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Land Suitability Analysis of Tiger Shrimp Aquaculture (*Penaeusmonodon.* Fab) in the Coastal Area of Labakkang District South Sulawesi - Indonesia

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Abstract

The coastal area of Labakkang District has a wide brackish water pond, but its productivity is relatively low. A research to determine land suitability as one of the brackish water pond productivity raising project is needed. Considerable factors in determining land suitability for shrimp aquaculture covers topography and hydrology, soil conditions, water quality and climate. Quality of water is observed during rainy and dry season. Spatial analysis using Geographic Information System is applied in the determination of land suitability for shrimp aquaculture. Results of the analysis reveal that within an area of 4,986 ha of brackish water pond in Labakkang District, there are 1,059 ha classified as highly suitable (class S1), 2,676 ha of pond is moderately suitable (class S2), 1,151 ha of pond is marginally suitable (class S3) and 102.7 ha is not suitable (class N) during rainy season, while during dry season there are 10.26 ha classified as S1, 3,591 ha classified as S2, 225,97 ha classified as S3 and 360.9 ha classified as class N. Delimitation factors during rainy season is flood, while salinity is the main limiting factor during dry season. Generally, other limiting factors are country mile of the water sources, low level of pH soil and roughness of soil texture in certain area.

Keywords: Brackishwater ponds; Shrimp; Land suitability; Coastal; Labakkang district

Introduction

One of the business activities in fisheries aquaculture in Indonesia is shrimp aquaculture. Shrimp aquaculture is a kind of business by cultivating coastal area in which it contributes to coastal community's income, vocation provider and potential foreign exchange earnings. South Sulawesi Province is one of the centers for shrimp aquaculture production and it has 104,240 ha of brackishwater pond or 21.27% by the total of brackishwater pond in Indonesia. However, it only nationally contributes 600,241.00 tons or 40.1 % of total production of shrimp aquaculture in Indonesia in 2011[1].

The use of land for shrimp cultivation in the Labakkang District reached 4,986 ha, with production in 2006 reached 4,592.2 tons and production value reached about 62 billion rupiahs, while the commonly cultivated commodities in ponds are shrimp (*Penaeusmonodon*) and milk fish (*Chanoschanos*) [1].

Land suitability is the degree of suitability of an area of land for a specific use, such as for shrimp aquaculture in ponds. Land suitability analysis for brackishwater pond needs to be counducted for the principle of consideration in the decision of the suitable land use. Based on Rossiter [2] land suitability analysis is very important because land has varied physical, social, economical, and geographical values which are influential for the land use.

Land suitability analysis is a process of estimating variability of land whenever it is used for a specific purpose [3] or as a method to explain or to predict the potential use of land [4]. If the potential of the land can be determined, then the land use planning can be based on rational considerations [5]. Thus, land suitability analysis is a strategic planning tool of land use that can predict the expected benefits and constraints of productive land use and environmental degradation that might occur due to the use of land. Land suitability is a key to success in aquaculture activities that affect the success and sustainability [6]. Therefore, the research aims to determine the suitability of land for shrimp farming in ponds and the limiting factors to increase productivity and sustainability and to provide a general reference for policy makers in the determination of theRegional Spatial Layout Plan.

Material and Method

Time and location of research

The study was conducted from January to September 2012 in the coastal farming areas of Labakkang District, and aims to know the level of suitability of land for shrimp farming in ponds.

Data collection

Primary data include the biophysical data: tide, soil condition and water quality. Tidal measurement was carried out for 39 hours with 1 hour interval. Measurement results were corrected by referring to tidal data from Biringkassi Station (119o23'00" BT, 4o51'37" LS), Labakkang District [7].

Determination of points was based on soil sampling map unit. Total sampling points are 116 points. Soil quality variables measured directly in the field is pHF (soil pH) with a pH-meter [8] and pHFOX (pH ground after oxidized with hydrogen peroxide (H2O2) 30%) with a pH-meter [8]. Soil quality variables analyzed in the laboratory includes organic materials using ignition loss method [9], pyrite [8,10-12]. Fe using atomic absorption spectrophotometer (AAS), Al using AAS, PO4 using Olsen or Bray 1 method [13] and texture using hydrometer method [14,15].

Measurement and water sampling follows soil sampling point, in the dry season and the rainy season as much as 116 points. Water quality variables measured directly in the field are the temperature, salinity,

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dissolved oxygen and pH by using Hydrolab® Minisonde. Water samples were taken for laboratory analysis using Kmerer Water Sampler and preserved by following the instructions of [15]. Water quality variables which were analyzed in the Laboratory incudes: NH_4, NO_3, NO_2, SO_4, Fe and total suspended solid by following the instructions of [15-17]. The whole observation points and sampling points are determined by its coordinate point using Global Positioning System (GPS).

Secondary data were collected through a search of the various reports, literatures and research results of various related agencies. Maps collected include soil type map 1:250,000 scale, map of Coastal Administration of Labakkang District 1:200,000 scale and Annual Rainfall map of South Sulawesi province. Secondary data are basically classified into two groups: spatial data in the form of maps and attribute data in the form of texts or tables.

Data analysis

Flow chart showing determination of land suitability for aquaculture can be seen in Figure 1. The used Land Use Map is manufactured by Citra SPOT-4 2010 acquisition of July 17, 2010 with Er Mapper 7.1 Program which is integrated with a base map of the Indonesian Topographic map sheet Pangkajene. The Land Use Map is unified with Land Form map to get Unit Map to be used as a reference for field survey in determining sampling points. Other spatial information derived from primary to secondary data is also integrated with land use maps.

Primary data, secondary and land use maps were collected, data processing is then performed using spatial analysis in Geographic Information Systems (GIS) [18]. Analysis process using ArcView 3.3 program is performed by entering each variable data to produce thematic maps for each of the data variables. Total weight of each variable data is obtained by multiplying the value of each variable with their relative weights.

Land suitability assessment process results are shown in the form of land suitability classification system set to Class and Sub-class (scale 1:50,000). In the Class category, they are: (a) Highly suitable class (S1): This field does not have a limiting factors for the sustainable use of land; (b) Moderately suitable (S2): This land has rather significant limiting factors for the sustainable use which can reduce productivity;

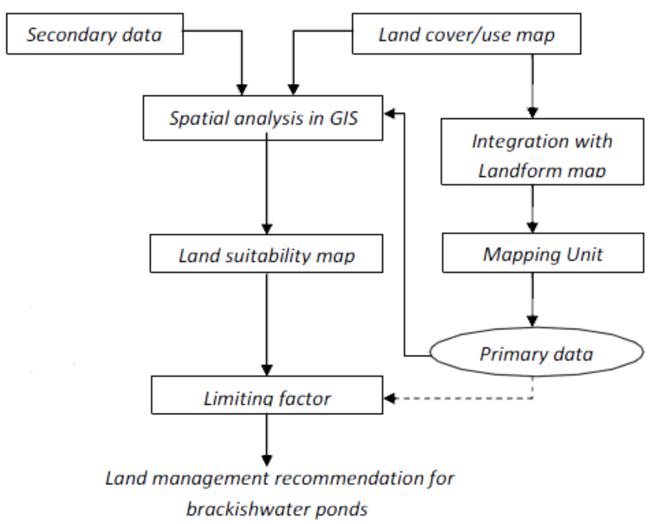

Figure 1: Flow chart of spatial analysis to determine land suitability for brackish water ponds.

and (c) Marginally suitable (S3): this land has severe limiting factors for sustainable use and they will reduce productivity, and (d) Not suitable class (N): this land has limiting factors that may preclude the possibility of its utilization.

Result and Discussion

Biophysical characteristics

Conducted land suitability analysis is a qualitative analysis based solely on the physical potential of the land. Therefore, the biophysical characteristics of the farming areas in Labakkang District which are also being the common factors considered in the analysis of land suitability include: topography and hydrology; soil condition; water quality and climate [19-23].

Topography and hydrology

Slope can affect the charging ability of the land and changing of the water of ponds, especially traditionally managed ponds (extensively) and intermediate (semi-intensive). Aquaculture area Labakkang District is generally considered as flat with a slope of less than 0.02% and highly suitable for aquaculture. Fernando and Chanratchakool suggested a good slope land for aquaculture is relatively flat [22,24].

Distance from the water source to the pond water conditions is also determined by the slope, elevation and tidal difference. Those factors have influence on the quantity and quality of water. Thus, it was found so many farms in Labakkang District that is low in productivity due to the distance away from the water source. In this case, areas which are far from water sources belongs to the class S3 and class N. Ponds with far distance are not only get inadequate water quality but also get insufficient water in terms of quantity.

Tidal range measured in January 2012 in Labakkang District was 1.75 m. Calculation results of Tidal Table [7] showed that the average tidal range is 1.53 m. Tidal range ideal for shrimp aquaculture is between 1.5 and 2.5 m. Thus the tidal range in Labakkang District is classified as highly suitable for aquaculture.

Flood is one of the causes of yield loss in the pond. Flood in the farm areas usually occurs during the rainy season and high tide occurrence. Based on the criteria suggested by Boyd CE regional aquaculture of Labakkang District is considered to have rare flood (20 year cycle).

Soil condition

Analyzed soil conditions in the determination of land suitability for aquaculture include soil quality. For shrimp aquaculture ponds, required water depth is approximately 1.0-1.2 m. In Labakkang District, relatively narrow stretch of rock is only found in the village of Bontomanai. Thus, the depth of the soil is highly suitable for aquaculture.

Pyrite (FeS_2) is a compound that its content is high in acid sulfate soil, if pyrite is exposed to air due to excavated pond, it will cause the oxidation of pyrite and drastically decrease soil pH and increased solubility of toxic elements and causes the low productivity of farms [25]. Because the ponds in Labakkang District are generally considered as non-acid sulfate soil, the content of pyrite is relatively low that is from undetected to 1.19% with an average of 0.15% (Table 1). Therefore, the presence of pyrite in the pond Labakkang District is not a serious problem.

Peat soil is soil that contains organic materials more than 20% or more than 30% (soil contains clay ≤ 60%). Similar with the presence of pyrite in the pond, peat soil is only found in nine stations among 116

Variables	Minimum	Maximum	Average	Standard deviation
pH_F	3.08	7.79	6.68	0.69
pHFOX	0.6	7	4.82	1.58
pH_F-pH_{FOX}	1.27	6.37	1.8	1.51
Organic matter (%)	0.3	20.55	6.2	5.89
Pyrite (%)	< 0.01	1.19	0.15	0.31
Fe (ppm)	< 0.01	10.36	1.29	2.69
Al (ppm)	< 0.01	779	123	181.11
PO_4 (ppm)	0.27	8.26	2.05	1.65
Texture*	C, SiC, SC, SCL, Si, L, SL, LS, S			

* : C = Clay, SiC = Silty clay , SC = Sandy clay, SiCL = Silty clay loam, SCL = Sandy clay loam, Si =Silt, L = Loam, SL = Sandy loam, LS = Loamy sand, S = Sand

Table 1: Soil quality of brackishwater ponds at different soil depth of Labakkang Regency, South Sulawesi Province (n = 116).

Variables	Minimum	Maximum	Average	Standard deviation
Temperature (°C)	26.9	35.1	29.28	2.36
Salinity (ppt)	3.5	70	36,5	22.1
Dissolved oxygen (mg/L)	2.02	14	8.01	2.46
pH	8	9.5	8.75	0.34
NH_4 (mg/L)	0.228	0.418	0.32	0.0945
NO_3 (mg/L)	0.0017	1.7858	0.921	0.7151
NO_2 (mg/L)	0.0005	0.2589	0.0169	0.041
PO_4 (mg/L)	0.0002	0.206	0.0169	0.0412
SO_4 (mg/L)	9.44	916.98	86.22	149.41
Fe (mg/L)	0.0136	0.3727	0.0826	0.0635
Total suspended solid (mg/L)	18	263	66	52

Table 2: Water quality in brackishwater ponds area of Labakkang Regency, South Sulawesi Province in the dry season (n = 116).

Variables	Minimum	Maximum	Average	Standard deviation
Temperature (°C)	26	34.05	30.1	2.27
Salinity (ppt)	0	45	18	12.32
Dissolved oxygen (mg/L)	2.02	14	8.01	3.36
pH	8	9.5	8.75	0.49
NH_4 (mg/L)	0.0015	0.8372	0.1079	0.1639
NO_3 (mg/L)	0.546	4.7098	1.0399	0.7168
NO_2 (mg/L)	0.0001	0.0732	0.0073	0.0119
PO_4 (mg/L)	0.0016	0.7969	0.1082	0.169
SO_4 (mg/L)	9.07	99.5	52.24	19.37
Total suspended solid (mg/L)	13	108	57	23

Table 3: Water quality in brackishwater ponds area of Labakkang Regency, South Sulawesi Province in the rainy season (n = 116).

stations and found in the area that was once a mangrove forest which is generally not a problem for the ponds aquaculture.

Measured soil pHs in the ponds are pHF and pHFOX which are typical of acid sulfate soil variables [26,27]. pHF calculation results of the ponds showed values between 3.08 and 7.79 with an average of 6.68 (Table 1). Low value of soil pHF is only found in acid sulfate soil ponds by which it can be a limiting factor in ponds aquaculture (belongs to the class S3). Pond soil with a pH between 6.5 and 8.5 were classified by Karthik as slight because the soil pH value is quite good and very easy to overcome the barriers. Then Gomez E stated that the optimum soil pH for shrimp farming in ponds is between 7.5 and 8.3. The residual of pHF and pHFOX (pHF-pHFOX) can be used to determine the potential of acid sulfate soil acidity and it is found that the potential acid sulphate soil acidity in ponds is relatively low (Table 1) [28].

Organic materials in the pond can affect the stability of the soil, oxygen consumption, sources of nutrients and habitat suitability of pond bottom [29]. Surface of mineral soil used for agriculture rarely contains 5-6% organic materials and in the tropic and sub-tropic area, its organic material content is usually lower [30]. In high clay contained soil (greater 60%), [19] defined organic material content of less than 8% classified as slight that is good and easy to overcome the limiting factors for aquaculture. The organic content of ponds in Labakkang District ranges from 0.35 to 20.55% with an average of 6.20% (Table 1).

Phosphate is an essential element as a source of energy in life. On aquatic systems, phosphorus is an essential element for primary production [19]. Phosphate availability of over 60 ppm in the pond soil can be categorized as slight or good with very easily solved limiting factors [27]. In ponds of Labakkang District, it is found that the average phosphate content is 2.05 ppm, so the actual farm land suitability is considered as not suitable with the limiting factors of soil fertility (class N). However, the potential suitability of land can be turned into a highly suitable land by the use of fertilizer containing phosphate.

Fe content of farm land in the Labakkang District ranges from undetected by < 0.01 up to 10.36 ppm with an average of 1.29 ppm. The content of Al ranges from undetected by < 0.01 to 758 ppm with an average of 127 ppm.

Pond soil texture and porosity highly affects the growth of algae that live in the bottom of pond which belongs to the source of food for fish and shrimp. Ponds with coarse-textured soil have a high level of porosity which cause the pond cannot restrain the water in it. Soil in the pond is commonly found to have fine texture such as clay, dusty clay and sandy clay with clay content of at least 20-30% to resist permeation [19]. Best texture of soil for pond is soil that contains clay, sandy clay, sandy clay loam and dusty clay. It is found nine classes of soil texture on the ponds soil surface of Labakkang District, that are: clay, dusty clay, sandy clay, sandy clay loam, dirt, loam, sandy clay, argillaceous sand and sand. Such soil texture can be classified as not porous and can restrain the water.

Water Quality

Because commodities cultivated in the ponds are living in the water, water quality is a deciding factor of the success. The quality of water is good if water can support life aquatic organisms and food remains at every stage of maintenance. Water quality variables that are important for shrimp farming is temperature, dissolved oxygen, salinity, pH, brightness, NH_4, NO_2, NO_3, PO_4 and total suspended solids [31]. Water quality in the Labakkang District during the dry season can be seen in Table 2 and during the rainy season is in Table 3.

Water temperature in the area of aquaculture in Labakkang District ranges between 26.00 and 34.05°C with an average of 29.28°C during the dry season and ranges between 26.90 and 35.10°C with an average of 30.10°C during the rainy season. Proper water temperature for tiger shrimp ranges between 26 and 32°C and the optimum is between 29 and 30°C [32]. At a temperature of 26-30°C, the growth of black tiger shrimp is relatively high and it has relatively high survival rate [33,34]. Water temperature in the area of aquaculture in Labakkang District is quite suitable and highly suitable for aquaculture.

Water salinity in the aquaculture areas in Labakkang District ranges between 3.5 ppt and 70.0 ppt with an average of 36.5 ppt in the dry season and between 0 and 45.0 ppt with an average of 18.0 ppt during the rainy season. Tiger shrimp, a euryhaline organism, needs well maintained optimum salinity for its growth [34]. Tiger shrimp can adapt to 3-45 ppt salinity, but its salinity necessity for optimum growth is 15-25 ppt [34]. It is seen that the salinity during dry season can be a limiting factor in aquaculture, but it does not cause significant problems during rainy season.

Dissolved oxygen is essential for respiration and is one of the main components in aquatic metabolism. Dissolved oxygen content in the pond of Labakkang District ranges between 2.74 and 13.55 mg/L with an average of 8.14 mg/L during dry season and ranges between 2.02 and 14.00 mg/L with an average of 8.01 mg/L in during rainy season. Minimum dissolved oxygen requirement for shrimp is 2 mg/L [34]. Dissolved oxygen limit for shrimp is 3-10 mg/L and its optimum is 4-7 mg/L [35] Limit of pH tolerance for aquatic organisms are affected by temperature, dissolved oxygen, alkalinity and the presence of anions and cations as well as the type and stage of the organism. The pH range for shrimp is 8.0 to 8.5 and its optimum range is 7.5 to 8.7 [31]. Water pH in the ponds of Labakkang District is relatively high that ranges between 8.00 and 9.50 with an average of 8.75 (Table 2). Soil acidity sources such as pyrites and peat are rarely found in the ponds of Labakkang District which causes a high level of water pH. Hence, this pH level is highly suitable for ponds aquaculture.

Sources of nitrogen that can be used directly by aquatic plants are nitrate (NO_3), ammonium (NH_4) and nitrogen gas (N_2). Nitrate is the main form of nitrogen in natural water and being a major nutrient for plant and algae growth. Nitrate is not toxic for aquatic organisms. NO_3 content in ponds water in Labakkang District ranges from 0.5460 Labakkang District to 4.7098 mg/L with an average of 1.0399 mg/L during rainy season and turning higher during dry season ranges from 0.0017 to 1.7858 mg/L with average of 0.9210 mg/L. It is known that nitrogen oxides in the form of NO_3 contained in the atmosphere and fall to the earth within rain water which contributes to the high content of NO_3 into the water during rainy season. Rainwater contains NO_3 around 0.2 mg/L [36,37].

Nitrite (NO_3) is a transition between NH_3 and NO_3 (nitrification) and between NO_3 and N_2 (de-nitrification).Similarly with NH_3, NO_2 is also toxic for fish, because it oxidizes iron (Fe) in hemoglobin. In this transition form, blood's ability to bind dissolved oxygen is very degenerate [38]. On the shrimp's body which blood contains copper (Cu) (hemocyanin) Cu oxidation may occur by the help of NO and it gives the same result as in fish's body [39]. Content of NO_2 in the ponds water of Labakkang District ranges from 0.0005 mg/L to 0.2589 mg/L with an average of 0.0174 mg/L during dry season and 0.0001 and 0.0732 mg/L with an average of 0, 0073 mg/L during rainy season. Content of NO_2 in the waters are relatively small because it is oxidized to nitrate immediately. Natural water contains NO_2 around 0.001 mg/L and it should not exceed 0.060 mg/L [37]. In waters, the content of NO_2 rarely exceeds 1 mg/L [40]. Content of NO_2 which is greater than 0.05 mg/L can be toxic to highly sensitive aquatic organisms [41]. On the average, the content of NO_2in pond water is still within the limits allowed for aquaculture, but it is found that the content of NO_2 still exceeds 0.060 mg/L.

Phosphorus plays a role in the transfer of energy within cells, such as those contained in Adenosine Triphosphate (ATP) and Adenosine Diphosphate (ADP). Phosphate (PO_4) is a form of phosphorus that can be utilized by plants. Content of PO_4in pond water of Labakkang District ranges from between 0.0002 to 0.2060 mg/L with an average of 0.0169 mg/L during dry season and 0.0016 and 0.7969 mg/L with an average of 0.1082 mg/L during rainy season. Content of PO_4 in natural waters is rarely exceed 1 mg/L [19].

Average total suspended solid in the water of Labakkang District's aquaculture is 66 mg/L during dry season and 57 mg/L during rainy season. Based on the criteria of [42], the use of the deposition swath critical is needed to reduce the total suspended solids in the water ponds in Labakkang District.

Climate

Rainfall in the Labakkang District ponds ranges from 1,117 to 4,824 mm/year with an average of 2,539 mm/year. Rainfall is highly suitable for aquaculture. Rainfall between 2000-3000 mm/year with a 2-3 month dry season is good enough for the pond. Pond preparation is one of the activities that must be performed prior to seeding. At the preparation phase, ponds are dried up to reform the physical nature of the soil, to upgrade its organical mineralization, and to decompress its toxic such as hydrogen sulfide (H_2S), amonia(NH_3) and methane (CH_4). Drying up the ponds is performed during dry months (Figure 2) in order to bring the drying process perfect. Temperature in the coastal Labakkang District ranges from 23 to 32°C [43] For ponds that are located far from the water sources, rain water can be a source of fresh water to reduce the salinity of the water, by which water salinity can be a limiting factor (which belongs to class S3, and class N) for the ponds during dry season and become problematic during rainy season. However, heavy rainfall during rainy season can also be a limiting factor (belongs to class S3 and class N).

Land suitability for aquaculture pond

The results showed that of the total ponds in Labakkang District, there are 1,059 ha 4,986 ha ponds classified as highly suitable (S1-class), 2,676 ha of ponds is moderately suitable (S2 class), 1,151 ha of ponds classified as marginally suitable (class S3) and 102.7 ha classified as not suitable (class N) for aquaculture in the rainy season (Figure 3). As a major limiting factor of ponds suitability during rainy season is the high water discharge resulting decline in water salinity up to 0 per mil.

In the dry season, the actual land suitability of Labakkang District shows that 10.26 ha is classified as highly suitable (S1-class), 3,591 ha is moderately suitable (S2 class), 225.97 ha is classified as marginally suitable (class S3) and 360.9 ha is classified not suitable (grade N) (Figure 4). High salinity is a major limiting factor of aquaculture during the dry season. The needs of fresh water is high enough during dry season, the use of boreholes can be used to address the need for fresh water, but can cause problems that the sea water intrusion jutting inland.

Other major limiting factors of aquaculture in Labakkang District

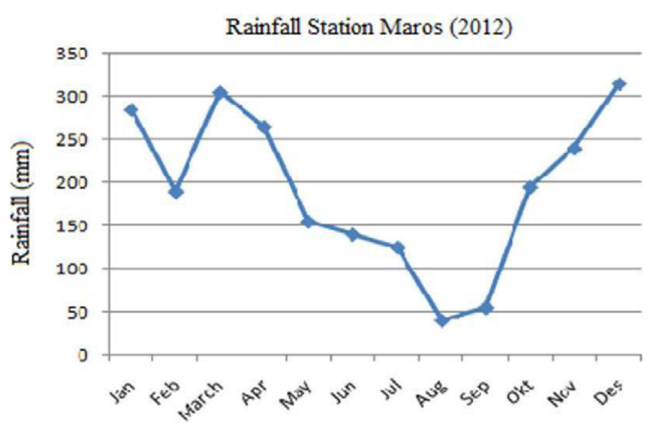

Figure 2: Monthly rainfall in the coastal area of Labakkang Regency, South Sulawesi Province.

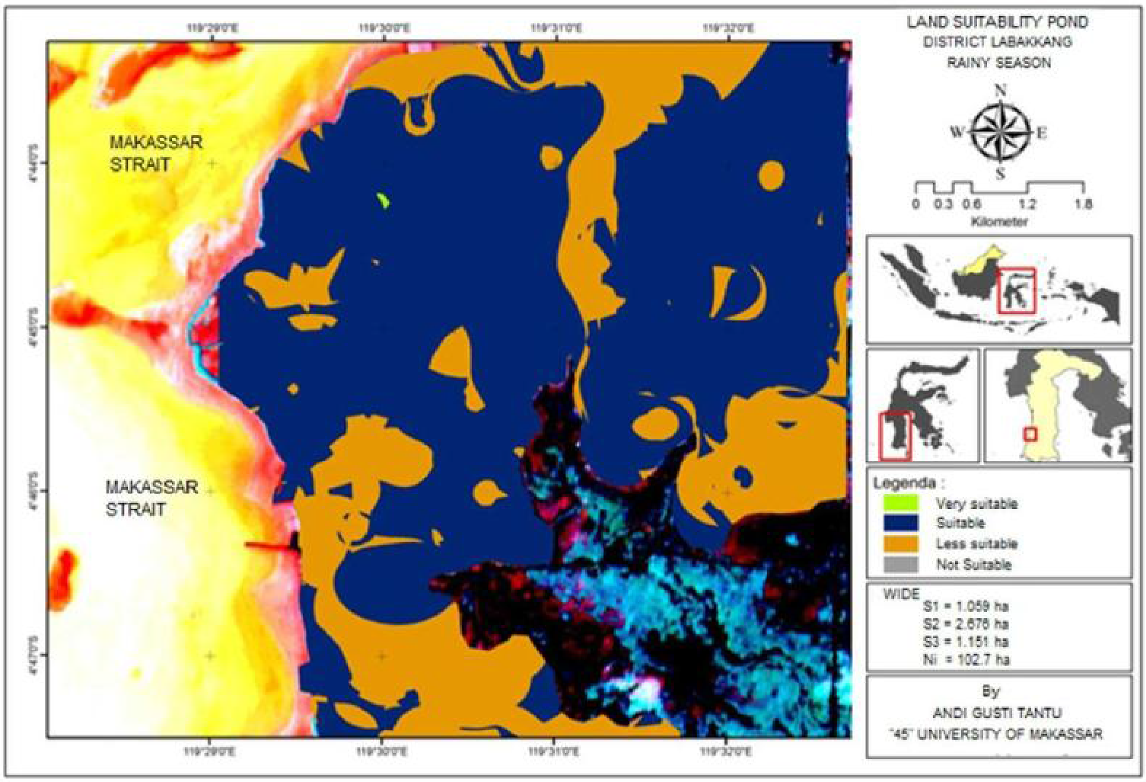

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Figure 3: Land suitability map for brackishwater ponds in the rainy season of Labakkang District, South Sulawesi Province.

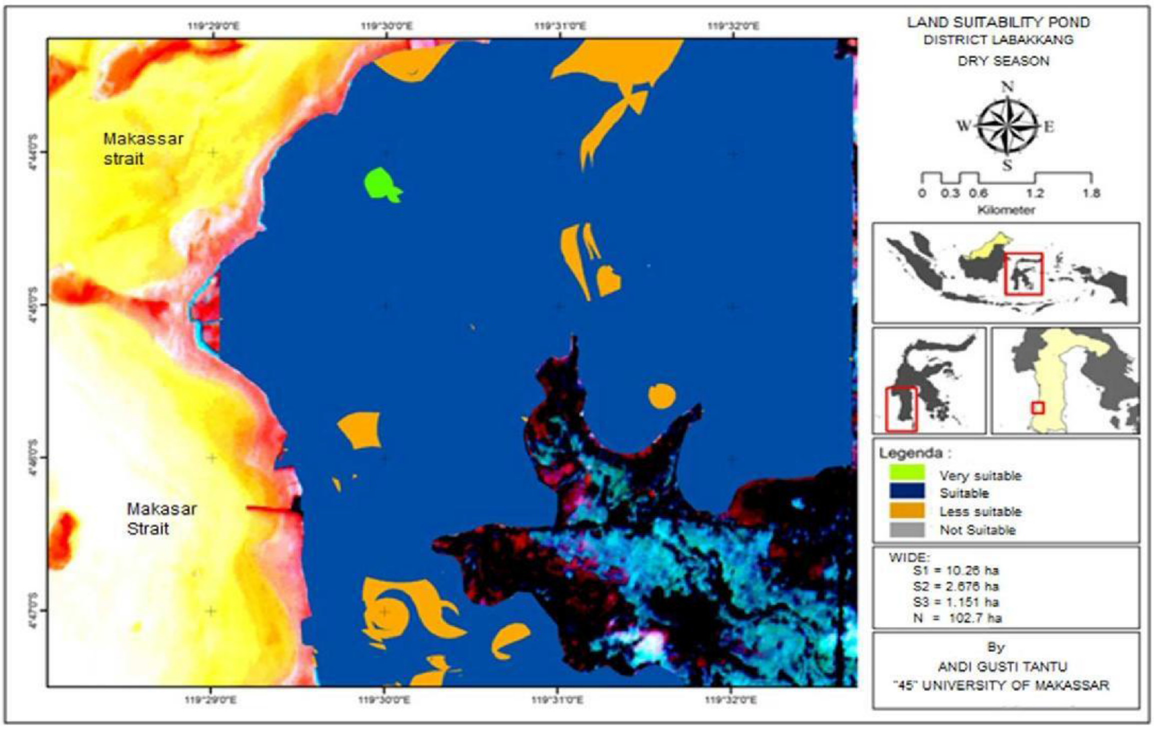

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Figure 4: Land suitability map for brackishwater ponds in the dry season of Labakkang District, South Sulawesi Province.

are the far distance of the water source and the less fertility of soil in the land, relatively low soil pH and the rough soil texture on certain areas. Lack of soil fertility in Labakkang District ponds can be overcome through fertilization, but fertilization will be more effective if the soil pH is increased through remediation process for areas with low pH level. Fertilizer containing phosphorus is not effective if the soil pH is low, because it is bound by Fe and Al of the soil Coarse-textured soils can be a limiting factor and soil texture "fixing" technology is very difficult and very expensive [44]. Another effort can be done is assembling bamboo stub on the ponds' embankment slope and ponds' water channels. For the coarse base soil, manure can be given especially to the areas with low level of organic contents under the expectation that its ponds' base soil structure will be improved.

Thus, the actual suitability of land in the rainy season and the dry season could turn into a potential land suitability where certain areas that belong to the class of S1 turns to S2, and class S3 turns to be class S2 and class N turns to class S3 after managing the ponds which are managed by its limiting factors.

Conclusion and Suggestion

From the total ponds of Labakkang District, 1.059 ha, it is 1.059 ha which is highly suitable (class S1), 2.676 ha of pond which is moderately suitable (class S2), 1.151 ha is marginally suitable (class S3) and 102,7 ha is not suitable (class N) during rainy season based on the actual land suitability for pond aquaculture. In the dry season, the actual land suitability of Labakkang District indicates that 10.26 ha classified as highly suitable (S1-class), 3.591 ha is moderately suitable (class S2), 225.97 ha is classified as marginally suitable (class S3) and 360,9 ha is classified as not suitable (class N).

As a major limiting factor of suitability in the Labakkang District during the rainy season is flood, while the salinity is the main limiting factor during the dry season. Other limiting factors in general are the far distance of the source water, relatively low fertility of soil, low soil pH and rough texture of soil in some places.

It is also needs good planting pattern arrangement, water channel activation, and pumping efforts related to high water salinity during dry season and far distance of water source. Low fertility can be overcome by fertilization and the low pH by remediation. The use of clay as a core of embankment is needed in the "biocrete" technology for pond embankment with rough texture.

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