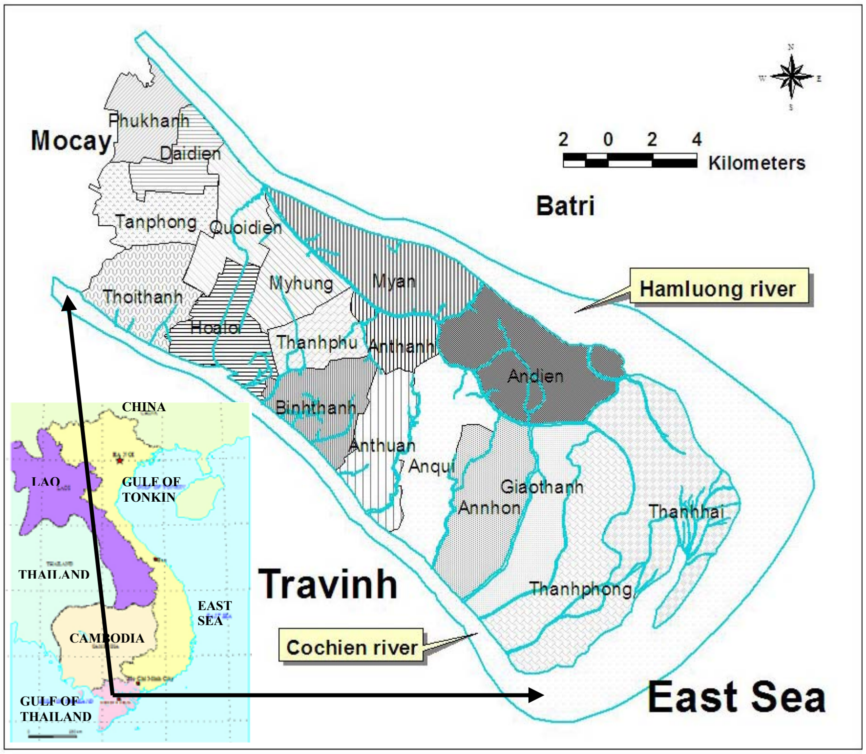


Figure 1: Location of Thanhphu district, Bentre province, Vietnam.

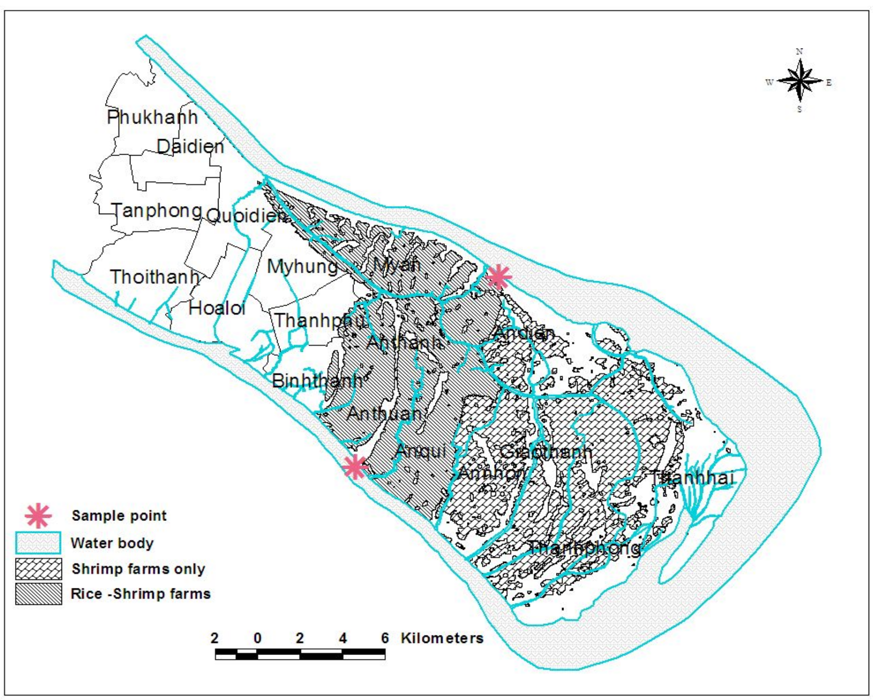


Figure 2: The existing shrimp farms of Thanhphu and sample collection points map

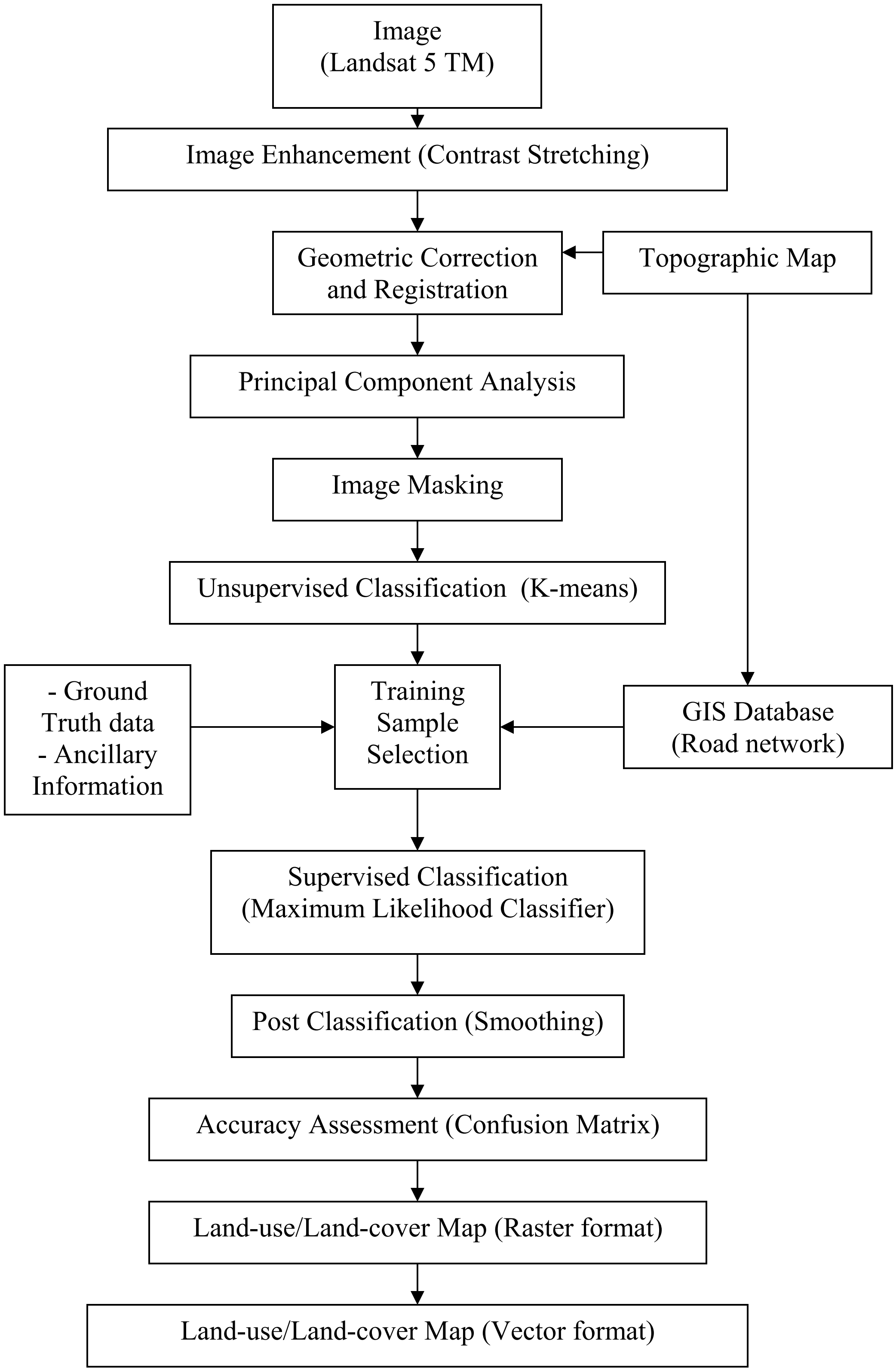


Figure 3: Land-use/Land-cover map making

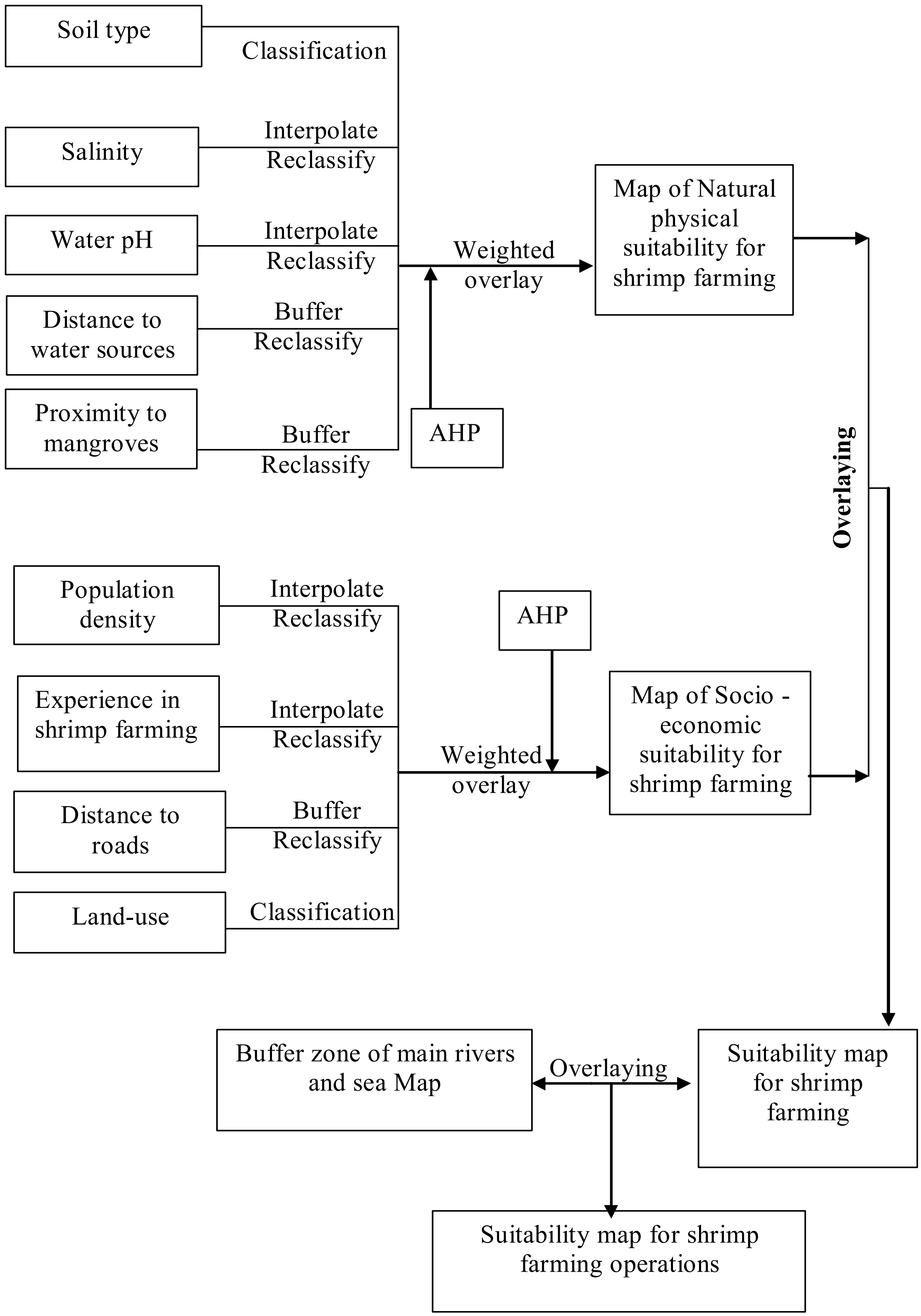


Figure 4: Integration of criteria into the model for development shrimp farming in Thanhphu district, Bentre province, Vietnam.

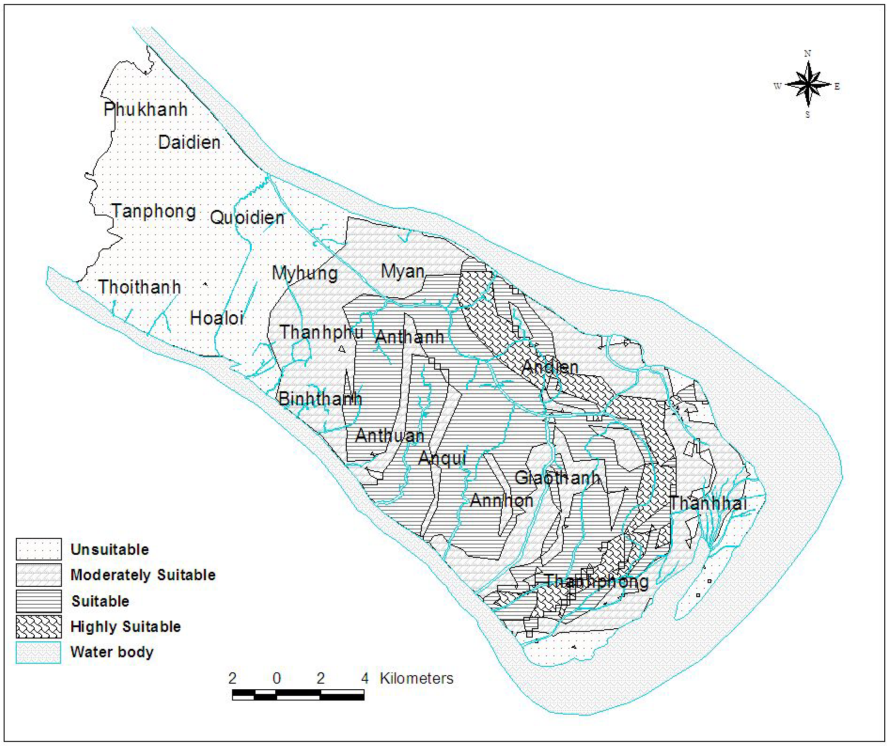


Figure 5: Shrimp Farming Suitability Map

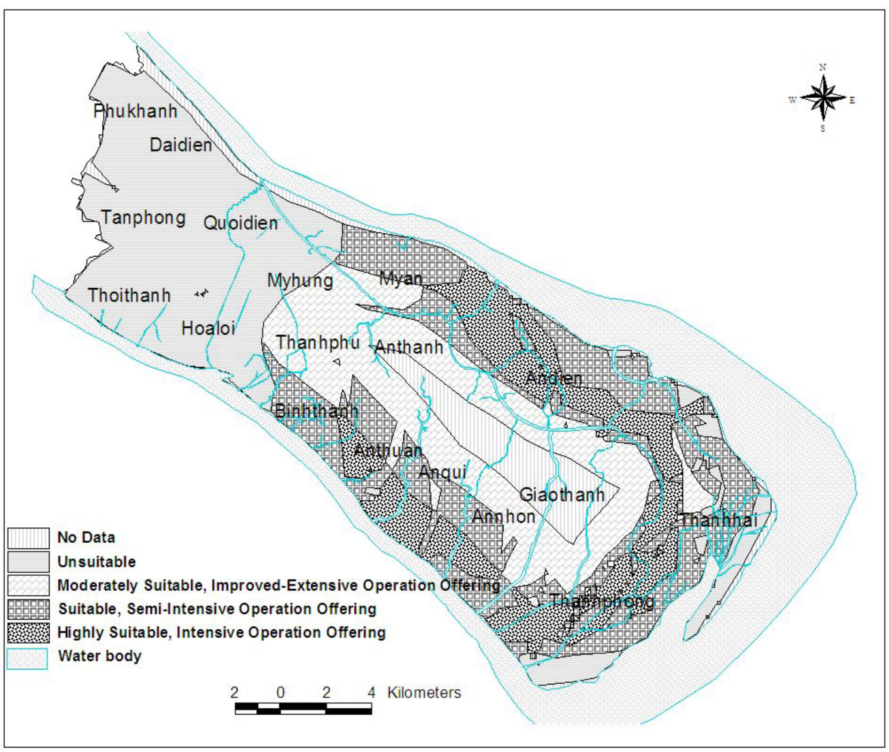


Figure 6: Shrimp Farming Suitability and Operations Offering Map