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Land Use Planning for Brackish Water Shrimp Ponds in The North Coast of Tuban, Indonesia

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Abstract Shrimp is a commodity that is increasingly in demand. The limited land resources implies the need of effective land use planning. The objective of this study was to assess land suitability for brackish water shrimp ponds, which then will be recommended for pond development in the north coast of Tuban, Indonesia. Analytical hierarchy process (AHP) were used to obtain the weight of the different criteria consisted of soil characteristics, topographic, water quality, and infrastructure criteria. The suitable land for brackish water shrimp ponds was determined by weighted overlay in GIS. The results show that the study area contains highly suitable land for brackish water shrimp ponds. Land use and land cover map was interpreted from 2014 SPOT 5 imagery. The area recommended for brackish water shrimp pond was delineated by taking into account the suitability and the constraints of land use and land cover.

Keywords: AHP, Coastal area, Land suitability, Land availability, Remote sensing, GIS

Abstrak *Udang merupakan komoditas yang semakin diminati. Lahan yang semakin terbatas mengharuskan perencanaan penggunaan untuk tambak udang dilakukan secara efektif. Penelitian ini bertujuan untuk mendelineasi kesesuaian lahan untuk budidaya tambak udang air payau, yang kemudian digunakan untuk menentukan lahan yang dapat direkomendasikan untuk pengembangan tambak di pantai utara Tuban, Jawa Timur, Indonesia. Proses hierarki analitik (AHP) digunakan untuk mendapatkan bobot kriteria, yang terdiri dari karakteristik lahan, topografi, kualitas air dan infrastruktur. Lahan yang sesuai untuk tambak udang didelineasi menggunakan overlay terbobot dalam model SIG. Hasil analisis menunjukkan bahwa pantai utara Tuban memiliki beragam tingkat kesesuaian lahan untuk tambak udang. Pada tahap berikutnya, tutupan lahan dan penggunaan lahan diinterpretasi menggunakan citra SPOT 5 tahun 2014. Wilayah yang direkomendasikan untuk tambak udang air payau kemudian didelineasi dengan mempertimbangkan kesesuaian lahan, tutupan lahan dan penggunaan lahannya.*

Kata kunci: *: AHP, Wilayah pesisir, Kesesuaian lahan, Ketersediaan lahan, Penginderaan jauh, SIG*

1. Introduction

Indonesia is the largest archipelago in the world (AsianInfo.org, 2015) with as many as 13,466 islands (Indonesian Geospatial Information Agency, 2014) and a coastal length of 99,093 km (National Geographic Indonesia, 2015), thus placing it as an archipelago country with the second longest coast in the world after Canada (Cicin-Sain and Knecht, 1998). These facts reflect the vast coastal areas which can support many kinds of land utilization. Coastal areas are multifunctional, as they have a high biodiversity and are part of the mainland with high economic growth (Ambarwulan, 2010). This area is the most populous part of the mainland, with various life activities (Miller et al., 2005; Xu et al., 2009). Coastal areas have become associated with food, aquaculture, tourism, mining, industry, residential, ports, tourism, and other economic activities and services (Xu et al., 2009; Ambarwulan, 2010). High demand of land for such various uses in the coastal region requires optimal plans for land utilization.

Aquaculture such as in brackish water ponds is one of the potential land utilizations in coastal areas. With such a long coast, the potential of Indonesia to develop the brackish water ponds is high. The inventory of the

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Ministry of Marine and Fisheries (2012) indicates that the potential for brackish water aquaculture ponds in Indonesian coastal areas comprises an area of 1.3 million ha, with developments that continue to grow. The increasing land utilization for ponds in recent years is reflected by an increase of brackish water shrimp production. The production of tiger shrimp (*Penaeus monodon*), white shrimp (*Penaeus indicus*), Vanamei shrimp (*Litopenaeus vannamei*) and others in Indonesia in 2004 amounted to 238,567 tons; in 2013, the production had increased to 590,258 tons, an increase of 247% (Directorate General of Aquaculture, 2014). Indonesian shrimp farming experienced a very strong period of development in the 1980s (Grahadyarini, 2009; Widiatmaka et al., 2014a). After experiencing a dark period in the 1990s because of the disease in black tiger shrimp resulting in the destruction of ponds, the situation was recovered through wide utilization of Vanamei shrimp (Grahadyarini, 2009; Widiatmaka et al., 2014a).

Shrimp has long attracted attention due to its value as a food supply and its high economic potential (FAO, 2010). Shrimp pond in Indonesia is cultured by aquaculture fisheries to meet the need for food fish. This is not only the case for Indonesia, but also globally. The world per capita supply of food fish from aquaculture has increased from 0.7 kg in 1970 (Herbeck et al., 2013) to 17.9 kg in 2008, and to 19.2 kg in 2012 (FAO, 2014). Increasing pond development has been triggered by several important factors. Globally, fisheries contribute to 17% of human animal-derived protein intake and more than 50% in many countries (FAO, 2014). Food from the aquatic environment has a specific role in providing the long-chain omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are important for optimal brain and neural system development in children (FAO, 2014).

Aware of this potential, the Indonesian government in 2012 set the north coast of Java island as a location for shrimp pond revitalization (Indonesian Government Portal, 2015; Widiatmaka et al., 2014a) because the area is considered to have potentially favorable conditions for pond development. The coast has flat beaches, formed by the alluvial plains that facilitate aquaculture.

The north coast of Tuban in East Java Province is part of the north coast of Java potential area. This region has long been used for shrimp pond culture, and currently, brackish water shrimp ponds are growing and continue to attract many investors. According to the statistics (Indonesian Statistic, 2014), shrimp pond development on the north coast of Tuban has been fast. Production from shrimp farms in 2013 was 4,432 tons, higher than the production from inland water fish culture, at 1,953 tons. This shrimp production is still less than fish production from marine fisheries, which amounted to 9,617 tons, but when looked at by economic value, the value of brackish water shrimp pond culture at 210 billion Indonesian Rupiah (1 USD = 12,000.00 Indonesian Rupiah) was higher than that of marine fish production, which was 43 billion Indonesian Rupiah, and that of inland waters fisheries at 17 billion Indonesian Rupiah. The annual increase in shrimp production is also significant. Shrimp production in 2013 has increased by 19.4% per year since 2008, when it only reached 2,249 tons. In the same period, sea fisheries increased their production by less than 3% per year (Indonesian Statistic, 2014). This data indicates the attractiveness of increasing the shrimp pond area. However, the need for land for various sectors is constantly increasing (Sachikonye, 2005), and this fact is even more applicable in coastal areas (Xu et al., 2009; Tammi et al., 2014). Therefore, in order to perform optimal land use planning, indication recommendation of the different levels of suitability should be provided, so that areas that can be prioritized for brackish water pond aquaculture can be defined. The planning should also consider land availability, by taking into account the existing land utilization.

Although the region -including in the north coast of Tuban- is said to have high potential for brackish water aquaculture, this is certainly not for the whole coastal region. With the diversity of natural resources, there will be suitable areas, and there will also be unsuitable areas for cultivation. In other words, every part of the land has a different level of suitability. Land suitability evaluation is one of the methods used to assess the suitability of an area for a variety of farming (FAO, 1976), including for shrimp culture. Several studies have been conducted to assess the suitability of locations for aquaculture (Hossain et al., 2007; Hossain et al., 2009; Hossain and Das, 2010). The suitability level is determined through ecological aspects. Culture in ecologically suitable areas will support sustainable cultivation. In turn, a high level of ecological suitability will be reflected in high production which is economically profitable (Rossiter, 1996; Sachikonye, 2005), and will lead to the improved welfare of farmers, so that social benefits are also achieved. Thus, land suitability evaluation in land use planning will lead to sustainable agriculture, meaning that ecological, economic and social objectives can be achieved. This is the essence of sustainable development (WCED, 1987). In other considerations, with the increasing need of land for a variety of sectors, exploitation of land for cultivation must be carried out within a framework of efficiency. Cultivation on unsuitable land means a waste of resources, because these resources should be used for more profitable cultivation (Widiatmaka et al., 2014b). Accordingly, aquaculture site selection in a coastal area must consider the land suitability. Cultivation in locations with good land suitability is a prerequisite for obtaining optimal results (FAO, 1976; Widiatmaka et al., 2014b). Land evaluation is also necessary for environmental preservation. Shrimp pond culture should only be undertaken in areas that are suitable for shrimp farming, while non-suitable areas, such as forests and mangrove forests, should be preserved, maintaining the environment to protect the coastal areas from coastal abrasion (Kusmana, 2011). The uncontrolled expansion of shrimp farming in coastal areas would cause a deterioration of the environment, because natural resources have a limited capacity to support this activity.

Remote sensing and geographic information system are among of the tools that can be used to assist site selection processes (Aronoff, 1989; Ambarwulan, 2010), including selection of locations for aquaculture ponds. Various aspects of site selection can be covered by both tools which are the two important aspects in the selection of the locations for ponds. In the next part of the process, the tools can also be used for management activities i.e. site selection based on the proximity to markets, infrastructure, sources of inputs for cultivation and others (Aronoff, 1989; Burrough and McDonnell, 1998; Hossain and Das, 2010; Widiatmaka et al., 2014a). Such assessments are needed, so that the application in the field at operational level can be well planned. In the context of a comprehensive plan, geographic information systems can also be used to select areas which are still available for land uses according to the official rules and to the existing land utilization.

Methods for land evaluation have evolved further in recent years. In its early development, suitability determination was based only on land characteristics (FAO, 1976). Subsequently, with the help of remote sensing and geographic information systems, various other aspects including infrastructure and ease of management have been integrated through a method called multi-criteria analysis (MCA), often also referred to as multi-criteria evaluation (MCE) and multi-criteria decision making (MCDM) (Malczewski, 2006; Chen et al., 2010; Osly et al., 2014). Basically, this method integrates various factors that determine the land suitability for a particular use; the factors are weighted accordingly to their role in decision making (Store and Jokimaki, 2003; Mendas and Delali, 2012). This method has been widely used in other researches in making decisions and determining land suitability for agriculture (Ryan, 1998; Ceballos-Silva and Lopez-Blanco, 2003; Mendas and Delali, 2012; Akinci et al., 2013; Sarkar et al., 2014), determining the suitability of locations for landfills (Bah and Tsiko, 2011; Effat and Hegazy, 2012; Gbanie et al., 2013), forestry planning (Diaz-Balteiro and Romero, 2008; Store, 2009), tourism and recreation planning (Zavadskas, 2001; Fung and Wong, 2007) and planning of appropriate locations for building (Das et al., 2010), industry (Rikalovic et al., 2014), energy (Rahman et al., 2013; Rosso et al., 2014) and airport expansion (Vreeker et al., 2002).

The objective of this study was to evaluate the land suitability of the northern coastal area of Tuban Regency, East Java Province, Indonesia for brackish water shrimp pond culture. A recommended area for brackish water shrimp pond development was then delineated by integrating the result of land suitability analysis with land cover map resulted from remote sensing analysis.

2. The Methods

The Tuban Regency is one of the regencies of East Java Province, Indonesia. This regency has an area of 1,839.94 km^2, lies between 111°34'10.613"-

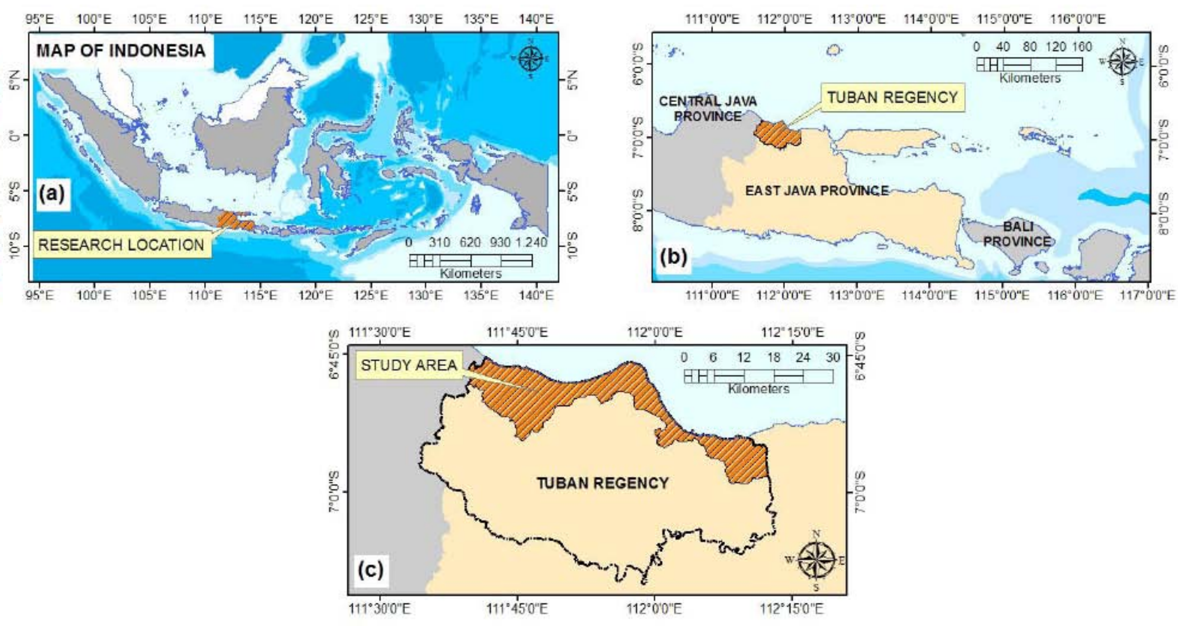

Figure 1. Research area of: (a) East Java Province; (b) Tuban Regency; and (c) the north coast of Tuban

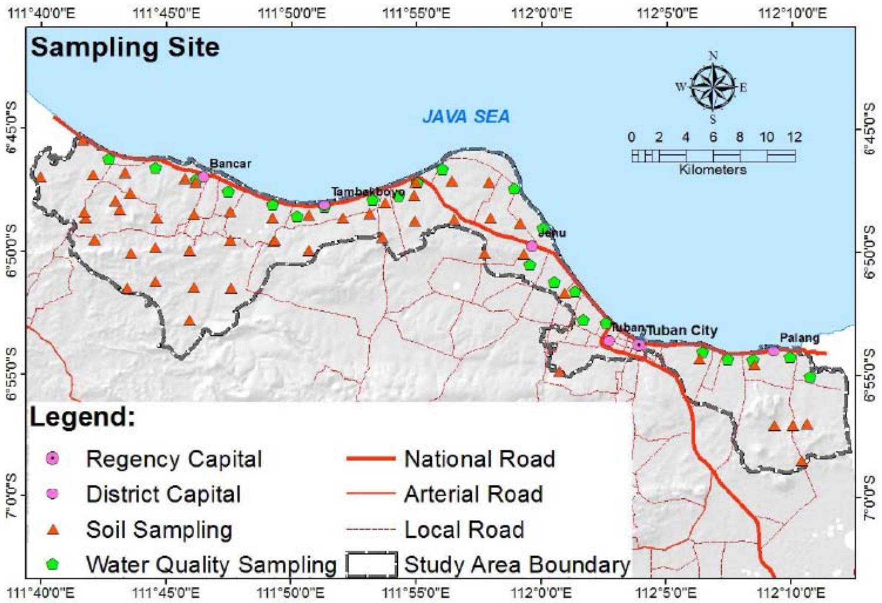

Figure 2. Soil and water sampling site in the north coast of Tuban

112°13'22.566"E and 6°45'9.968"–7°9'56.944"S, and consists of 20 districts. The scope of this study includes the coastal districts of the regency, which are the districts along the northern coast of Java Island. The study area thus includes five coastal district areas (Bancar, Tambakboyo, Jenu, Tuban and Palang), lying in the geographical region of 111°39'33.019"-112°12'23.677"E and 6°45'9.968"-6°59'0.117"S (Figure 1). The study area is flat, with alluvial fan, covering an area of 39,424.2 ha as the major substrate. The climate of the region is monsoonal, with an average annual rainfall of 2,132.7 mm.year^{-1} according to 2004-2013 data from the local meteorological station. The rainy season is October–April.

Based on the geological map (1:100,000) of Jatirogo sheet (Situmorang et al., 1992) and Tuban sheet (Hartono and Suharsono, 1997), this region consists of several geological formations, among others the geological formations of karst rock, igneous rock and sedimentary and alluvium rock. Nonetheless, alluvium formations are the formations with the most extensive deployment, providing an early indication of suitability for aquaculture.

The data used in this research were partly obtained from field and laboratory measurements, and were partly obtained through the calculation and processing of maps and satellite imagery. For land evaluation purposes, all of the data can be grouped into four criteria, with each criterion consisting of several sub-criteria. The soil characteristic criterion consists of three sub-criteria, which are soil pH, soil texture and soil organic carbon; the topographic criterion consists of two sub-criteria which are elevation and slope; the water quality criterion consist of four sub-criteria which are water pH, dissolved oxygen, salinity and water temperature; the infrastructure criterion consists of two sub-criteria, which are distance to main road and distance to market. The criteria and sub-criteria used may differ with some previous studies (Hossain and Das, 2010; Widiatmaka et al., 2014a), mainly due to the different characteristics, and the ease of data acquisition. Soil, topography and water quality are natural resource factors that influence the environmental quality of shrimp pond culture. Infrastructure influences the ease of shrimp culture, in terms of marketing as well as ease of transferring the production inputs to the pond area. When used for site selection, multi-criteria evaluation may include a variety of factors, such as natural resources, infrastructure, marketing and ease of management (Hossain et al., 2007; Hossain et al., 2009; Hossain and Das, 2010; Akinci et al., 2013).

In 2014, a survey was conducted involving soil and water sampling and measurements (Figure 2). Soil samples were taken according to the land mapping units on the 1:25 000 soil map, made available by the joint work of the Regional Government of Tuban Regency and Bogor Agricultural University, Indonesia (Regional Government of Tuban Regency, 2014; Widiatmaka et al., 2015). In total, 35 soil samples from the study area were taken. The soil samples were analyzed at the Laboratory of the Department of Soil Science and Land Resources at Bogor Agricultural University where the laboratory methods of Tan (2002) were employed. The water quality measurements were conducted at several points according to hydrogeological map patterns, and were measured outside the actual shrimp ponds to obtain the natural water properties, avoiding water that had already receiving treatment as part of existing cultivation. All water quality measurements were conducted in the field using a Horiba U-10 digital

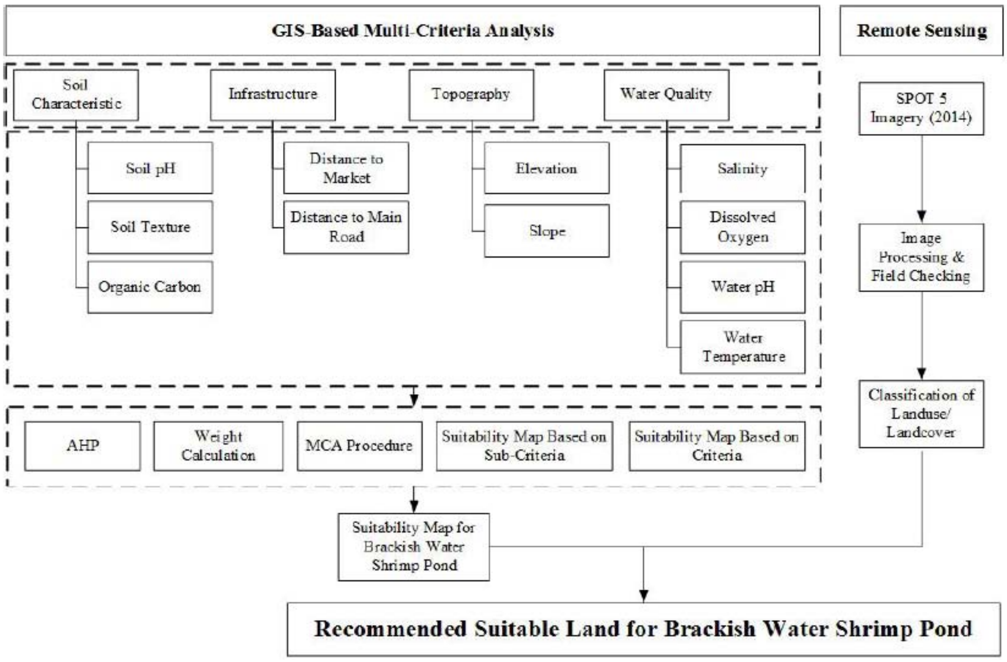

Figure 3. Research methodology used for assessing recommended land suitable for brackish water shrimp ponds on the north coast of Tuban

water checker. In total, 23 points were measured for water quality. Topographic maps at a scale of 1:25,000 (Indonesian Geospatial Information Agency, 2001) were used to derive the topographical data by using Arc-GIS 10.2 developed by the Environmental Systems Research Institute Inc., USA. The ease of marketing and culture input entry to the pond sites, represented by main road parameters were also obtained from the 1:25,000 scale topographic maps. In total, there are eleven sheets of 1:25,000 topographic maps which cover the study area. Market locations were obtained from field survey.

Two major analysis steps were used in this study: biophysical brackish water shrimp pond site selection using GIS-based multi criteria analysis and identification of land use and land cover using remote sensing. Overlay between the results of multi-criteria analysis and land use and land cover analysis was then used to delineate the recommended area for brackish water shrimp pond culture. The procedure followed is illustrated schematically in Figure 3.

In biophysical shrimp pond site selection, all data points were initially used to create map using Arc-GIS 10.1, and specifically the spatial analyst extension. Spatializing soil data was performed according to land mapping units. Spatializing water quality was done via the interpolation method, taking into account hydrogeological units in order to obtain representative water samples. Interpolation was performed using interpolation in the geostatistical module of Arc-GIS 10.2. The data was first classified and then weighted accordingly to its contribution to brackish water shrimp suitability, to enable the creation of a suitability map. Factor weight was classified based on a bibliographical study and on expert judgment; suitability was classified into three levels: 3 (highly suitable), 2 (suitable), and 1 (not suitable) (Table 1). Five experts were consulted in order to establish this classification.

Each sub-criterion, and then criteria, was weighted in the next step. For this purpose, an analytical hierarchy process (AHP) was used. AHP was the concept introduced by Saaty (1988) for weighting many factors in decision making process. This method has been widely used because of its effective mathematical concepts (Triantaphyllou and Mann, 1995; Akinci et al., 2013). In this method, the relative criteria are compared in pairs. This procedure has been widely described and used in decision making process in land use planning (Hossain and Das, 2010; Akinci et al., 2013; Widiatmaka et al., 2014a). The ratings were derived from nine point interest scales, with values from one to one-ninth. When the line has significantly less importance than the column, the value of one ninth was allocated. The value of one was given when the two variables were equally important (Widiatmaka et al., 2014a). A group of experts was asked to compare the matrix in pairs for estimating such weights. The results of the pairwise comparisons conducted in this study are given in Table 2. The results indicate that the Consistency ratios (Cr) were 0.0-0.065. These Cr were within the ratio of equal to or less than 0.10, indicated as acceptable values (Saaty, 1988).

The weights obtained from AHP were then used to determine the suitability, by multiplying the weight of the criteria with the weight of the sub-criteria and the suitability weight as predetermined in Table 1. The multiplication was performed in raster format of 25 m x 25 m on the map. The result of this multiplication was then reclassified using equal distances as three classes

Table 1. Levels of Suitability for Brackish Water Shrimp Pond In The North Coast Of Tuban According to Different Sub-Criteria

Sub-criteria	Suitability Range (Score)			
	Unit	Highly Suitable (3)	Suitable (2)	Not Suitable (1)
Soil pH[a)b)]	-	6-8	4-6; 8-9	<4; >9
Soil texture[b)c)]	-	clay, silty clay, clay loam	sandy clay loam, silty clay loam, silt loam	loam, sand, loamy sand, sandy loam
Soil Organic Carbon[b)]	%	<1	1-2	>2
Elevation[c)d)]	meter	0-10	10-30	>30
Slope[c)d)]	%	0-2	2-3	>3
Salinity[c)d)]	0/00	10-20	20-35	<10; >35
Dissolve oxygen[e)]	mg/l	4-7	2.5-4	<2.5
Water pH[e)]	-	6-8	4-6; 8-9	<4; >9
Water Temperature[a)e)f)]	oC	25-32	12-25	<12; >32
Distance to Market[g)]	km	<3	3-6	>6
Distance to Main Road[h)i)]	km	<0.5	0.5-1	>1

References: [a)]New (2002); [b)]Hossain and Das (2010); [c)]Widiatmaka et al. (2014a); [d)]Wiradisastra et al. (2004); [e)]Boyd and Zimmermann (2000); [f)]Janssen et al. (1988); [g)]present study; [h)]Giap et al. (2005); [i)]Hossain et al. (2007; 2009).

Table 2. Matrix of Pairwise Comparisons For The Assessment Of Relative Importance Of Criteria and Sub-Criteria For Brackish Water Shrimp Ponds In The North Coast Of Tuban, Indonesia

	Soil pH	Soil Texture	Soil Organic C	Weight
Soil Characteristic				
Soil pH	1	1/3	3	0.260
Soil Texture	3	1	5	0.633
Soil Organic C	1/3	1/5	1	0.106
Consistency ratio (Cr) 0.047				

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

	Salinity	Dis-solve Oxygen	Water pH	Water 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
Water Temperature	1/7	1/5	1/3	1	0.057
Consistency ratio (Cr) = 0.065					

Table 2 continued...

	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 brackish water shrimp pond					
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 (γmax) = 4.109310391
n = 4
Consistency index (Ci) = (γmax - n)/(n - 1) = 0.036
Random index (Ri) = 0.9
Consistency ratio (Cr) = Ci/Ri = 0.041

of suitability: highly suitable, suitable and not suitable.

An analysis of SPOT 5 imagery from June 2014 (Regional Government of Tuban Regency, 2014) was conducted to obtain land use and land cover data for the study area. Image analysis of SPOT 5 was performed by a supervised classification using image processing software. The standard classification from the Ministry of Forestry (Forestry Planology Agency, 2012) was used for land use and land cover classification. For this analysis, a series of field checks was performed to obtain a valid imagery classification.

3. Result and Discussion

A summary of soil analysis and water quality measurement results, used as soil and water characteristics, is presented in Table 3. In Table 4 and Figure 4, the results of suitability analysis based only on the soil characteristics criteria are presented. Each step of soil characteristic criteria classification, according to each sub-criterion, is shown in each figure, showing the results of the map calculation as well as the classification according to the suitability scale and the resulting suitability class.

In the context of pond development, the soil is a natural body where pond is constructed and thus, diverse soil characteristics determine the success of the pond construction. Soil properties will also determine the initial cost of construction. The soils at the pond bottom and the accumulated sediments are integral parts of the pond. Concentrations of nutrients, organic matter and microorganism density at the bottom of the ponds are several orders of magnitude greater than those in the water (Avnimelech and Ritvo, 2003; Nimrat et al., 2008) and thus should be taken into consideration. In this research, three major soil characteristics, considered to have a strong relationship to brackish water shrimp pond culture were chosen: soil pH, soil texture and soil organic carbon.

When considering only the soil pH, the majority of the area (95.3%) in the north coast of Tuban is classified as highly suitable, and 4.7% of the area is classified as suitable. According to soil pH, none of the area is unsuitable for brackish water shrimp pond culture. This is due to the vast influence of sea water on the soil in this coastal area, partly because of the flat slope which allows sea water to reach and extensively influence the soil of the coastal area. Near neutral soil pH has a positive influence on brackish water shrimp. For this reason, the criteria used in this study apply near neutral soil pH as being more suitable (New, 2002; Hossain and Das, 2010). The relatively high soil pH of the north coast of Tuban indicates relatively high suitability for brackish water shrimp ponds. However, it should be noted that within the suitable range of soil pH, the suitability will still vary. The research of Lemonnier et al. (2004) indicates a significant positive correlation between the pH of the sediment surface and the osmotic pressure affecting shrimp; osmotic pressure decreased significantly as pH decreased from 7.0 to 6.5. Such changes in osmotic pressure influence the physiological condition of shrimp.

The largest part of the area (76.2% of the area) is also classified as highly suitable for brackish water shrimp pond according to soil texture, and only small part of the area (16.7% of the area) is classified as suitable. Soil with fine soil texture is the most suitable soil for pond construction (Hossain and Das, 2010; Widiatmaka et al., 2014a). The soil at pond sites should have enough clay content to ensure that the ponds will hold water. Good quality dikes are usually built from sandy clay or sandy loam materials which harden and are easily compacted (Kungvankij et al., 1986)

According to soil organic carbon, 44.1% of the area is classified as highly suitable, 54.5% is classified as suitable; only 1.4% of the area is not suitable for brackish water shrimp pond culture. Only a little literature exists on the relationship between soil organic carbon and shrimp pond culture. Banerjea (1967) and Ritvo et al. (1998a) suggested that for several species, the optimum soil for shrimp pond culture contains 1.5-2.5% of soil organic carbon.

When the weights of the sub-criteria according to the AHP results are applied, 76.2% of the area is classified as highly suitable in terms of soil characteristic criteria, 23.8% of the area is classified as suitable for brackish water shrimp ponds (Table 4). It can thus be stated that according to the soil characteristics criteria, the north coast of Tuban has a good basic potential because most of the area is suitable for brackish water pond culture. The research of Ritvo et al. (1998b) indicated that the influence of the substrate can be independent of the effect of water in obtaining high shrimp production, and so it is necessary to have good soil as an initial condition for shrimp pond culture.

The results of the analysis according to topographical criteria, based on the sub-criteria of elevation and slope, are presented in Table 5 and Figure 5. Elevation and slope are important factors in determining suitability for brackish water shrimp ponds; they determine the potential of sea water with sufficient salinity to enter the ponds. In the next planning, it is essential to have the detailed topography of a selected site, in order to determine pond design and farm layout. Coastal sites where the slopes run gently towards the sea make pond development easier, requiring less financial input since excavation is minimal (Kungvankij et al., 1986; Ritvo et al., 1998a; Joyni et al., 2011). According to the elevation criterion, 37% of the area is not suitable for brackish water shrimp pond culture, and based on the slope, 28% of the area is not suitable. An analysis using the combination of both criteria resulted in 25% of the area being classified as highly suitable and 38% as suitable for brackish water shrimp pond culture. Thus, based on all topographical criteria, more than 62% of the area is classified as either highly suitable or suitable for brackish water shrimp ponds. The 37% of the area that is not suitable in terms of topographical criteria suggests that attention should be paid to topography during pond construction, especially in the detailed engineering design phase, to ensure that water with sufficient salinity can enter the pond.

Water availability is highly dependent on climate,

Table 3. Summary of Soil and Water Analyses Used in This Study

Soil Samples[1)]							Water Samples				
n		Soil pH	Texture (%)			C-org (%)	n	Salinity o/oo	Diss. Ox. mg/l	Water pH	Temp. (°C)
			Sand	Silt	clay						
35	Max	8.4	89.6	61.8	78.0	2.3	23	30.2	4.2	7.5	33.8
	Ave	7.6	30.5	32.0	37.5	1.1		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

[1)]The soil data which consist of soil pH, soil texture and organic Carbon (C-org) of the north coast of Tuban were extracted from the data of the soil survey of whole Tuban Regency, described in Regional Government of Tuban Regency (2014) and Widiatmaka et al. (2015), taken in the part of the north coast only for this paper.

Table 4. Land Suitability for Brackish Water Shrimp Ponds In The North Coast Of Tuban According To Soil Characteristics Criteria

Sub-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
Soil 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

however, the climatic data show that the study area of north coast of Tuban is suitable for shrimp pond culture in terms of rainfall. As this is a humid tropical region, the rainfall is sufficient. The topographical elements that determine the ease with which saline water enters the pond are therefore more important than rainfall. This is a different case than that found in the Mahakam Delta (Widiatmaka et al., 2014a), where in a much wider region, the climate differed within the area analyzed.

Water quality, including all of the physico-chemical and microbiological characteristics of the water, determines the success of brackish water shrimp pond culture. There are numerous studies dealing with chemical fluxes and the water quality of shrimp pond effluents (Paez-Osuna, 2001; Jackson et al., 2003; Ruiz-Fernandez and Paez-Osuna, 2004; Casillas-Hernandez et al., 2007; Dineshkumar et al., 2014). Although there are many water characteristics, only four major water characteristics, which were measurable in the field, were used in this research. An important element is pH, and the pH of water on or adjacent to the pond site should be within a certain 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 order to implement shrimp pond culture. The subsurface intrusion of salt water under the fresh-water is especially important for rivers and canals (Kungvankij et al., 1986).

The results of analysis according to water quality measurements, in this case water pH, salinity, dissolved oxygen and water temperature, are presented in Table 6 and Figure 6.

Based on the water pH, the entire part of the study area is classified as highly suitable. According to salinity, 10% of the area is classified as unsuitable. Salinity is very important for shrimp ponds, although younger shrimp appear to tolerate a wider fluctuation of salinity than the adults (Kungvankij et al., 1986; Casillas-Hernandez

Table 5. Land Suitability For Brackish Water Shrimp Ponds in The North Coast of Tuban According To Topographical Criteria

Sub-criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	ha	%
Elevation	10,354.4	26.3	14,598.2	37.0	14,471.6	0.0
Slope	20,873.2	52.9	7,544.1	19.1	11,006.9	7.1
Sub-overall	10,001.8	25.4	14,950.7	37.9	14,471.7	1.4

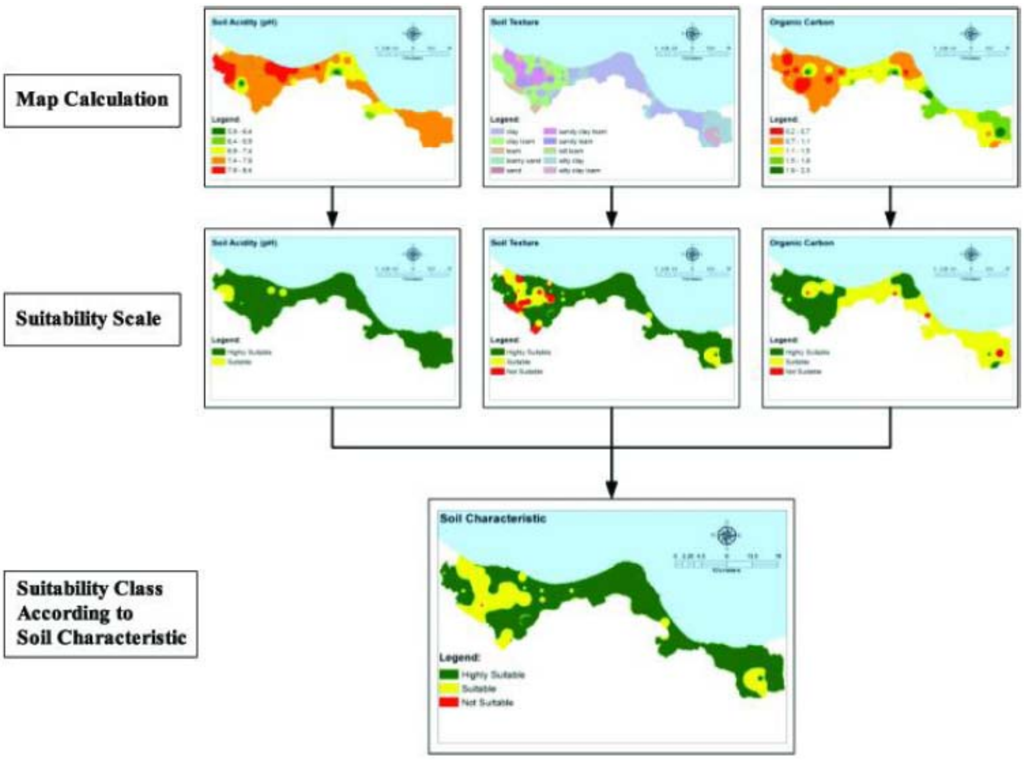

Figure 4. The use soil characteristics criteria to assess land suitability for brackish water shrimp ponds in the north coast of Tuban

et al., 2007). According to the dissolved oxygen, 75% of the area is unsuitable, but dissolved oxygen can be rectified in the advanced technology used for shrimp pond culture. The maintenance of adequate levels of dissolved oxygen in pond water is very important for shrimp growth and survival. Prolonged exposure to the stress of low oxygen concentration lowers disease resistance and inhibits growth. In most cases, oxygen depletion results in the mass mortality (anoxia) of shrimp stock. This is particularly common in intensive culture operations (Kungvankij et al., 1986; Herbeck et al., 2013). According to the water temperature, 99% of the area in the north coast of Tuban is classified as highly suitable. In tropical areas of Indonesia, water temperature is not a constraint for shrimp farming.

In the overall water quality criteria, the analysis showed that 15% of the regions can be classified as highly suitable for brackish water shrimp ponds, and 82% of the region can be classified as suitable. Only 2.7% of the area is not suitable for brackish water shrimp pond. The results of the water quality analysis confirm the high suitability of the northern coastal areas of Tuban for brackish water shrimp ponds.

Land suitability for brackish water shrimp ponds according to infrastructure criteria is presented in Table 7 and Figure 7. When considering infrastructure criteria including proximity to roads and markets, 21% of the land was classified as highly suitable, and 38% was classified as suitable. Areas comprising 42% of the north coast of Tuban are unsuitable for brackish water

Table 6. Land Suitability For Brackish Water Shrimp Ponds In The North Coast Of Tuban According To Water Quality Criteria

Sub-criteria	Highly Suitable		Suitable		Not Suitable	
	ha	%	ha	%	ha	%
Salinity	26,336.00	66.8	8,989.70	22.8	4,098.50	10.4
Dissolve Oxygen	0	0	9,606.90	24.4	29,817.30	75.6
Water pH	39,424.20	100	0	0	0	0
Temperature	39,259.60	99.6	0	0	164.6	0.4
Sub-overall	5,901.50	15	32,444.90	82.3	1,077.80	2.7

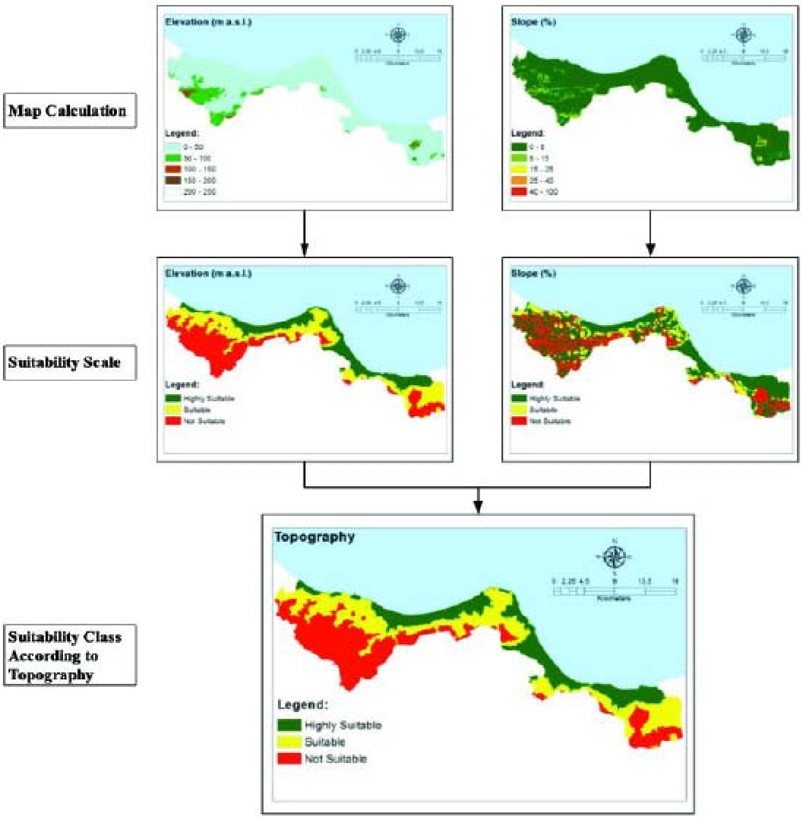

Figure 5. The use of topographical criteria to assess land suitability for brackish water shrimp ponds in the north coast of Tuban

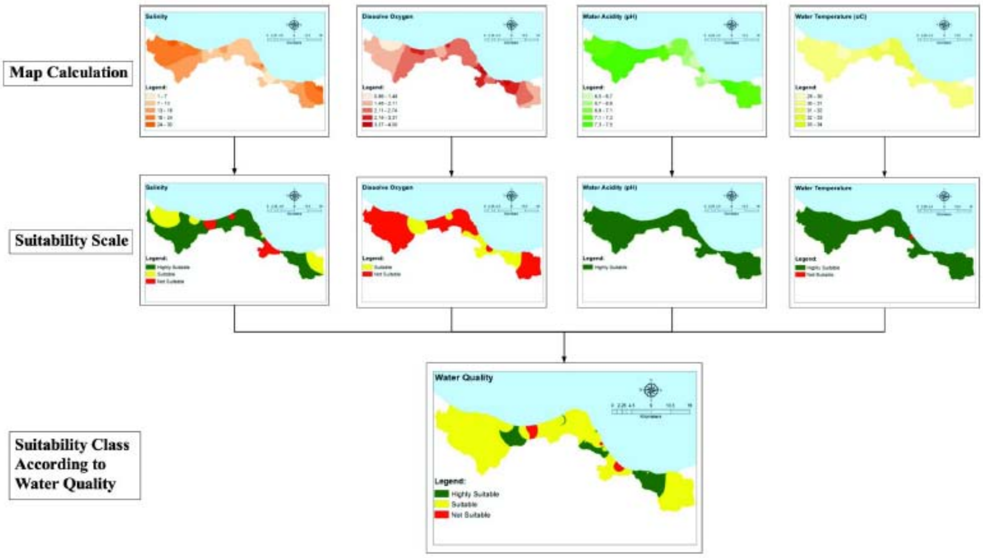

Figure 6. The use of water quality criteria to assess land suitability for brackish water shrimp ponds in the north coast of Tuban

Table 7. Land Suitability For Brackish Water Shrimp Ponds In The North Coast Of Tuban According To Infrastructure Criteria

Sub-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

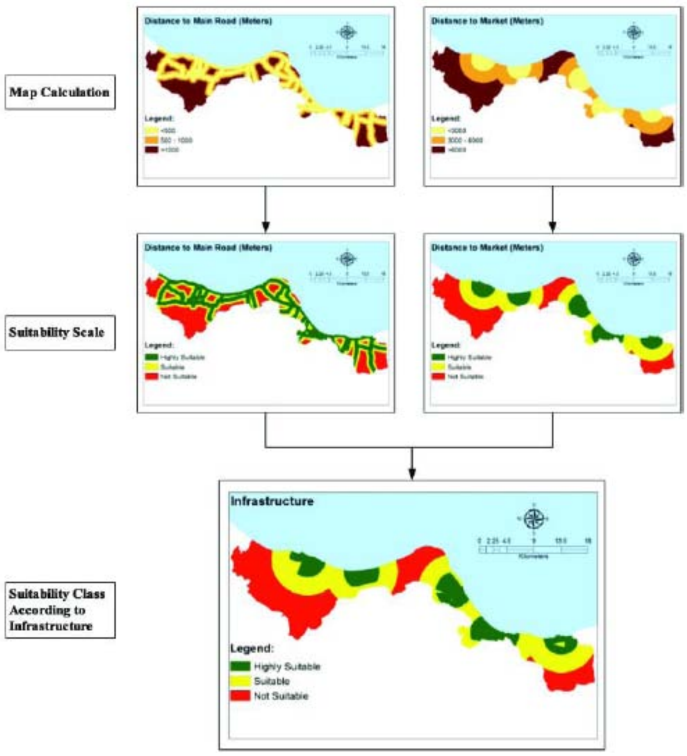

Figure 7. The use of infrastructure criteria to assess land suitability for brackish water shrimp ponds in the north coast of Tuban

shrimp ponds. The results of the field survey suggest that the market is relatively small, and roads are limited to a single main paved road. The future development of shrimp farming in this region needs to be supported by improved infrastructure. This is not only true for brackish water shrimp ponds in north coast of Tuban, but also for agricultural development in Indonesia in general.

The final suitability map for brackish water shrimp ponds is given in Figure 8, while the area of this final suitability map is presented in Table 8.

The results show that 33% of the north coast of Tuban is highly suitable for brackish water shrimp ponds, and 67% of the area is suitable. The entire area is deemed suitable for brackish water shrimp ponds. This explains the high demand of land for the construction of brackish water shrimp pond culture in this region.

It should be noted however, that suitability alone is not sufficient for the implementation of shrimp pond culture. It is necessary to know whether actual land use and land cover allows for the development of shrimp ponds. Determining current land use and land cover can provide information about the suitability and availability of the locations recommended for the development of brackish water shrimp ponds.

Land use and land cover analysis using SPOT 5 imagery on the north coast of Tuban resulted in ten classes of land use and land cover in the north coast of Tuban (Figure 9). The existing land use and land cover classes include: forest, dry land, agricultural land, settlements, paddy fields, shrubs, existing ponds, bare land, and bodies of water. There were some areas that could not be interpreted due to cloud cover.

According to this variety of land use and land cover, some land can be defined as available for the development of brackish water shrimp pond culture, while some other land can be defined as not available for the development of brackish water shrimp ponds. Accordingly, land that can be recommended for use for brackish water shrimp was identified based on the results of land use and land cover analysis and the results of the land suitability analysis. Technically, this is done by overlaying the maps of land use and land cover with the land suitability maps. The result is a recommendation map for brackish water shrimp pond area development (Figure 10 and Table 9).

In this recommendation map, several parts of the area can be delineated. The first part is the area which is not recommended for brackish water shrimp ponds. Included in this not recommended area is the area where land use and land cover does not allow the development of shrimp ponds, for example existing settlements and industry. Also included in this not-recommended area are areas for the purpose

Table 8. Land Suitability for Brackish Water Shrimp Ponds in The North Coast of Tuban

Criteria	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	16 495.7	41.8
Overall land suitability	12,902.8	32.7	26,521.4	67.3	0.0	0.0

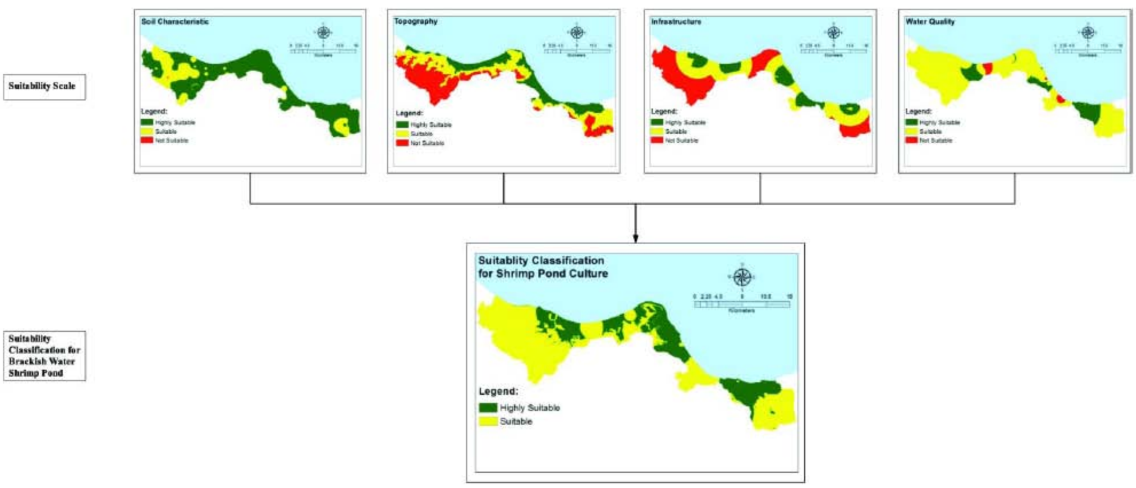

Figure 8. The final suitability map for brackish water shrimp ponds on the north coast of Tuban

Figure 9. Land use and land cover of the north coast of Tuban as analyzed by SPOT 5 imagery

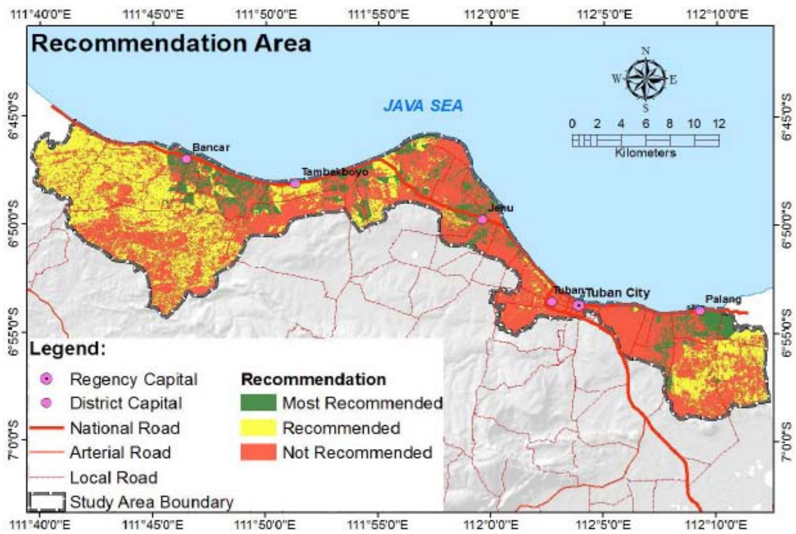

Figure 10. Recommended area for brackish water shrimp pond land use planning in the north coast of Tuban

of environmental conservation. These include forest areas, including dry land forest and mangrove forest, of which there is very little left in Tuban. The research of Teneorio et al. (2015) shows that the considerable value of the ecosystem services provided by the mangroves especially and forest generally is greater than that of the production of shrimp in ecological and economic terms.

The second delineated part is the most recommended area. This is the area which according to the analysis is highly suitable for brackish water shrimp ponds, while according to its land use and land cover analysis, brackish water shrimp pond culture development is allowable. The third part is the recommended area. This is the area where the land use and land cover allows the development of ponds and the land suitability is assessed as suitable.

The area in the north coast of Tuban, which is recommended for brackish water shrimp pond planning, is presented in Table 10. Of the total analyzed area of 39,424 ha, 4,787 ha (12%) is categorized as most recommended, 12,162 ha (31%) is recommended, and 22,475 ha (57%) is not recommended for brackish water shrimp ponds. Statistical data about existing shrimp pond culture on the north coast of Tuban has not been collected, however, the current image interpretation indicates an existing brackish water shrimp pond area of 1,015.7 ha (Table 9). There is therefore a potential for the extension of these ponds according to the analysis of the most recommended and recommended areas in this study, although this calculation is based only on land suitability and land use and land cover analysis. An analysis of the carrying capacity to determine the extent of the potential for pond development would also be

Table 9. Results of Overlaying Land Use/Land Cover Data Against Land Suitability Obtained From The Analysis and Its Recommended Use

Land use	Suitability	ha	%	Recommendation
Cloud	Highly Suitable	574.8	1.5	Not Recommended
Cloud	Suitable	764.7	1.9	Not 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

Recommendation of land use planning for brackish water shrimp pond	ha	%
Most Recommended	4,212.2	10.7
Recommended	11,397.5	28.9
Not Recommended	23,814.5	60.4
Total	39,424.2	100.0

necessary. In the context of sustainable development, we must consider not only the economic standpoint, but also the physical carrying capacity of the environment, and social issues also need to be considered in a balanced manner (WCED, 1987). Analysis based on the requirements of other sectors for land utilizations is also necessary.

4. Conclusion

The study area was the north coast of Tuban, in East Java Province, where brackish water shrimp ponds have been developing significantly in recent years. An analysis using GIS-based multi-criteria evaluation indicates areas of different levels of suitability for brackish water shrimp ponds. The results of this analysis indicated that 33% of the north coast of Tuban is highly suitable for brackish water shrimp ponds, and 67% of the area is suitable. A further step of analysis taking into account the existing land use and land cover data mapped from SPOT 5 imagery showed that of the total 39,424 ha on the north coast of Tuban, 4,212.2 ha (10.7%) are highly recommended for brackish water shrimp ponds development, 11,397.5 ha (28.9%) are recommended, and 23,814.5 ha (60.4%) is not recommended for brackish water shrimp ponds. The potential area available for the development of brackish water shrimp farming on the north coast of Tuban is thus quite large, but further analysis of the land carrying capacity and the land requirements of other sectors are necessary before the expansion of ponds.

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References

Akıncı, H., A.Y. Ozalp and B. Turgut (2013), Agricultural land use suitability analysis using GIS and AHP technique, *Computers and Electronics in Agriculture, 97*, 71 - 82, http://dx.doi.org/10.1016/j.compag.2013.07.006.

Ambarwulan, W. (2010), Remote sensing of tropical coastal waters: study of the Berau Estuary, East Kalimantan, Indonesia *(Unpublished doctoral dissertation)*, University of Twente, Netherlands.

Aronoff, S. (1989), GIS a Management Perspective. Ottawa, Canada: WDL Publications.

AsianInfo.org (2015), Indonesia's Geography, http://www.asianinfo.org/asianinfo/indonesia/pro-geography.htm.

Avnimelech, Y. and G. Ritvo (2003), Shrimp and fish pond soils: processes and management, *Aquaculture,* 220, 549-567, http://dx.doi.org/10.1016/S0044-8486(02)00641-5.

Bah, Y. and R.G. Tsiko (2011), Landfill site selection by integrating geographical information systems and multi-criteria decision analysis: a Case study of freetown, Sierra Leone, *African Geographical Review,* 30(1), 67-99, DOI: 10.1080/19376812.2011.10539136.

Banerjea, S.M. (1967), Water quality and soil condition of fish ponds in some states of India in relation to fish production, *Indian Journal of Fisheries*, 14, 113 - 144.

Boyd, C. and S. Zimmermann (2000), Grow-out systems water quality and soil management, in: M. B. New and W. C. Valenti (eds.), *Freshwater Prawn Culture: the Farming of Macrobrachium rosenbergii,* 221-238, Blackwell Science, Oxford, England. http://dx.doi.org/10.1002/9780470999554.ch14

Burrough, P.A. and R.A. McDonnell (1998), *Principles of Geographical Information Systems,* New York: Oxford University Press.

Casillas-Hernandez, R., H. Nolasco-Soria, T. Garcı´a-Galano, O. Carrillo-Farnes and F. Paez-Osuna (2007), Water quality, chemical fluxes and production in semi-intensive Pacific white shrimp *(Litopenaeus vannamei*) culture ponds utilizing two different feeding strategies, *Aquacultural Engineering,* 36, 105-114, http://dx.doi.org/10.1016/j.aquaeng.2006.09.001

Ceballos-Silva, A. and J. Lopez-Blanco (2003), Delineation of suitable areas for crops using a multi criteria evaluation approach and land use/cover mapping: a case study in Central Mexico, *Agricultural Systems,* 77, 117-136, http://dx.doi.org/10.1016/S0308-521X(02)00103-8

Chen, Y., Yu J. and S. Khan (2010), Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental Modelling and Software, 25,* 1582-1591, http://dx.doi.org/10.1016/j.envsoft.2010.06.001

Cicin-Sain, B. and R. Knecht (1998), *Integrated Coastal and Ocean Management:* Concepts and Practices, Island Press.

Das, S., M.Y.L. Chew and K.L. Poh (2010), Multi-criteria decision analysis in building maintainability using analytical hierarchy process, *Construction Management and Economics,* 28(10), 1043-1056, http://dx.doi.org/10.1080/01446193.2010.501806.

Diaz-Balteiro, L. and C. Romero (2008), Making forestry decisions with multiple criteria: a review and an assessment, *Forest Ecology and Management, 255, 3222-3241,* http://dx.doi.org/10.1016/j.foreco.2008.01.038.

Dineshkumar, N., C. Saravanakumar, M. Vasanth, M. Muralidhar and S.V. Alavandi (2014), Genetic and physiological characterization of denitrifying bacteria from brackishwater shrimp culture ponds of India, *International Biodeterioration and Biodegradation,* 92, 49-56, http://dx.doi.org/10.1016/j.ibiod.2014.04.017

Directorate General of Aquaculture (2014), *Indonesian Aquaculture Statistics.* Directorate General of Aquaculture, Indonesian Ministry of Marine and Fisheries.

Effat, H.A. and M.N. Hegazy (2012), Mapping potential landfill sites for North Sinai cities using spatial multi criteria evaluation, *The Egyptian Journal of Remote Sensing and Space Sciences*, 15, 125-133, http://dx.doi.org/10.1016/j.ejrs.2012.09.002.

Food and Agriculture Organization. (1976), A framework for land evaluation, *Soils Bulletin No. 32*, Rome: Food and Agriculture Organization.

Food and Agriculture Organization (2010), *The State of World Fisheries and Aquaculture.* Rome: Fisheries and Aquaculture Department, Food and Agricultural Organization.

Food and Agriculture Organization (2014), *The State of World Fisheries and Aquaculture: Opportunities and Challenges.* Rome: Fisheries and Aquaculture Department, Food and Agricultural Organization.

Forestry Planology Agency (2012), *Land Use and Land Cover Map.* Indonesian Ministry of Forestry (in Indonesian).

Fung, T. and F.K.K. Wong (2007), Ecotourism planning using multiple criteria evaluation with GIS, *Geocarto International,* 22(2), 87-105, http://dx.doi.org/10.1080/10106040701207332

Gbanie, S.P., P.B. Tengbe, J.S. Momoh, J. Medo and V.T.S. Kabba (2013), Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA): Case study Bo, Southern Sierra Leone, *Applied Geography,* 36, 3-12, http://dx.doi.org/10.1016/j.apgeog.2012.06.013.

Giap, D.H., Y. Yi and A. Yakupitiyage (2005), GIS for land evaluation for shrimp farming in Haiphong of Vietnam, *Ocean and Coastal Management, 48,* 51-63, http://dx.doi.org/10.1016/j.ocecoaman.2004.11.003.

Grahadyarini, B.M.L. (2009), *Restoring the glory of shrimp farming* [Article], Retrieved from http://bisniskeuangan.kompas.com/read/2009/02/25/08375379/Mengembalikan.Kejayaan.Budidaya.Udang. (in Indonesian)

Hartono and Suharsono (1997), *Geological Map of Tuban Sheet, Scale 1:100.000,* Bandung: Geological Center for Research and Development.

Herbeck, L.S., D. Unger, Y. Wu and T.C. Jennerjahn (2013), Effluent, nutrient and organic matter export from shrimp and fish ponds causing eutrophication in coastal and back-reef waters of NE Hainan, tropical China, *Continental Shelf Research*, 57, 92-104, http://dx.doi.org/10.1016/j.csr.2012.05.006.

Hossain, M. S., S.R. Chowdhury, N.G. Das and M.M. Rahaman (2007), Multi-criteria evaluation approach to GIS-based land suitability classification for tilapia farming in Bangladesh, *Aquaculture International,* 15, 425-443, http://dx.doi.org/10.1007/s10499-007-9109-y.

Hossain, M.S., S.R. Chowdhury, N.G. Das, S.M. Sharifuzzaman and A. Sultana (2009), Integration of GIS and multicriteria decision analysis for urban aquaculture development in Bangladesh, *Landscape and Urban Planning,* 90, 119-133, http://dx.doi.org/10.1016/j.landurbplan.2008.10.020.

Hossain, M. S. and N.G. Das (2010), GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (Macrobrachium rosenbergii) farming in Companigonj Upazila of Noakhali, Bangladesh, *Computers and Electronics in Agriculture,* 70, 172-186, http://dx.doi:10.1016/j.compag.2009.10.003.

Indonesian Geospatial Information Agency (2001), *Topographical Map of Tuban,* East Java, Cibinong: Indonesian Geospatial Information Agency.

Indonesian Geospatial Information Agency (2014), *Indonesia has 13 466 islands registered and georeferenced* [Article], Retrieved from http://www.bakosurtanal.go.id/berita-surta/show/indonesia-memiliki-13-466-pulau-yang-terdaftar-dan-berkoordinat (in Indonesian).

Indonesian Government Portal (2015), *Revitalization of shrimp industry* [Article], Retrieved from http://indonesia.go.id/in/perikanan/11139-perlu-bangkitkan-kembali-industri-udang.pdf (in Indonesian)

Indonesian Statistic (2014), *Tuban Regency in Figures. Tuban, East Java: Indonesian Statistic (in Indonesian).*

Jackson, C., N. Preston, P.J. Thompson and M. Burford (2003), Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. *Aquaculture,* 218, 397-411, http://dx.doi.org/10.1016/S0044-8486(03)00014-0.

Janssen, J.A.J., N. Bhasayavan and C. Pongsri (1988), Studies on the culture of the freshwater prawn *Macrobrachium rosenbergii* at various stocking size and density in ricefields, NACA/WP/88/75, FAO, Rome, 21 pp.

Joyni, M.J., B.M. Kurup and Y. Avnimelech (2011), Bioturbation as a possible means for increasing production and improving pond soil characteristics in shrimp-fish brackish water ponds, *Aquaculture,* 318, 464-470, http://dx.doi.org/10.1016/j.aquaculture.2011.05.019.

Kungvankij, P., T.E. Chua, B.J. Pudadera Jr, G. Corre, E. Borlongan, L.B. Alava, I.O. Tiro, Jr., G. Potestas, A. Taleon and J.N. Paw (1986), *Shrimp Culture: Pond Design, Operation and Management, NACA Training Manual Series No. 2,* Rome: FAO Corporate Document Repository.

Kusmana, C. (2011), Forest resources and forestry in Indonesia. *Forest Science and Technology,* 7(4), 155-160, http://dx.doi.org/10.1080/21580103.2011.625241.

Lemonnier, H., E. Bernard, E. Boglio, C. Goarant and J-C. Cochard (2004), Influence of sediment characteristics on shrimp physiology: pH as principal effect, *Aquaculture,* 240, 297-312, http://dx.doi.org/10.1016/j.aquaculture.2004.07.001

Malczewski J. (2006), GIS-based multicriteria decision analysis : a survey of literature, *International Journal of Geographic Informaton Science,* 20(7), 703-726, http://dx.doi.org/10.1080/13658810600661508

Mendas, A. and A. Delali (2012), Integration of multi criteria decision analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. *Computers and Electronics in Agriculture,* 83, 117-126, http://dx.doi.org/10.1016/j.compag.2012.02.003

Miller, R.L., C.E. Del Castillo and B.A. McKee (2005), *Remote Sensing of Coastal Aquatic Environments.* Springer, Dordrecht, http://dx.doi.org/10.1007/978-1-4020-3100-7.

Ministry of Marine and Fisheries (2012), *Strategic Planning 2010-2014*, Indonesian Ministry of Marine and Fisheries. Jakarta.

National Geographic Indonesia (2015), *Latest: Long Coastline Indonesia Reaches 99 000 Kilometers,* http://nationalgeographic.co.id/berita/2013/10/terbaru-panjang-garis-pantai-indonesia-capai-99000-kilometer

New, M. B. (2002), *Freshwater prawn farming, a manual* *for the culture of Macrobrachium rosenbergii, FAO Fisheries Technical Paper 428*, Rome: Food and Agriculture Organization of the United Nations.

Nimrat, S., S. Suksawat, P. Maleeweach and V. Vuthiphandchai (2008), Effect of different shrimp pond bottom soil treatments on the change of physical characteristics and pathogenic bacteria in pond bottom soil, *Aquaculture*, 285, 123-129, http://dx.doi.org/10.1016/j.aquaculture.2008.08.020

Osly, P.J., Widiatmaka, B. Pramudya and K. Gandasasmita (2014), Land use optimization for sugarcane plantations in Eastern Seram District, Indonesia, *Journal of Developments in Sustainable Agriculture,* 9, 89-96.

Paez-Osuna, F. (2001), The environmental impact of shrimp aquaculture: causes, effects and mitigating alternatives, *Environmental Management,* 28, 131-140, http://dx.doi.org/10.1007/s002670010212.

Rahman, M.M., J.V. Paatero and R. Lahdelma (2013), Evaluation of choices for sustainable rural electrification in developing countries: A multi criteria approach, *Energy Policy,* 59, 589-599, http://dx.doi.org/10.1016/j.enpol.2013.04.017.

Regional Government of Tuban Regency (2014), *Land Carrying Capacity of Tuban Regency, Repport of Collaboration Study of Government of Tuban Regency with Bogor Agricultural University, Tuban*: Regional Government of Tuban Regency (in Indonesian)

Rikalovic, A., J. Cosic and D. Lazarevic (2014), GIS based multi criteria analysis for industrial site selection, 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013, *Procedia Engineering, 6*9, 1054-1063, http://dx.doi.org/10.1016/j.proeng.2014.03.090

Ritvo, G., Y. Avnimelech and M. Kochba (2003), Empirical relationship between conventionally determined pH and in situ values in waterlogged soils, *Aquacultural Engineering,* 27, 1-8, http://dx.doi.org/10.1016/S0144-8609(02)00040-7.

Ritvo, G., J.B. Dixon, T.M. Samocha, A.L. Lawrence and W.H. Neill (1998a), Low-cost experimental unit and growth medium for testing soil effects on shrimp culture, *Aquacultural Engineering,* 18, 245-249, http://dx.doi.org/10.1016/S0144-8609(98)00036-3

Rossiter, D.G. (1996), A theoretical framework for land evaluation: discussion paper, *Geoderma,* 72(1-2), 165-190, http://dx.doi.org/10.1016/0016-7061(96)00031-6

Rosso, M., M. Bottero, S. Pomarico, S. La Ferlita and E. Comino (2014), Integrating multi criteria evaluation and stakeholders analysis for assessing hydropower projects, *Energy Policy,* 67, 870-881, http://dx.doi.org/10.1016/j.enpol.2013.12.007.

Ruiz-Fernandez, A.C. and F. Paez-Osuna (2004), Comparative survey of the influent and effluent water quality of shrimp ponds on Mexican farms, *Water Environment Research,* 76, 5-14, http://dx.doi.org/10.2175/106143004X141528.

Ryan, M.J. (1998), Multiple criteria and framing of decisions, *Journal of Information and Optimization Sciences,* 19(1), 25-42, http://dx.doi.org/10.1080/02522667.1998.10699359.

Saaty, T.L. (1988), *The Analytic Hierarchy Process. Suffolk:* Typesetters Ltd., Becceles, http://dx.doi.org/10.1007/978-3-642-83555-1_5.

Sachikonye, L. (2005), *The land is the economy, African Security Review*, 14(3), 31-44, http://dx.doi.org/10.1080/10246029.2005.9627368.

Sarkar, A., A. Ghosh and P. Banik (2014), Multi-criteria land evaluation for suitability analysis of wheat: a case study of a watershed in eastern plateau region, India, *Geo-spatial Information Science,* 17(2), 119-128, http://dx.doi.org/10.1080/10095020.2013.774106

Situmorang, R.L., R. Smit and E.J. van Vessem (1992), *Geological map of Jatirogo sheet, Scale 1:100.000, Bandung:* Geological Center for Research and Development.

Store, R. and J. Jokimaki (2003), A GIS-based multi-scale approach to habitat suitability modeling, *Ecological Modelling.* 169, 1–15, http://dx.doi.org/10.1016/S0304-3800(03)00203-5.

Store, R. (2009), Sustainable locating of different forest uses, *Land Use Policy* 26, 610–618, http://dx.doi.org/10.1016/j.landusepol.2008.08.013.

Tammi, I. and R. Kalliola (2014), Spatial MCDA in marine planning: Experiences from the Mediterranean and Baltic Seas, *Marine Policy,* 48, 73–83, http://dx.doi.org/10.1016/j.marpol.2014.03.015.

Tan, K.H. (2002), *Soil Sampling, Preparation and Analysis,* New York: Marcel Dekker.

Teneorio, G.S., P.W.M. Souza-Filho, E.M.L.S. Ramos and P.J.O. Alves (2015), Mangrove shrimp farm mapping and productivity on the Brazilian Amazon coast: Environmental and economic reasons for coastal conservation, *Ocean and Coastal Management,* 104, 65-77, http://dx.doi.org/10.1016/j.ocecoaman.2014.12.006.

Triantaphyllou, E. and S.H. Mann (1995), Using the analytic hierarchy process for decision making in engineering applications: some challenges. *International Journal of Industrial Engineering: Applications and Practice,* 2 (1), 35–44.

Vreeker, R., P. Nijkamp and C.T. Welle (2002), A multi criteria decision support methodology for evaluation airport expansion plan. *Transportation Research,* Part D7, 27-47, http://dx.doi.org/10.1016/S0969-6997(01)00005-9.

Widiatmaka, W. Ambarwulan, B. Riadi, I. Nahib, S. Budhiman and A. Halim (2014a), Spatial multi criteria land evaluation and remote sensing for area delineation of shrimp pond culture revitalization in Mahakam Delta, Indonesia, *Proceeding of the 12th Biennial Conference of Pan Ocean Remote Sensing Conference (PORSEC 2014) 04 – 07 November 2014*

(Pp. 839-847), Bali-Indonesia.

Widiatmaka, A. Sutandi, I. Anas, U. Daras, M. Hikmat and A. Krisnohadi (2014b), Establishing land suitability criteria for cashew (*Anacardium occidentale L.*) in Indonesia, *Journal of Applied and Environmental Soil Science,* 2014, 1-14, http://dx.doi.org/10.1155/2014/743194

Widiatmaka, W. Ambarwulan, M.Y.J. Purwanto, Y. Setiawan and H. Effendi. (2015), Land capability based-environmental carrying capacity in Tuban, East Java, *Jurnal Manusia dan Lingkungan,* 22(2), 247-259 (in Indonesian).

Wiradisastra, U.S., Widiatmaka, M. Ardiansyah and K. Nirmala (2004), *Suitability of marine culture*, Jakarta: Center for Survey of Marine Resources, Geospatial Information Agency.

World Commission on Environment and Development (WCED) (1987), *Our Common Future,* New York: Oxford University Press.

Xu, X., H. Peng, Q. Xu, H. Xiao and G. Benoit (2009), Land changes and conflicts coordination in coastal urbanization: a case study of the Shandong Peninsula in China. *Coastal Management,* 37(1), 54-69, http://dx.doi.org/10.1080/08920750802612788.

Zavadskas, E.K., A. Kaklauskas, S. Raslanas and V. Malienė (2001), The application of multicriterion methods for valuation of recreation property, *Statyba,* 7(4), 327-333, http://dx.doi.org/10.1080/13921525.2001.10531744.