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MULTICRITERIA EVALUATION TO ASSES LAND SUITABILITY FOR BRACKISH WATER SHRIMP POND IN NORTH COAST OF TUBAN, INDONESIA

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ABSTRACT

This study used Geographic Information System (GIS)-based multi criteria evaluation and remote sensing to delineate locations for brackish water shrimp pond suitability in the north coast of Tuban, Indonesia. An Analytical Hierarchy Process was conducted to obtain the weight of thematic layers. The thematic layers used consisted of soil characteristics theme (pH, texture and base saturation), topographic theme (elevation and slope), water quality theme (salinity, water pH, dissolved oxygen, and temperature) and infrastructure theme (distance to market and distance to main road). A weighted overlay in GIS was done to delineate the suitable land for brackish water shrimp pond. The result indicated that there are areas of highly suitable and suitable for brackish water shrimp pond. Land cover map, interpreted from the 2014 SPOT 5 satellite imagery was used to define the constraints of land utilization. A recommendation map for brackish water shrimp pond area land use planning could then be done by overlaying suitability map and land use map.

Key words: Analytical Hierarchy Process, Land suitability, Spatial Analysis, SPOT 5 imagery

ABSTRAK

Pengembangan tambak udang memerlukan indikasi kesesuaian lahan. Penelitian ini menggunakan teknik evaluasi lahan multi-kriteria berbasis Sistem Informasi Geografi (SIG) dan penginderaan jauh untuk mendelineasi lokasi yang sesuai untuk pengembangan tambak udang di pantai utara Tuban, Jawa Timur, Indonesia. Analisis kesesuaian lokasi untuk tambak menggunakan Proses Hierarki Analitik (AHP) untuk mendapatkan bobot tema yang akan digunakan dalam model SIG. Tema yang dipertimbangkan terdiri dari karakteristik lahan (pH, tekstur dan kejenuhan basa), topografi (ketinggian tempat dan lereng), kualitas air (pH air, oksigen terlarut, salinitas dan temperatur) dan infrastruktur (jarak dari jalan dan jarak dari

pasar). *Overlay* terbobot menggunakan GIS dilakukan untuk mendelineasi lokasi yang sesuai untuk tambak udang. Hasil analisis menunjukkan bahwa wilayah pantai utara Tuban terdiri dari wilayah yang sangat sesuai dan cukup sesuai untuk tambak. Pada tahap berikutnya, penggunaan lahan diinterpretasi dari citra SPOT 5 tahun 2014. Peta wilayah yang direkomendasikan untuk pengembangan tambak udang dibuat dengan *overlay* antara peta kesesuaian dengan peta penggunaan lahan.

Kata kunci : Proses Hierarki Analitik (AHP), Kesesuaian lahan, Analisis spasial, Citra SPOT 5

INTRODUCTION

As an archipelagic country, fisheries are one of the important sectors in Indonesia, where shrimps have become one of the main commodities in this sector. The Indonesian shrimp farming recorded a golden era during the 1980. This was characterized by the excellent state of exports of tiger shrimps (*Penaeus monodon)*, which at that time accounted for 15% of the total non-oil and gas commodities exported each year. In between 1985-1988, there was an increase of shrimp exports from 30,800 tons valued at 202.3 million USD, to become 56,552 tones valued at 499.85 million USD (Grahadyarini, 2014). Shrimp culture has attracted considerable attention since quite some time not only because of its value as food supply but also of its high potential as a foreign exchange earner (FAD, 2010).

However, since 2003, the Indonesian shrimp industry entered a dark period, triggered by a deadly disease. About 60% of the 410,000 traditional farms were destroyed due to harvest failure. To overcome this problem, in 2005 the government announced as a priority to fisheries revitalization to improve shrimp farming. There were many challenges, but slowly the efforts paid off, among others by the cultivation of Vaname shrimp (*Litopenaeus vannamei)*. The 2011 statistical data indicated that the Indonesian shrimp exports reached 1.3 billion USD which are derived from 200,000 tons yields. The Indonesian shrimp production in 2011 reached 400,000 tons, in which 260,000 tons was from Vaname shrimp (Anonymous, 2012). In 2012, the revitalization was conducted at various shrimp farms in 6 regencies along the northern coast of Java Island (Anonymous, 2012). Actually in Indonesia, shrimp culture is part of efforts to meet the supply needs of food fish from aquaculture fisheries. This is not only true in Indonesia, but also in the whole world. The per capita supply of food fish from aquaculture has already increased from 0.7 kg in 1970 to 7.8 kg in 2008 (FAO, 2010; Herbeck *et al.*, 2013).

Northern coast of Java island is one of the potential area for development of brackish water shrimp ponds. This area has a flat beach, formed from alluvium plains that facilitate the culture. North coast of Tuban, East Java Province is part of this potential area. This area is an area that has long been used for the pond. Today in Tuban, the pond grows and attracts many investors. Looking at the statistics (BPS, 2014), pond development of the north coast of Tuban is quite fast. The production of shrimp farms in 2013 was 4,432 tonnes, higher than the production of inland waters of 1,953 tons. This value is still less than the production of marine fisheries which amounted to 9,617 tons, but when viewed from the value of money, the result from shrimp pond culture that is Rp. 210 billion was higher compared to marine fish production of Rp. 43 billion, as well as inland waters of Rp. 17 billion. Increasing year to year production is also significant. The production of 2013 is an increase from the production of 2008, which only reached 2,249 tons, or an increase of 19.4% per year. In the same period, increasing production of sea fisheries during 2008-2013 was only less than 3%. These data indicate the potential for an increasing pond area.

However, an aquaculture site selection in a coastal area needs to consider the land suitability. Cultivation in locations with high land suitability is a prerequisite to obtain optimal results (FAO, 1976). Therefore, the land evaluation is necessary, not only for economic reason but also for environment preservation. Shrimp pond culture should only be done in suitable areas for shrimp farming, while non-suitable areas should be preserved through maintaining environment, for example for forest and mangrove forests, to protect the coastal areas from abrasion. It must also be noted that uncontrolled expansion of shrimp-farming will cause a deterioration of the environment, because natural resources has limited supporting capacity.

One of the methods to select a site for shrimp pond culture is by using remote sensing and geographic information system (GIS). The use of remote sensing and GIS is able to cover a lot of planning aspects in aquaculture, including defining land characterics and water properties, which can then be used to determine the habitat suitability and zoning areas for shrimp farming (Hossain & Das, 2009). Furthermore, GIS has been able to assist the management of shrimp culture through the identification of efficient areas, not only in terms of cultivation, but also in storage-wise, ease of its marketing, transport system and other subjects (Aronoff, 1989). A lot of planning is necessary, so that its application in the field can provide good results (Hossain *et al*., 2009).

Multi-criteria land evaluation (MCLE) often referred to as a multi-criteria evaluation (MCE) and multi-criteria decision making (MCDM), has been widely used to evaluate a particular use of resource utilization. This is based on a decision-making concept driven by a variety of factors. These factors were weighed according to its decision-making role. This evaluation method has been widely used to determine the use of resources, for example in the case of allotting a suitable place or locations for: waste disposals (Gbanie, *et al*., 2013; Effat and Hegazy, 2012), agricultural purposes (Mendas & Delali, 2012; Ceballos-Silva and Lopez-Blanco, 2003; Akinci *et al*., 2013), forestry development (Diaz-Balteiro & Romero, 2008), energy development (Rahman *et al*., 2013; Rosso *et al*., 2014), industry (Rikalovic *et al*., 2014), airport expansion (Vreeker *et al*., 2002), and many other cases in need of decision-making.

The aim of this study is to evaluate the land suitability of northern coast area of Tuban Regency, East Java Province, Indonesia for brackish water shrimp pond culture using MCLE. Delineation of recommended shrimp area development will then be done by integrating suitable map with land use/land cover data from remote sensing data.

THE METHODS

Study Area. Tuban Regency is located in East Java Province, Indonesia. Tuban Regency has an area of 1.839,94 km^2, and it is lying between 111°30'-112°35'E dan 6°40'–7°18'S, it consisted of20 district.

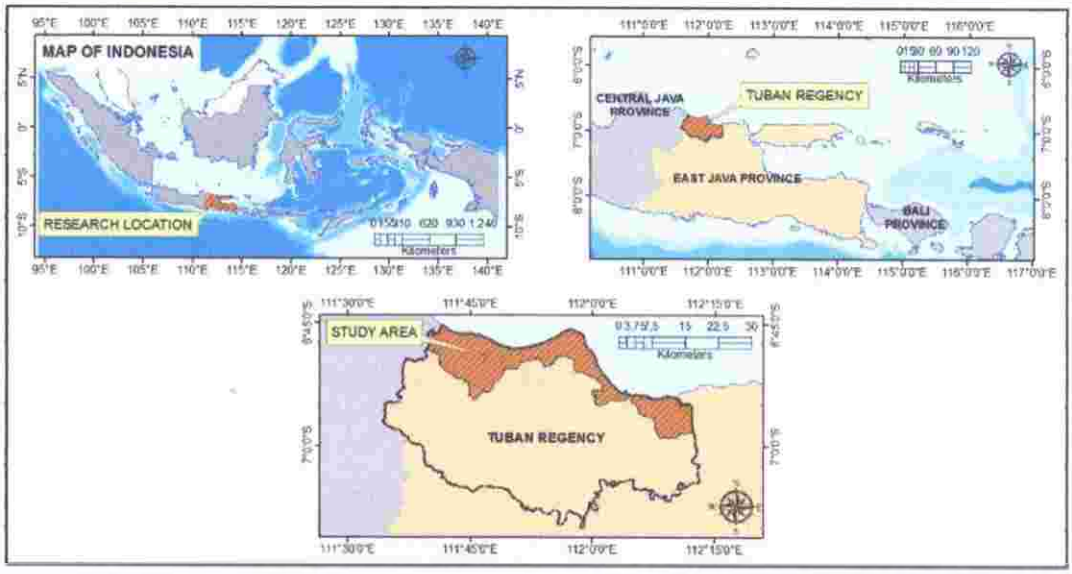

Figure 1. Research area in the north coast of Tuban, East Java Province, Indonesia

Figure 2. Soil and water sampling site in the north coast of Tuban

The scope of this study is the coastal districts of Tuban, which is the districts along the northern coast of Java Sea. The study area is so includes 5 coastal district areas (Bancar, Tambakboyo, Jenu, Tuban and Palang), lying the geographical location of 111°31'-112°34'E dan 6°40'–7°00'S. The study area includes the area that are relatively flat, referred as fan alluvium, covering an area of 39,424.2 ha (**Figure 1**). Monsoon is the climate of this region, with an average annual rainfall of 2,132.7 mm.year^{-1} according to the data from the local meteorological station of 2004-2013. The rainy seasons are between April-May and December-January.

The geological overview of the region, observed from a geological map (1: 100,000) sheet of Jatirogo and Tuban (Situmorang *et al.*, 1992 and Hartono & Suharsono, 1997) indicate that

the north coast of Tuban consists of several geological formations, however alluvium formation is the most widely spread.

Data. Data used for this study can be classified into 4 themes in which each theme is consisted of several criteria: soil characteristics theme (pH, texture and base saturation criteria), topographic theme (elevation and slope criteria), water quality theme (water pH, dissolved oxygen, salinity and temperature criteria) and infrastructure theme (distance to main road and distance to market). Soil, topography and water quality are considered as natural resources factors which influence the environmental quality of the shrimps culture. Infrastructure influence the facility of shrimp culture, either in term of market as well as facility of entering the production input into the pond area. A multi-criteria evaluation used for site selection can incorporate a variety of factors, such as natural resources, infrastructure, marketing, ease of management and others (Hossain *et al.*, 2009; Hossain & Das, 2010; Akinci *et al.*, 2013).

A survey was conducted in 2014 for soil and water sampling (**Figure 2**). The soil samples were taken according to land mapping unit of the 1:25,000 soil map, made available by joint work of Tuban local Government Agency and Bogor Agricultural University, Indonesia. Totally, 35 soil samples of the study area were analyzed. Soil samples were analyzed at the Laboratory of the Dept. of Soil Science & Land Resources, Bogor Agricultural University using routine laboratory methods (Tan, 2002). The water samples were taken in the several water sources according to hydrogeological map pattern, and were sampled outside the actual location of shrimp pond culture. All water samples were measured in the field using Horiba U-10 digital water checker. Totally, 23 point were measured in term of water measurement. Topographic data were derived from topographic map using Arc-GIS 10.1 developed by the Environmental Systems Research Institute Inc., USA. Main road parameter was obtained from the 1:25,000 topographic map of Bakosurtanal (2001). Totally, there are 11 sheets of 1:25,000 topographic maps covering the study area. Market location was obtained from field survey.

GIS and Weighed Procedure. All of the data points were initially used to create spatial data by using Arc-GIS 10.1, specifically using the spatial extension module. Spatialization for soil characteristics data was done according to land mapping unit. Spatializations for water quality was conducted through interpolation method, taking into account the hydrogeological unit in order to obtain the representative water samples. In this research, interpolation was done by using Spline interpolation in geostatistical module of Arc-GIS 10.1. Spatial data were classified and weighed according to their contribution to the shrimp growth environment, to enable the creation of a suitability map. The procedure done is illustrated schematically in **Figure 3**. Classification of factor weight was based on the bibliographic study and expert's judgment, the suitability was classified into 3 levels: 3 (highly suitable), 2 (suitable), and 1 (not suitable) (**Table 1**). In total 5 experts were consulted to establish this classification.

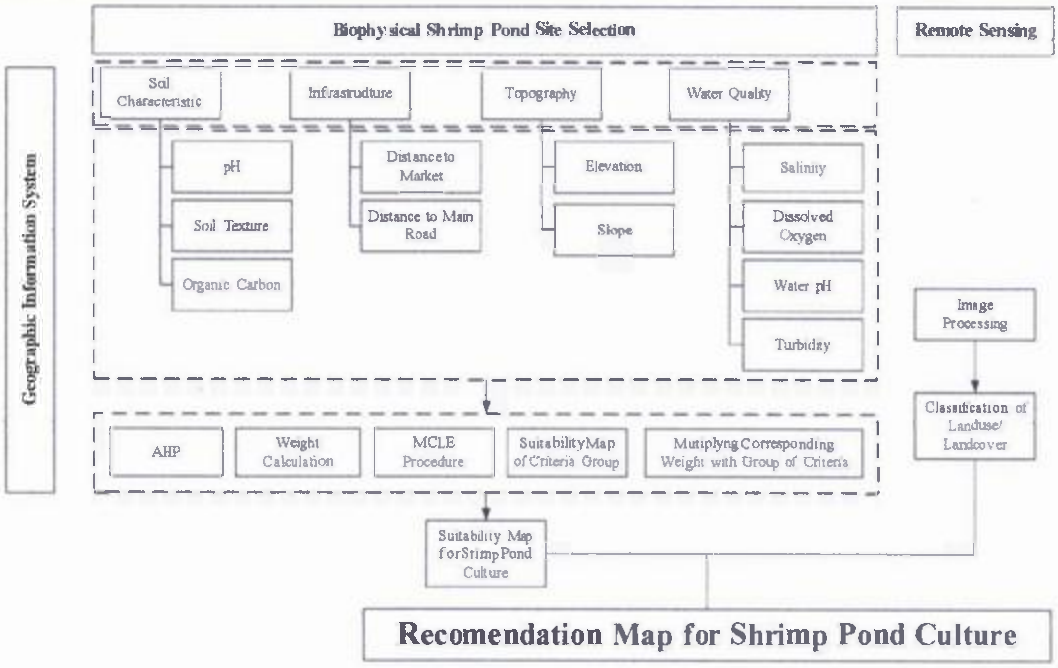

Figure 3. Research methodology structure

Table 1. Suitability levels of themes (soil characteristic, topography, water quality and infrastructure) for shrimp pond culture in north coast of Tuban.

Criteria	Unit	Suitable Range and Score			References
		Highly Suitable (3)	Suitable (2)	Not Suitable (1)	
Soil pH	-	6-8	4-6; 8-9	<4;>9	New (2002), Hossain & Das (2010)
Texture	-	Clay, silty clay, clay loam	Sandy clay loam, silty clay loam, silt loam	Loam, sand, loamy sand, sandy loam	Present study, Hossain & Das (2010)
Organic Carbon	%	<1	1-2	>2	Hossain & Das (2010)
Elevation	Meter	0-10	10-30	>30	Wiradisastra *et al.* (2004)
Slope	%	0-2	2-3	>3	Wiradisastra *et al.* (2004)
Salinity	0/00	10-20	20-35	<10; >35	Wiradisastra *et al.* (2004)
Dissolve oxygen	mg/l	4-7	2.5-4	<2.5	Boyd & Zimmermann (2000)
Water pH	-	6-8	4-6; 8-9	<4;>9	Boyd & Zimmermann (2000)
Temperature	°C	25-32	12-25	<12; >32	Janssen et al. (1988); Boyd and Zimmermann (2000); New (2002)
Distance to Market	meter	<3000	3000-6000	>6000	Present Study
Distance to Main Road	meter	<500	500-1000	>1000	Giap *et al.* (2005); Hossain *et al.* (2007, 2009)

Each criteria, and then theme, were weighed in the next step. This is a main procedure for MCE (Voogd, 1983; Ceballos-Selva & Lopez-Blanco, 2002). Weighing is done by using the Analytical Hierarchy Process (AHP), a concept of Saaty (1988). Although other procedures are available, however this procedure is the most commonly performed in MCE (Eastman *et al.*, 1995). The assessment and evaluation are done by comparing the relative importance of two criteria involved in determining the suitability (Eastman *et al.*, 1995). The ratings were derived from 9 interests scale, with a value from 9 to 1/9. The value of 9 indicates that the line is relatively more important than the column, while the value of one-ninth shows that the

line has significantly less importance than the column. If two variables are equally important, they are given a value of 1. In estimating the weights, a group of experts are asked to compare the matrix in pairs. In this study, the pairwise comparison was developed **(Table 2)**, the consistency ratios (CR) of 0.0-0.05 for the table was well within the ratio of equal to or less than 0.10 recommended by Saaty (1988). This value signify small probability that the weights were developed by chance.

Table 2. A pair-wise comparison matrix for assessing the relative importance of theme and criteria for brackish water shrimp pond (numbers show the rating of the row relative to the column).

	Soil pH	Texture	Organic C	Weight
Soil Characteristic				
Soil pH	1	1/3	3	0.260
Texture	3	1	5	0.633
Organic C	1/3	1/5	1	0.106
Consistency ratio (Cr) 0.047725425				

	Elevation	Slope	Weight
Topography			
Elevation	1	3	0.750
Slope	1/3	1	0.250
Consistency ratio (Cr) = 0			

	Salinity	Dissolve Oxygen	Water pH	Temperature	Weight
Water Quality					
Salinity	1	3	5	7	0.558
Dissolve Oxygen	1/3	1	3	5	0.263
Water pH	1/5	1/3	1	3	0.122
Temperature	1/7	1/5	1/3	1	0.057
Consistency ratio (Cr) = 0.065436949					

	Distance to Market	Distance to Main Road	Weight
Infrastructure			
Distance to Market	1	3	0.750
Distance to Main Road	1/3	1	0.250
Consistency ratio (Cr) = 0			

	Soil characteristics	Infrastructure	Topography	Water Quality	Weight
Theme requirement for assessment of site suitability for shrimp pond culture					
Soil characteristics	1	3	1/3	1/5	0.123
Infrastructure	1/3	1	1/5	1/7	0.047
Topography	3	5	1	1/3	0.285
Water Quality	5	7	3	1	0.545

Max eigenvalue (ymax) = 4.109310391
n = 4
Consistency index (Ci) = (ymax - n)/(n - 1) = 0.036436797
Random index (Ri) = 0.9
Consistency ratio (Cr)= Ci/Ri = 0.04048533

The weight obtained from AHP were used to determine the suitability, by multiplying the weight of theme with the weight of criteria and the suitability weight predetermined in Table 1. The multiplication is done in raster format on the map. The result of this multiplication was then reclassified with equal distance in 3 classes suitability: highly suitable, suitable and unsuitable.

Land Use and Land Cover Analysis. Land use and land cover was obtained through an analysis of SPOT 5 imagery of 2014. Image analysis was done using a supervised classification of ERDAS imagine software. Land cover classification used the standard classification from the Ministry of Forestry (Badan Planologi, 2012). Land cover data was not used in the preparation of land suitability map, but it was used in the final step to develop and delineate the recommended area.

RESULT AND DISCUSSION

The summary of soil and water analysis results which were used as soil and water characteristics is presented in **Table 3**.

Table 3. Summary of soil and water analysis used in this study

Soil Samples							Water Samples				
n		pH	Texture(%)			C-org(%)	n	Salinity	Diss.Ox.	pH	Temp
			Sand	Silt	clay			‰	Mg/l		(°C)
	Max	8.4	89.6	61.8	78.0	2.3		30.2	4.2	7.5	33.8
35	Ave	7.6	30.5	32.0	37.5	1.1	23	14.9	2.3	7.2	30.6
	Min	5.9	1.4	3.5	5.8	0.2		0.2	0.1	6.5	29.1

The results of suitability analysis based on the soil characteristics theme is presented in **Table 4** and **Figure** S. In this figure, each step of soil characteristic theme classification according to each criterion is shown.

Table 4. Land suitability for brackish water shrimp pond in the north coast of Tuban according to soil characteristics theme

Criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	Ha	%	ha	%
Soil pH	37,554.0	95.3	1,870.2	4.7	0.0	0.0
Texture	30,036.4	76.2	6,576.6	16.7	2,811.3	7.1
Organic C	17,362.4	44.1	21,491.1	54.5	570.7	1.4
Sub-Overall	30,035.9	76.2	9,369.7	23.8	18.6	0.0

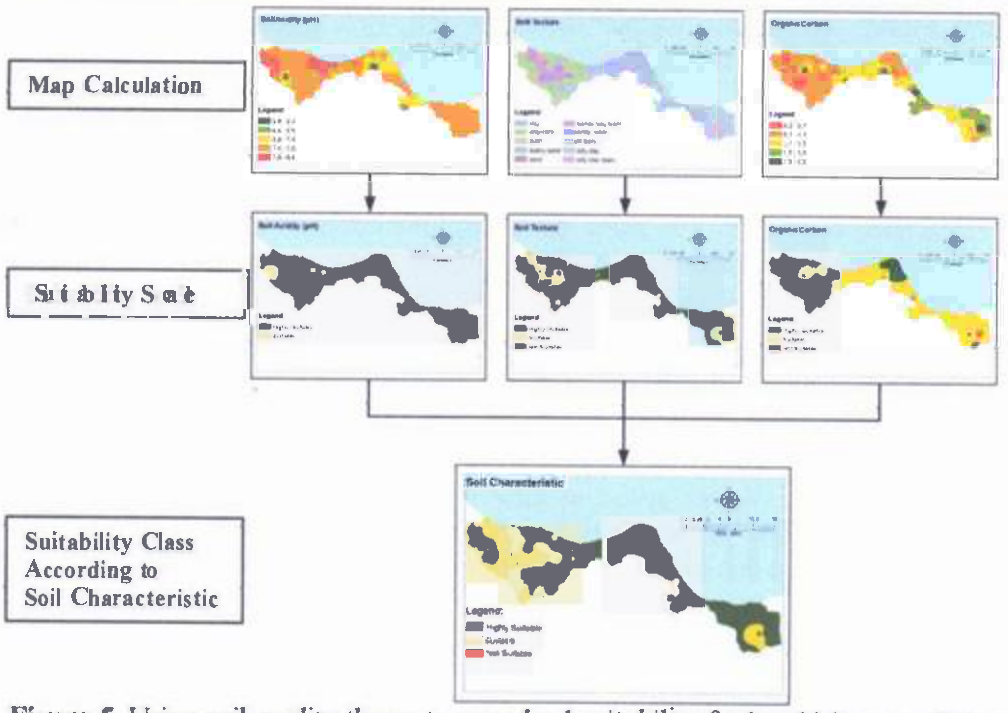

Figure 5. Using soil quality theme to asses land suitability for brackish water shrimp pond in the north coast of Tuban

Soil is the base matrix for ponds and has become the initial cost in pond construction. In other, the pond bottom soil and the accumulated sediments are integral parts of ponds. Concentrations of nutrients, organic matter and microorganism density in the pond bottom are several orders of magnitude greater than in the water (Avnimelech and Ritvo, 2003; Nimrat *et al*., 2008). In this research, three major soil characteristics that were considered having a high relation with shrimp pond culture were chosen, they are pH, texture and soil organic carbon.

According to soil pH, the area of north coast of Tuban is classified as highly suitable and suitable for shrimp pond culture. There are 95.3% of the area which are classified as highly suitable and 4.7% of the area which are classified as suitable. None of the area which are not suitable for shrimp pond culture. These fact relate with influence of sea water to the soil in this coastal area. The research of Lemonnier *et al.* (2004) indicate a significant positive correlation between the pH of the sediment surface and the shrimp osmotic pressure; the osmotic pressure decreased significantly as water pH decreased from 7.0 to 6.5. Such osmotic pressure influences the physiological condition of shrimp. Hence, fact that this north part of Tuban coastal area has a soil pH relatively high indicate the relatively suitable for brackish water shrimp pond.

Meanwhile, according to soil texture, the majority of the area (76.2%) is classified as highly suitable, while 16.7% of the area is classified as suitable. The suitable texture for ponds construction is fine texture (Hossain & Das, 2010; Hardjowigeno & Widiatmaka, 2007). The soil at the pond site should have enough clay content, to ensure that the ponds will hold water.

According to soil organic carbon (organic-C), 44.1% of the area is classified as highly suitable, 25% is classified as suitable and 54.5% is classified as suitable, there are only 1.4% area which is not suitable for shrimp pond culture. Just a little literature on the relationship between soil organic carbon with shrim pond culture were found, which are of Banerjea

(1967) and Ritvo *et al.* (1998), who suggested that for several fish species, optimum soil conditions for shrimp pond culture in term of soil organic carbon is soil with 1.5-2.5% organic carbon.

When the weight according to AHP results is applied, in terms of soil characteristic theme, 76.2% of the area is classified as highly suitable, 23.8% of the area is classified as suitable and no area of not-suitable for shrimp pond culture (**Table 4**). Thus, it can be stated that according to soil characteristics, the north coast of Tuban has a good basic capital by having most of the area suitable for pond culture. According to the research of Ritvo *et al.* (1998), the influence of the substrate can be independent with the effect of water to obtain a high shrimp production, and so, it is necessary to have a good soil in advance.

The result of the analysis according to topographical theme, in this case based on the elevations and slopes, is presented in **Table 5** and **Figure 6**. More than 63% of the area is classified as highly suitable and suitable for brackish water shrimp pond. Elevation and slope were important factors in determining suitability for brackish water shrimp pond. They determine the possibility of sea water with sufficient salinity enter into the ponds. It is essential to have detail topography of the selected site for pond design and farm layout. Coastal sites where the slopes run gently towards the sea are easier for pond development requiring less financial inputs since excavation is minimal (Kungvankij *et al.*, 1986; Ritvo *et al.*, 1998; Joyni *et al.*, 2011). According to the elevation, 37% of the area are not suitable for shrimp pond culture, while based on the slope, 28% of the area are not suitable. An analysis using a combination of both criteria resulted in making 25% of the area are highly suitable and 38% suitable for shrimp pond culture. The presence of 37% of the area which are not suitable in terms of topography indicate that in the pond construction, topographic aspect should receive attention, especially in the detailed engineering design phase, to ensure that water with sufficient salinity enter into the pond.

Table 5. Land suitability for brackish water shrimp pond in the north coast of Tuban according to topographic theme

Criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	ha	%
Elevation	10,354.4	26.3	14,598.2	37.0	14,471.6	36.7
Slope	20,873.2	52.9	7,544.1	19.1	11,006.9	28.0
Sub-overall	10,001.8	25.4	14,950.7	37.9	14,471.7	36.7

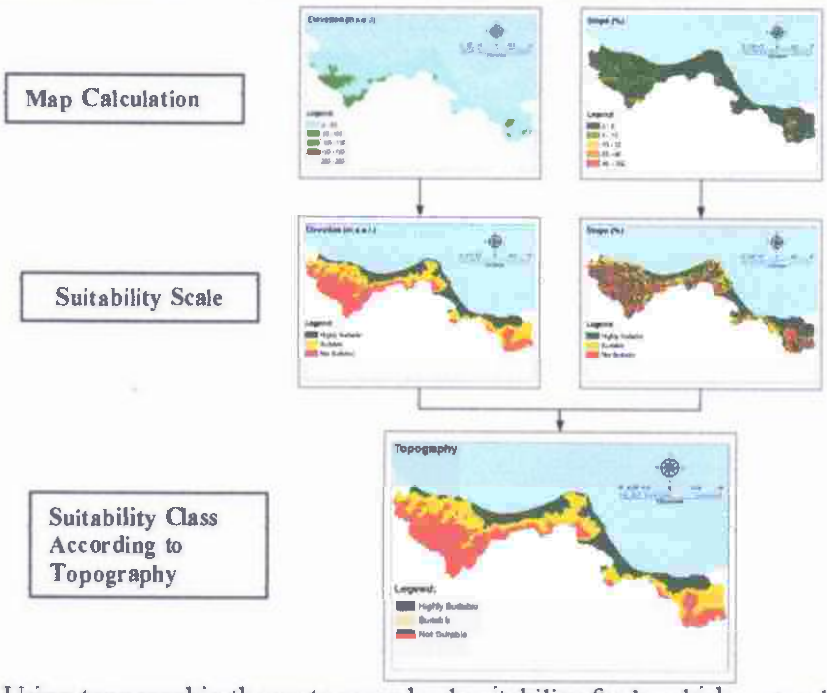

Figure 6. Using topographic theme to asses land suitability for brackish water shrimp pond in the north coast of Tuban

Water availability is in fact very dependent on the climate. However, studying the climatic data, the area is classified as suitable for shrimp pond culture in term of rainfall. As a humid tropical region, rainfall is relatively enough. Therefore, topographic aspect that determines the ease saline water enter into the pond is more important than rainfall.

Water quality, including all the physio-chemical and microbiological characteristics of the water, determines the success of shrimp pond culture. There are numerous studies dealing with chemical fluxes and water quality of shrimp pond effluents (e.g., Paez-Osuna, 2001; Jackson *et al*., 2003; Ruiz-Fernandez and Paez-Osuna, 2004; Casillas-Hernandez *et al*., 2007). Even though there are many water characteristics, only four major one which were measurable in the field were used in this research. The pH is certainly an important aspect, and pH of water on or adjacent to the pond site should be within a certain considered range (Kungvankij *et al*., 1986; Ritvo *et al*., 2003). The normal salinity of water during high tide at different seasons of the year should be known in shrimp pond culture. Especially important for rivers and canals is the subsurface intrusion of salt water under the fresh-water.

The results of water quality analysis, in this case water pH, salinity, dissolve oxygen and temperature are presented in **Table** 6 and **Figure** 7. Based on water quality theme (pH, dissolve oxygen, salinity and temperature), most of the area (> 97%) is classified as highly suitable and suitable.

According to salinity, 10% of the area is classified as not suitable. Salinity is very important for shrimp pond, although younger shrimps appear to tolerate a wider fluctuation of salinity than the adults (Kungvankij *et al*., 1986; Cassilas-Hernandez, 2007). According to dissolved oxygen, 75% area is not suitable. However, the dissolved oxygen can actually treated by advanced technology of shrimp pond culture. Maintenance of adequate level of dissolved oxygen in pond water is very important to shrimp growth and survival. Prolong exposure to the stress of low concentration of oxygen lowers their resistance to disease and inhibits their growth. In most cases, oxygen depletion often resulted in mass mortality

(anoxia) of shrimp stock. This is particularly common in intensive culture operation (Kungvankij *et al.*, 1986; Herbeck *et al.*, 2013).

According to water temperature, 99% area of north coast of Tuban are classified as highly suitable. In tropical areas of Indonesia, the water temperature is not a constraint for shrimp farming. The water pH is so as well. As far as the results of the analysis, the overall water pH are suitable for shrimp farming.

For overall water quality theme, the analysis showed that 15% of the regions can be classified as highly suitable for brackish water shrimp pond, 82% of the region can be classified as suitable. There are only 2.7% area which are not suitable for brackish water shrimp pond. The results of the water quality analysis confirm the high suitability of northern coastal areas of Tuban for brackish water shrimp pond.

Table 6. Land suitability for brackish water shrimp pond in the north coast of Tuban according to water quality theme

Criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	ha	%
Salinity	26,336.0	66.8	8,989.7	22.8	4,098.5	10.4
Dissolve Oxygen	0.0	0.0	9,606.9	24.4	29,817.3	75.6
Water pH	39,424.2	100.0	0.0	0.0	0.0	0.0
Temperature	39,259.6	99.6	0.0	0.0	164.6	0.4
Sub-overall	5,901.5	15.0	32,444.9	82.3	1,077.8	2.7

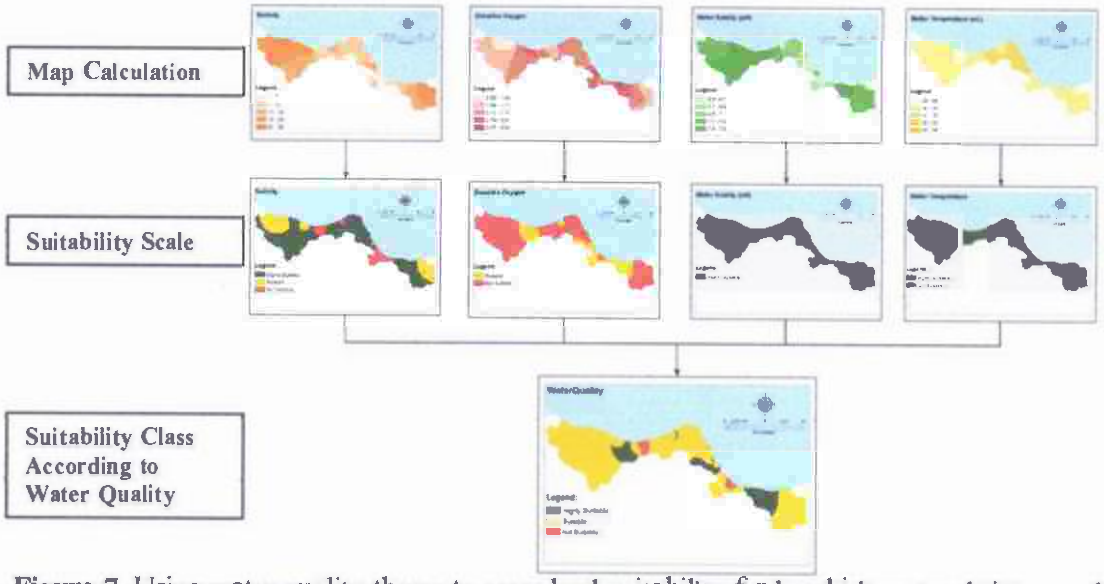

Figure 7. Using water quality theme to asses land suitability for brackish water shrimp pond in the north coast of Tuban

Land suitability for brackish water shrimp pond from the infrastructure point of view was presented in **Table 7** and **Figure 7**. Viewed from infrastructure, road as well as market simultaneously, 21% of land was classified as highly suitable, while 38% area was classified as suitable. In the region, there are 42% of north coast of Tuban area which are relatively unsuitable area. Results of the field survey indicate, it seems that the market is relatively small, while the road is limited to the main paved road. Development of shrimp farming in this region in the future needs to be supported by a more adequate infrastructure. This is not

only true for brackish water shrimp pond culture in Tuban, but also for agricultural development in Indonesia in general.

Table 7. Land suitability for brackish water shrimp pond in the north coast of Tuban according to infrastructure theme

Criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	Ha	%
Market	8,912.8	22.6	14,015.3	35.6	16,496.1	41.8
Main Road	17,041.5	43.2	9,429.7	23.9	12,953.0	32.9
Sub-overall	8,153.1	20.7	14,775.4	37.5	16,495.7	41.8

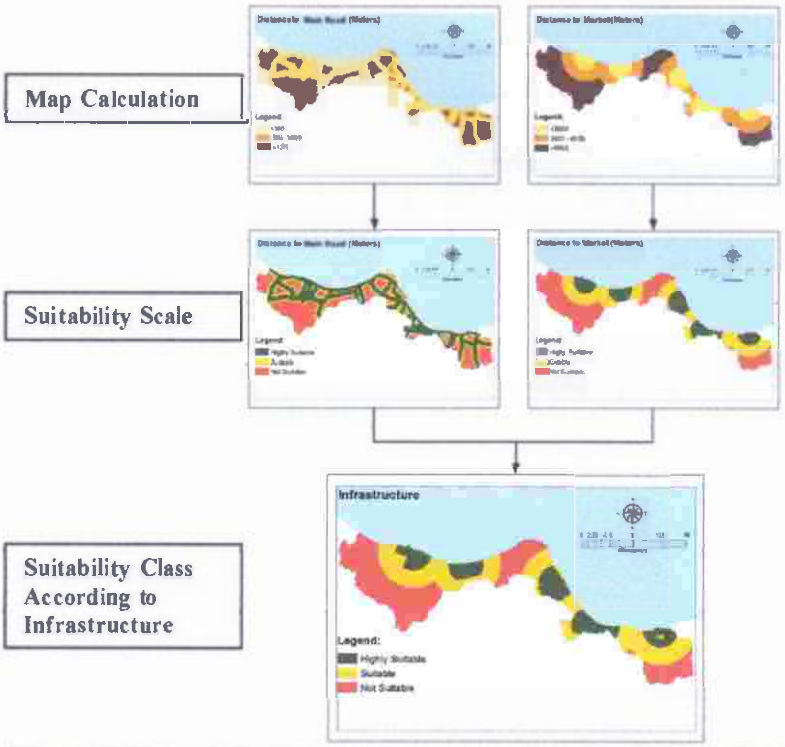

Figure 8. Using infrastructure theme to asses land suitability for brackish water shrimp pond in the north coast of Tuban

The final suitability map for shrimp pond culture given in **Figure 9** is presented together with **Table 8**. According to its suitability, 33% area in north coast of Tuban is highly suitable for shrimp pond culture, while 67% of the area is suitable for shrimp pond culture. All area is deemed suitable for shrimp pond culture. This result confirm the high demand for land for construction of shrimp pond culture in this region.

It should be noted however, that suitability alone is not enough for the implementation of development shrimp pond culture. To that end, it should be known whether the actual land use and land cover allows for the development of the shrimp pond. To that end, checking the current land use and land cover can provide information of suitable and available location for the development of the shrimp pond.

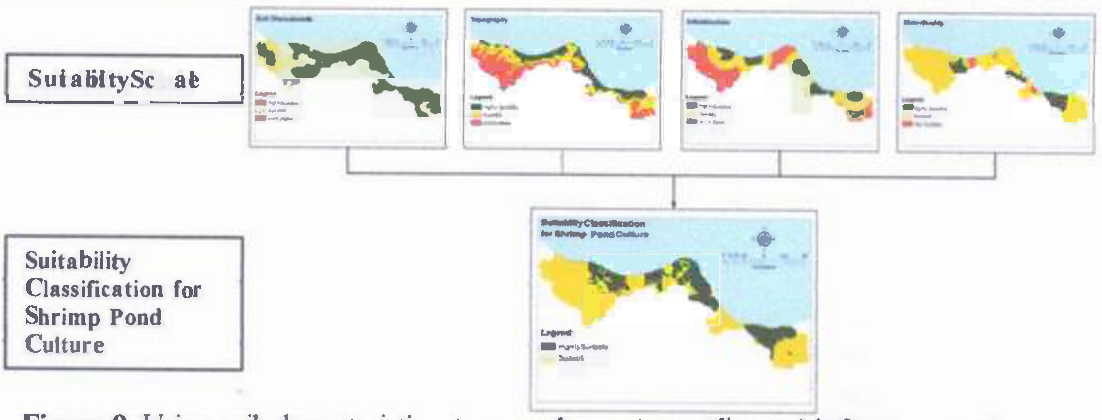

Figure 9. Using soil characteristics, topography, water quality and infrastructure themes to asses land suitability for brackish water shrimp pond in the north coast of Tuban

Table 8. Overall land suitability for brackish water shrimp pond in the north coast of Tuban

Theme	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	Ha	%
Soil Characteristic	30,035.9	76.2	9,369.7	23.8	18.6	0.0
Topography	10,001.8	25.4	14,950.7	37.9	14,471.7	36.7
Water Quality	5,901.5	15.0	32,444.9	82.3	1,077.8	2.7
Infrastructure	8,153.1	20.7	14,775.4	37.5	16495.7	41.8
Overall Suitability of Site	12,902.8	32.7	26,521.4	67.3	0.0	0.0

Figure 10. Land use and land cover of the north coast of Tuban as analyzed by SPOT 5 imagery

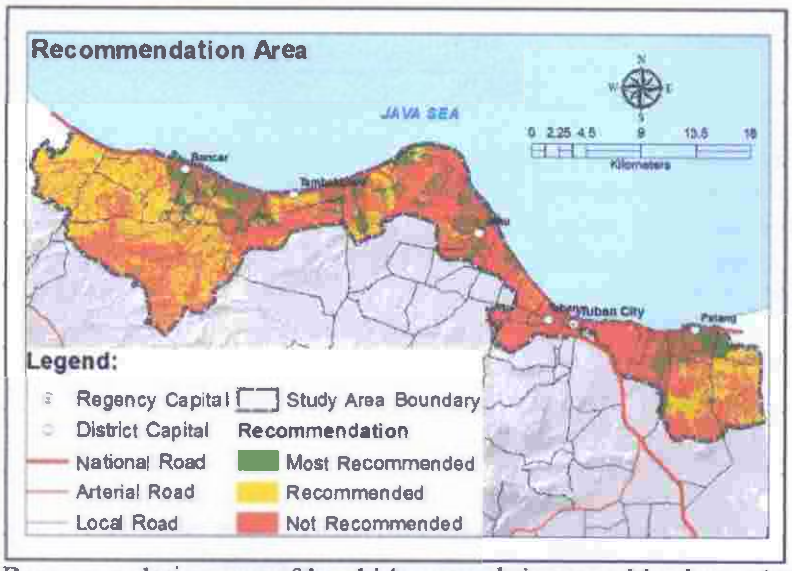

Figure 11. Recommendation map of brackish water shrimp pond land use planning in the north coast of Tuban

Table 9. Result of overlaying land use/land cover data against the land suitability obtained from the model and its recommendation use

Land use	Suitability	ha	%	Recommendation
Cloud	Highly Suitable	574.8	1.5	Most Recommended
Cloud	Suitable	764.7	1.9	Recommended
water Body	Highly Suitable	96.2	0.2	Most Recommended
water Body	Suitable	60.3	0.2	Recommended
Forest	Highly Suitable	1,798.2	4.6	Not Recommended
Forest	Suitable	4,031.9	10.2	Not Recommended
Dry Land	Highly Suitable	1,834.0	4.7	Not Recommended
Dry Land	Suitable	2,562.4	6.5	Not Recommended
Agriculture Land	Highly Suitable	1,244.7	3.2	Not Recommended
Agriculture Land	Suitable	5,277.9	13.4	Not Recommended
Settlement	Highly Suitable	1,748.1	4.4	Not Recommended
Settlement	Suitable	1,900.4	4.8	Not Recommended
Paddy Field	Highly Suitable	1,398.9	3.5	Not Recommended
Paddy Field	Suitable	678.5	1.7	Not Recommended
Shrub	Highly Suitable	1,792.9	4.5	Most Recommended
Shrub	Suitable	4,162.6	10.6	Recommended
Pond	Highly Suitable	660.4	1.7	Most Recommended
Pond	Suitable	355.3	0.9	Recommended
Bare Land	Highly Suitable	1,662.7	4.2	Most Recommended
Bare Land	Suitable	6,819.3	17.3	Recommended

Table 10. Recommendation summary of brackish water shrimp pond land use planning for the north coast of Tuban area

Recommendation of land use planning for brackish water shrimp pond	ha	%
Most Recommended	4,787.0	12.1
Recommended	12,162.2	30.8
Not Recommended	22,475.0	57.0

Recommendation of land use planning for brackish water shrimp pond	ha	%
Total	39,424.2	100.0

The results obtained from SPOT 5 imagery analysis show 10 kinds of land use/land cover in the north coast of Tuban (Figure . The existing land use/land cover was: forest, dry land, agricultural land, settlement, paddy field, shrub, existing pond, bare land, and water bodies. Selain itu, ada beberapa wilayah yang tidak dapat diinterpretasi karena tertutup awan. From such a variety of land use/land cover, some can be defined as land use that is allowed for shrimp pond culture, while some others are not allowed. Therefore, by overlaying the suitability map for shrimp pond culture with the land use map resulting from imagery analysis result, a recommendation map can be developed (Figure 10 and Table 9). In this recommendation map, the classification area is done as follows: (i) area not recommended for pond culture; such area include area where its land use does not allow the construction of shrimp pond (e.g. settlements), or because it is not allowed in the context of environmental conservation (forest); concerning the forest area, these include the mangrove forest, which in Tuban left very little. Therefore, in this planning, we did not enter the existing forest area as an area that allows for the development of shrimp pond. It should be noted the research of Teneorio *et al.* (2014) which result that considerable value of the ecosystem services provided by the mangroves especially and forest generally, is more valuable than production of shrimp in ecological and economic terms; (ii) the most recommended area; this is the highly suitable area according to its suitability and its land use allows for shrimp pond culture, and (iii) the recommended area; this is the area where the land use allow the development of pond and its land suitability is assessed as suitable.

With this analysis, the area on the north coast of Tuban which are recommended for brackish water shrimp pond planning is presented in Table 10. Of the total area analyzed of 39,424 ha, there are 4,787 ha (12%) which are categorized as most recommended, 12,162 ha (31%) which are recommended and an area of 22,475 ha (57%) which are not recommended for brackish water shrimp pond land use planning. So far, the statistical data of actual existing shrimp pond culture was not found, however, the current image interpretation indicate an area of 1,015.7 ha (Table 9). With the potential of land of highly recommended and recommended resulted from this study, it is still possible extension of the pond. However, this calculation is based only from the land suitability side. An analysis of carrying capacity to see the extent of the pond which can be developed would need to be done. In the context of sustainable development, of course we should not look only from an economic standpoint, but the physical carrying capacity of the environment and social aspects need to be considered in a balanced manner (WCED, 1988). In addition, the analysis based on the need of land for other sectors is also needed to be done.

CONCLUSION

The study was conducted in the north coast of Tuban, East Java Province, region where brackish water shrimp ponds was developped significantly in this recent year. The study shows that GIS can be used to delineate areas at various levels of suitability for brackish water shrimp pond. The analysis shows that 33% area in north coast of Tuban is highly suitable for brackish water shrimp pond, while 67% of the area is suitable for brackish water shrimp pond. An overlay analysis of suitability area using remote sensing data shows that of the total area of 39,424 ha in the north coast of Tuban, there are 4,787 ha (12%) which are most recommended for brackish water shrimp pond, 12,162 ha (31%) which are recommended and an area of 22,475 ha (57%) which are not recommended for brackish

water shrimp pond. Hence, potential area for development of brackish water shrimp farming in the north coast of Tuban is still quite large. However, for the implementation of the expansion of the pond, further analysis of the land carrying capacity and land requirements for other sectors still needs to be done.

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