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RESEARCH ARTICLE

DEVELOPMENT OF SUSTAINABLE SHRIMP FARMING BASED ON LAND SUITABILITY AND COASTAL WATERS CARRYING CAPACITY

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Abstract

This research aims to examine the opportunities for developing a sustainable shrimp farming according to the carrying capacity of the waters. It explores the suitability of coastal land, and assess the carrying capacity of the coastal waters for shrimp farming. The suitability analysis method used the Geographic Information System (GIS) based on the physical-chemical spatial data of the waters. Analysis of the carrying capacity of the environment was based on the total volume of sea water and the capacity of available dissolved oxygen in the waters. The overall result of the study indicated that the entire farming area in Pasangkayu Regency was of 3,965.76 ha, comprising of 732.95 Ha of a highly suitable land, 2,984.98 Ha of a suitable land, and 247.83 Ha of a conditionally suitable land. With regard to the water carrying capacity to accommodate organic waste and for keeping the development of shrimp farming sustainable, the area for intensive farming was much smaller than that for semi-intensive and traditional farming.

Introduction:-

Shrimp has become one of the leading export commodities of Indonesia. In Pasangkayu Regency, it is the second greatest commodity after palm oil products which has been decreasing lately. The management of shrimp farming in the coastal area of Pasangkayu Regency only reaches 13.13 percent of its potential, despite having been able to maintain and balance the negative decline in the contribution of plantation as a sub-sector in regional economic growth in 2016 Therefore, the potential of shrimp farming needs to be optimized through strategic policies and plans allowing a large and broad impact, to improve the production of high-value export commodities, and to the fisheries as a sub-sector a new locomotive in boosting economic growth in the Pasangkayu Regency.

According to (Hossain et al., 2013) one of the fisheries and aquaculture sectors contributing greatly is shrimp farming. (Fao, 2012) claims that half of fish consumption in 2018 was supplied by aquaculture business. According to some reports (Asia, 2006; FAO., 2004; Barbier & Cox, 2002), farming has become a reliable source of meeting the world's seafood needs.

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The development of farm fishery commodities must consider the economic aspects, including the potential for strong market demand and high selling prices, in both the domestic and international markets. It is expected to be produced at a reasonable cost and to provide opportunities for value added products (Anderson, 2007). B. Widigdo (2013) explains that maximizing short-term economic benefits without considering ecological support would only result in an environmental degradation and an ecological crisis.

Indonesia especially in Java has a negative experience with the development of shrimp farming, pursuing high production without paying much attention to the carrying capacity of the environment, consequently leading to rapid environmental degradation and failure of aquaculture (in 1990). Development of shrimp farming is generally conducted using an intensive farming scale. Ecological changes in the ponds will affect the carrying capacity of the entire environment which will ultimately affect the overall production. The carrying capacity of the environment for a pond farming means its natural ability to provide for a pond (Barg, 1992). According to (Nash et al., 1995; Lewis, 2005) the the impact of organic waste discharges consisting of left overs, feces and dissolved materials on an intensive scale has been proven to impact and to risk the environment.

Therefore, the development of sustainable shrimp farming should consider two important aspects, including the quantification of pond waste and the ability of coastal waters to contain pond waste or its carrying capacity (Soewardi, 2002). One method developed to measure the ability of coastal areas to contain pond waste is by calculating the carrying capacity of the environment, which is based on the capacity of available dissolved oxygen in the waters to decompose the organic wastes generated from farming activities. This estimation is done by predicting the amount of waste that can be accommodated by coastal waters based on the capacity of available dissolved oxygen in the water column depending on the tides (Boyd; Meade, 2012). In addition, the development of the farming must be set at a location that meets the parameters of the farming to obtain compatibility.

In farming activities, determining the suitable location is the initial stage. A suitable location will support the sustainability of farming and can minimize its negative impact on the surrounding environment (Radiarta et al., 2008). Suitability analysis is a complex stage in which researchers must consider several aspects including such as physical and chemical characteristics, and fertility of waters (Valavanis, 2002). Land suitability analysis may utilize the Geographic Information System (GIS). GIS and remote sensing data play an important role in the development and management of aquaculture, especially shrimp farming. The applications of GIS for aquaculture have been comprehensively documented (Kapetsky & Aguilar-Manjarrez, 2007; Aguilar-Manjarrez et al., 2010). Studies generally focus on: zoning and land suitability, the impact of farming on the aquatic environment, planning for aquaculture development with regard to other land users, and inventory and monitoring of aquaculture activities.
Therefore, this research aims to determine the suitability of shrimp farming land, taking it into consideration in sustainable aquaculture management, and in assessing the carrying capacity of coastal areas for shrimp farming development based on the quality and quantity of waters.

Research Method:-

Research Period and Site:

This research was conducted from March to December 2018. The research site was in the coastal district of Pasangkayu Regency, West Sulawesi. Pasangkayu Regency is located at the coordinates of 0˚ 40’ 10” - 1˚ 50’ 12” of south latitude and 119˚ 25’ 26” - 119˚ 50’ 20” of east longitude. Pasangkayu Regency consists of 12 districts, covering an area of 3,043.75 Km. The distribution of district areas is presented in Table 1.

Table 1:- Area of Pasangkayu Regency by Sub-district

No.	Sub-district	Area (Km^2)	Percentage (%)	Number of Village
1	Sarudu	97.05	3.19	5
2	Dapurang	930.06	30.56	5
3	Duripoku	217.26	7.14	4
4	Baras	275.12	9.04	6
5	Lariang	81.65	2.69	7
6	Bulu Taba	432.65	14.21	7
7	Pasangkayu	310.91	10.21	6

8	Tikke raya	262.61	8.63	5
9	Pedongga	92.09	3.02	4
10	Bambalamotu	243.65	8.00	6
11	Bambaira	64.22	2.11	4
12	Sarjo	36.49	1.20	4
	Pasangkayu	**3.043,75**	**100,00**	**63**
Source : Statistics Indonesia of Pasangkayu (BPS), 2018				

Data Collection and Measurement:-

This study includes (1) biophysical data collection in the farming area, consisting of water quality parameters and soil parameters, (2) biophysical data collection of water channels at the opening, primary and secondary channels. The replication was performed 3 times for each spot. The quality parameters of the observed water environment and the tools/methods of measurement are presented in Table 2.

Table 2:- The parameters of the observed water environment and the tools/methods of measurement

No	Parameter	Measurement Unit	Tools/Methods of Measurement	Measurement Site
A	**Physical Parameter**			
1	Temperature	(^oC)	Mercury thermometer	In situ
B	**Chemical Parameter :**			
1	pH	-	pH-meter	In situ
2	Salinity	(ppt)	Refractometer	In situ
3	Dissolved oxygen	(ppm)	DO Meter	In situ
4	Ammonia	(ppm)	Sample bottle , Spectrophotometer	Laboratory
6	Nitrate	(ppm)	Sample bottle , Spectrophotometer	Laboratory
7	Phosphate	(ppm)	Sample bottle , Spectrophotometer	Laboratory

The analyses explored the suitability of the coastal area for farming and the carrying capacity of the pond environment. Measurement of suitability analysis based on water quality for carrying capacity of the area was based on the quantity and quality of water.

Tidal observations were conducted at a depth of 3 meters at the lowest tide using a scale stick, for approximately 15 (fifteen) days. Tidal data released by the 2016 Naval Oceanographic Hydro Office was used as a comparison. Tidal current speed was measured using the current meter. While the current pattern was observed by tracing the direction of current movement. Analysis of suitability of pond areas used geographic information systems (GIS) with the Arc View GIS Application Version 3.3.

Analysis Method:-

The method was quantitative analysis of the assimilation capacity and carrying capacity of the pond environment both ecologically and physically. Carrying capacity analysis is a development planning instrument providing an overview of how land use is related to environmental capability. According to (Krom, 1986) the carrying capacity of an area for the development of ponds is the ability of the coastal environment to produce optimal fish products using certain technologies and at certain seasons. The carrying capacity analysis can provide the information needed in assessing the level of land capability in supporting all farming activities in the coastal area.

Pond Waste Assimilation Capacity of the Waters

The dilution capacity of coastal waters was determined by the quantification of the volume of water available on the coast for farming ponds. Quantification of available water volume on the coast was determined by: (1) the volume of sea water entering the beach when the tide rises and (2) the volume of discharge of river water entering the coastal waters.

1. The volume of seawater entering the coastal waters when the tide rises (V_{Lo}) could be calculated using the formula from (B. J. J. I.-i. P. d. P. I. Widigdo) as follows:

$$V_{Lo} = 0{,}5.h.y(2X - \frac{h}{tg\theta}) \quad \text{...} \quad (1)$$

in which: y : the length of the coastline

h : tidal range

$tg\theta$: the bottom slope of the beach

X : the distance between the coastline at the time of the average tide towards the sea to a point where at a depth of 1.5 meters it is no longer affected by basic water turbulence.

Next , to determine the volume of seawater left when the sea water recedes (V_{Ls}), the following formula was used:

$$V_{Ls} = 0{,}5h.y\left(2x - \frac{(2h-1)}{tg\theta}\right) \quad \text{..} \quad (2)$$

assuming h > 1

Then, remaining time : $T = \dfrac{V_{Lo} + V_{Ls}}{V_{Ls}}$ .... (3)

2. River water discharge entering coastal waters (Q_n).

To find out the volume of water available in the river every month, an estimation was conducted using a method based on meteorological analysis of water balance, in the following formula:

DRO : Ws - I .... (4)

DRO : direct runoff

I : infiltration; Ws = R – E = water surplus; R = precipitation

E : evapotranspiration of catchment area

The monthly volume of water entering the coastal areas through the river could be calculated using the following formula :

$$(Q)_n = Q_n.A \quad \text{..} \quad (5)$$

in which : $(Q)_n$ = volume of water available in the river at n (m^{-3} dt^{-})

Q_n = run off at n (m^{-3} dt^{-1} km^{-2})

A = catchment area (km^2)

2 Quantification of the Volume of Water Available at the Beach (V_{Pt})

A river could be determined, which was the volume of sea water entering the coast (V_{Lo}) plus the volume of fresh water entering the coastal waters through the river $(Q)_n$, by modifying the (B. J. J. I.-i. P. d. P. I. Widigdo):

$$V_{Pt} = V_{Lo} + \sum (Q)_n$$

$$V_{Pt} = 0{,}5.h.y(2X - \frac{h}{tg\theta}) + \sum_{i}^{n} (Q)_n \quad \text{..............................} \quad (6)$$

in which : V_{Pt} = the volume of sea water entering the coastal waters

(Q)n = freshwater/river water entering the coast

$\sum_{i}^{n} (Q)_n$ = total amount of freshwater/river water entering the coast

n = total number of rivers

Quantification of Waste from Farming Activities

Quantification of farm waste was determined in the following assumptions:

1. The outcome of organic waste load corresponds the result of the study by (Primavera, 1997)stating that 35% of the total feed given will become friendly pollutants as it is left unconsumed (15%) or as it turned into feces (20%).
2. The load of inorganic waste per 1,000 kg of shrimp production will become polluting nitrogen of 21 kg ha^{-1} and phospor of 3,6 kg ha^{-1} (Boyd)
3. Pond waste load from good quality feed with a protein content in the range of 35% - 45% will be able to produce FCR of 1.5. This suggests that to produce 1 kg of shrimp, 1.5 kg of feed is needed, and the waste discharged into the water in the form of a total solid suspension (TSS) is 514 grams (Huisman et al., 2002)

Analysis of the Carrying Capacity of Pond Environment

The carrying capacity of the environment (land) for the development of farming ponds was estimated using three approaches:

1. By exploring the relationship between the quantity of water (the volume of water for farming activities) and the waste load, referring to the study by Rakocy and Allison (1981), claiming that the capacity of waters to contain waste is directly proportional to the quantity of water. To maintain the quality of the waters, the containing waters must have a volume of 60-100 times the volume of waste discharged into it.
2. The carrying capacity of the waters is based on the capacity of the available dissolved oxygen content. Availability of dissolved oxygen in water bodies is the difference between the concentration of O_2 dissolved in inflow (O_{in}) and concentration of O_2 dissolved in a minimum amount for the farming system (O_{out}), which is 3 ppm (Boyd, 1990). If water inflow is Q_o m^3/min, then total dissolved O_2 terlarut within 24 hours is:

$$Q_o\ m^3/\text{min} \times 1.440\ \text{min/hari} \times (O_{in} - O_{out})\ grO_2/m^3 = X\ kg\ O_2 \ldots\ldots\ldots\ldots (7)$$

in which:
Q_o = water inflow (m^3/min)
O_{in} = dissolved oxygen content of inflow
O_{out} = minimum oxygen content needed by organisms

To break down organic matter (TSS) of every 1 kg of organic waste, it requires 0.2 kg of O_2 per organic waste. The amount of organic waste that can be accommodated without exceeding the carrying capacity is calculated using :

$$\frac{\textbf{Capacity dissolved oxygen}}{\frac{\textbf{0,2 kg O 2}}{\textbf{kg Organic Waste}}} = \text{A kg Organic Waste} \ldots\ldots\ldots\ldots (8)$$

If the amount of organic waste/kg organism = B, the carrying capacity of the aquatic environment (per kg organism) for farming is:

$$\text{Carrying Capacity} = \frac{\textbf{A kg Organic Waste}}{\frac{\textbf{B kg Organic Waste}}{\textbf{kg organism}}} \ldots\ldots\ldots\ldots (9)$$

$$= \text{C kg organisme}$$

The carrying capacity analysis was based on the assimilation capacity of the waters, which is the ability of waters to contain waste without causing the waters to be polluted. Waste parameters used as benchmarks in determining the assimilation capacity included nitrogen and phosphorus. The feasibility of nitrogen and phosphorus as waste parameters referred to the statement in (Poernomo, 1992; B. J. J. I.-i. P. d. P. I. Widigdo). The allowed nitrogen amount for farming is 1,0 mg lt^{-1}, and the allowed amount of phospor is 0,5 mg lt^{-1}.

Model of suitability of brackish water farming land:

Analysis of suitability of land for marginal farming used geographic information system (GIS), specifically the Arc View GIS Application Version 3.3. Area mapping was done by overlaying various maps of land suitability in the current coastal area. It used the geographic information system (GIS), by querying GIS data using the principles of the area discussed earlier, so that spatial information could be obtained: (1) which areas are available for aquaculture development activities using traditional, semi-intensive, and intensive technology, (2) what activities are permitted and not permitted; (3) issues on: (a) the suitability of the area with its allotment; (b) land use for its purpose; (4) the result of the mapping of the area in accordance with its allotment being different from the use of the current area.

The suitability of coastal land for aquaculture activities was based on several criteria. They were arranged based on relevant biophysical parameters. In this study, the suitability is divided into four classes:

1. Class S1 (Highly suitable). This land is not limited for a certain use only in a sustainable manner, or is only slightly limited and it would not significantly affect what the land produces, and will not increase the expenses for the exploitation of the land.
2. Class S2 (Suitable). This land is moderately limited for a certain sustainable use, the limitation will reduce the productivity or the benefits of the land and increase expenses for the exploitation of the land.
3. Class S3 (Conditionally Suitable). This land is highly limited, but the condition is still manageable, meaning that it can still be improved using a more sophisticated technology or with additional treatment at a reasonable cost.
4. Class N (Not Suitable). This land is seriously limited, thus it would not be possible to use it for a certain sustainable use.

The division of classes was adjusted based on the use of technology in shrimp farming, including the traditional, semi-intensive, and intensive methods. The weighting on each limiting factor was based on the dominance of these parameters on a land allotment. The weighting was indicated by a parameter for the entire evaluation of the land, slope as a parameter of farming pond suitability has a greater weight compared to soil type.

The use of land for farming was based on the criteria of suitability of farming ponds. The criteria used in determining the suitability of farming land were based on the land suitability matrix of the farm area. Based on the weighting and scoring of the parameters, the scores of land suitability classes could be determined for the area of the farm.

Highly suitable (S1) : 3.26 – 4.00
Suitable (S2) : 2.51 – 3.25
Conditiinally suitable (S3) : 1.76 – 2.50
Permanently not suitable (N) : 1.00 – 1.75

Model of land suitability and carrying capacity for brackish water farming based on the level of technology

Scoring was conducted based on data/information from the results of laboratory analysis and direct measurements in the field, along with the climate, tidal data and freshwater availability data. Scoring was determining a value to the unit of land based on its characteristics. Land assessment with a scoring system, according to (Kapetsky & Aguilar-Manjarrez, 2007), is carried out by combining the results of laboratory analyses of soil and water samples and their eligibility criteria to obtain parameters of land characteristics. A score of 4 is "highly suitable" (S1), score 3 is "suitable" (S2), score 2 is "conditionally suitable" (S3), and score 1 is "not suitable" (N).

The weighting of each limiting factor or variable was based on the dominant influence of the variable on the suitability of the vaname shrimp farm, which were then sorted based on how much they affected the allotment. The next step was digitizing the information system by merging thematic maps to get an overview of the coastal areas potential for the application and development of farming ponds. In the GIS process, thematic maps of each parameter of soil and water quality were scored, weighted and categorized based on land suitability, then classified using a score system. The next step was to overlay all soil quality parameters. The result of the merging process was then overlaid again by water quality through matching method to obtain potential locations for farming management. Based on the results of this GIS analysis, thematic maps of land suitability and the level of technology for farming were obtained.

Results and Discussion:-

Land Suitability Analysis

The land suitability analysis was based on the land suitability criteria according to the technical guideline by the (Poernomo, 1992). These criteria were arranged based on biophysical parameters relevant to each activity.

Analysis of Suitability Parameters

Details of land and water suitability parameters are presented in Table 3.

Table 3:- Land and Water Suitability Parameters (score) for shrimp farming

Parameter	S1 (Highly suitable)	S2 (Suitable)	S3 (Conditionally suitable)

Slope (%)	0 – 3	3 – 6	6 – 9
Distance from beach (m)	200 – 300	300 – 4000	< 200
Distance from river (m)	0 – 1000	1000 – 2000	2000 – 3000
Salinity (ppt)	12 – 20	20 – 30	5 – 12; 30 – 45
Temperature (^oC)	25 – 32	23 – 25	32 – 34
Dissolved Oxygen (mg/l)	6 – 7	3 – 6	1 – 3
pH	8.1 – 8.7	7.6-8.0; 6.1-7.6	8.8-9.5; 4.0-4.5
Phosphate (PO_4)	0	0,000001	0,00001
Ammonia (NH_3)	0	0,000001	0,00001
Nitrite (NO_2)	0	0,000001	0,00001

Source : Modified from: Bakosurtanal (1996) in Asbar and Fattah (2017); Yustiningsih (1997) in Laili (2004)

Topography:
Land slope greatly affects the management of pond environment. In addition to its excavation and levelling for a new use being costly, it has an impact on the loss of fertile surface soil at the time of water disposal (Higgins et al., 2013). Therefore, it is very important to select a flat or level land or with a slope of around 0% -1%. In general, lands in Pasangkayu have a flat surface with a slope range of 0% -1%, thus they were suitable to be used for shrimp farming due to adequate supply of sea water with tidal energy and freshwater drainage.

Quality of Waters:
Pond water conditions are affected by the water sources (sea and river). Not only does the distance from water sources affect the quantity of water but also the quality of water. Water quality in the farming area of Pasangkayu Regency is presented in Table 3. The effect of the distance from the water source on the pond water conditions is also determined by the slope, elevation, and tidal differences (Lucas et al., 2019) As a tropical country, the climate in Indonesia also affects the condition of water quality at the farming site. However, differences in water quality conditions will not be extreme despite the change of seasons (McQuillan, 2004). The result of water quality measurements is presented in Table 4.

Table 4:- Result of Measurement of Water Quality Parameters in Pasangkayu Regency

	Min	Max	Av	std dev
Temperature	29.10	32.50	30.80	1.7
Salinity	6.50	27.00	16.75	10.25
DO	4.20	9.65	6.93	2.725
PO4	0.04	2.19	1.12	1.076725
NO2	0.03	1.63	0.83	0.802275
NH3	0.42	4.03	2.22	1.806
pH	6.70	7.57	7.14	0.435

Temperature:
The appropriate water temperature for shrimp farming ranges between 26^{o}C and 32^{o}C and it would be best in the range of 29^{o}C and 30^{o}C (Fontenot et al., 2007). Furthermore, at the temperatures of 26^{o}C-30^{o}C, shrimps grow relatively fast with relatively high survival rate. It is believed that shrimp can live at 14^{o}C-40^{o}C, but the optimum range for growth is 26^{o}C-32^{o}C. In the pond, the temperature shall affect the photosynthetic activity of algae and the solubility of the gases in it (Subasinghe et al., 2009). Water temperature is highly influential on the physical, chemical, and biological characteristics of ponds, which consequently affects the physiological life of aquaculture organisms. Generally, the rate of shrimp growth will increase as the temperature rises to certain limits (Ponce & Bour, 1997). Specifically, the temperatures of pond waters in Pasangkayu Regency were still appropriate for shrimp farming. The result of temperature measurements is presented be seen in Table 4.

Salinity (mg/l)
The water for irrigating shrimp ponds can be obtained directly from the sea with a salinity of 30 - 36 o/oo. Shrimps are able to live in the range of salinity of 15-50 o/oo. At a salinity of <15 o/oo shrimps can grow well, provided that

the change in salinity does not occur suddenly. Although shrimps have euryhaline properties, a good salinity range for shrimp ponds is 10 - 35 o/oo with an optimum range of 15 - 25 o/oo (Poernomo, 1992). The salinity in the coastal waters of Pasangkayu Regency was around 6.50 - 27 o/oo with an average of 16.75 o/oo. Shrimps can live in the salinity range of 1-2 ppt until the seawater is at 40 ppt (Menz et al., 1980). (Hernández et al., 2006) state that the best growth and survival rate of shrimp is found at a salinity of 33-40 ppt, as they have a high tolerance for a salinity range of 3-45 ppt while its optimum salinity is at 15-25 ppt (Roy et al., 2010). In the Pasangkayu Regency, the salinity was supportive for shrimp farming, as presented in in Table 4.

Dissolved Oxygen / DO (mg/l)

Dissolved oxygen is one of the chemical parameters of water playing a role in the life of aquatic biota. Decreasing dissolved oxygen can compromise the efficiency of oxygen uptake for aquatic biota thereby reducing its ability to live a normal life. According to Lung (1993), the minimum oxygen solubility to support fish life is around 4 ppm. The level of dissolved oxygen in Pasangkayu waters was in the range of 4.2 - 9.6 ppm. This level supports the life of aquatic biota which is a minimum of 0.0 ppm. The dissolved oxygen level deadly for vaname shrimps is 1 mg/L (Hopkins et al., 1991). In farming activities, dissolved oxygen level of less than 2 mg/L can result in shrimp death, and its optimum limit is 4-7 mg/L (Zang et al., 2011). DO measurement result is presented in Table 4.

Phospat/PO4 (mg/l)

Phosphate found in waters originates from domestic waste in the form of detergents, agricultural residues (fertilizer), industrial waste, crushed organic matter and phosphate minerals (Lin et al., 2002). Generally, the phosphate content in natural waters is very small and never exceeds 0.1 mg/l, except when there are additions from external sources including fish food waste and agricultural waste. The result of water quality analysis showed phosphate level in the waters of Pasangkayu Regency ranging from 0.04-2.19 mg/l, with an average value of 1.1 mg/l. The result of PO4 measurements is presented in Table 4.

Nitrate NO2 (mg/l)

The result of measurements of nitrate level in Pasangkayu waters indicates a range of 0.03-1.63mg/l, with an average value of 0.83 mg/l. Generally, the nitrate content of Pasangkayu waters was above the water quality standard, which requires the nitrate content for raw water to be a maximum of 10 mg/l. Thus, it can be concluded that the waters of Pasangkayu were polluted by nitrate compounds. The content of nitrate and phosphate in traditional farming pond water is indispensable to stimulate the growth of kelekap, plankton, and moss as the main natural food for fish and shrimp. Sea water nitrate content appropriate for marine life is 0,008 mg/L (Brown et al., 2013). Phosphate content in natural waters ranges from 0.005 to 0.020 mg/L, whereas it is usually around 0.02 mg/L in ground water (Effendi, 2003)(Effendi, 2003). Result of nitrate measurements is presented in Table 4.

Ammonia / NH3 (mg/l)

Ammonia can be present in a molecular form (NH3) or an NH4 ion form, with NH3 being more toxic than NH4 (Mook et al., 2012). NH3 can penetrate parts of the cell membrane faster than NH4. NH3 content of 0.05-0.20 mg/L shall inhibit the growth of aquatic organisms in general. The NH3 content in pond waters in Pasangkayu Regency was detected in the range of 4.03 mg/L with an average of 2.22 mg/L (Table 3, Figure 9). (Chanratchakool et al., 1995) states that the ammonia content permitted for shrimp farming is less than 0.1 mg/L. Ammonia calculation result is presented in Table 4.

Acidity (pH)

The tolerance limit of aquatic organisms for pH varies and is affected by many factors, including temperature, dissolved oxygen, alkalinity, and the type and stage of the organism. A good pH range for shrimp is at 7.5-8.5 with an optimum of 8.0-8.5 (Harahap et al., 2015). In situ measurement of the pond water pH level in Pasangkayu Regency showed a neutral level thus allowing farming development in Pasangkayu Regency area. The result of pH measurements is presented in Table 4.

Suitability Level

Determination of the land suitability class for the area of the farming pond using the parameters is presented in Table 5. The suitability level of the farm in the area was categorized into 4 classes including highly suitable (S1), suitable (S2), conditionally suitable (S3) and not suitable (N).

Table 5:- Weighting and scoring of the suitability parameter

Parameter	Weight	Category and Score							
		S1	score	S2	score	S3	score	N	score
Slope (%)	0.20	0 – 3	4	3 – 6	3	6 – 9	2	> 9	1
Distance from beach (m)	0.10	200 – 300	4	300 – 400	3	< 200	2	> 4000	1
Distance from river (m)	0.10	0 – 1.000	4	1.000-2.000	3	2.000-3.000	2	-	1
Soil type	0.10	Alluvial Pantai	4	Alluvial Hydromel	3	Regosol, Gleihumus	2	Regosol, Gleihumus	1
Elevation (m)	0.15	0 – 3	4	3 – 6	3	6 – 9	2	> 9	1
Drainage	0.10	Waterlogged	4	Waterlogged	3	Unwatered	2	Unwatered	1
Geology	0.10	Loose sediment	4	Loose sediment	3	Indurated sediment	2	Indurated sediment	1
Salinity ppt)	0.3	12 – 20	4	20 – 30	3	5-12;30-45	2	<5; >45	1
Temperature (^oC)	0.3	25 – 32	4	23 – 25	3	32 – 34	2	0 – 23	1
Dissolved oxygen (mg/l)	0.3	6 – 7	4	3 – 6	3	1 – 3	2	<1; <8	1
H_2S (mg/l)	0.3	zero	4	<0.001	3	>0.003	2	>0.3	1
pH	0.3	8.1 – 8.7	4	7.6 – 8.0; 6.1 – 7.6	3	8.8-9.5; 4.0- 4.5	2	9.6 – 11.0; <4.0	1

Source: Modified from: Bakosurtanal (1996) in Asbar and Fattah (2012); Yustiningsih (1997) in Laili (2004)

Based on Table 5 and the data collected, the result of the suitability analysis shows the area of farming in each district as presented in Table 6:

Table 6:- Result of Analysis of Land Suitability in Coastal Areas of Pasangkayu Regency

No	Sub-district	Analysis Result (Ha)		
		Highly suitable (S1)	Suitable (S2)	Conditionally Suitable (S3)
1	Sarjo	154.88	77.16	27.26
2	Bambaira	33.15	-	24.73
3	Bambalamotu	15.19	63.04	3.69
4	Pasangkayu	50.72	166.21	77.54
5	Pedongga	1.72	484.98	77.54
6	Dapurang	136.73	107.28	20.13
7	Tikke Raya	-	1,395.86	-
8	Lariang	85.65	47.79	8.6
9	Baras	240.17	642.66	8.34
10	Sarudu	14.74	-	-
Total		**732.95**	**2,984.98**	**247.83**

Based on Table 6, it shows that overall farming pond in Pasangkayu Regency has an area of 3,965.76 ha, with 732.95 Ha of highly suitable land, 2,984.98 Ha of suitble land, and 247.83 Ha of conditionally suitable land. The level of land suitability based on GIS analysis is illustrated in Figure 1.

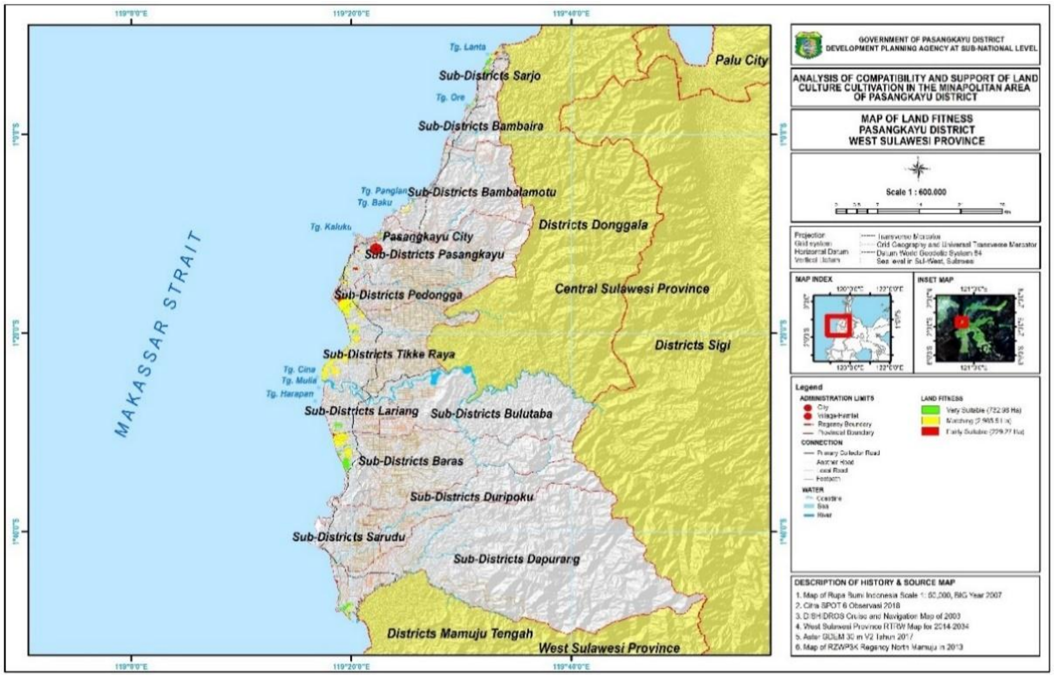

Figure 1:- Map of land suitability of ponds in Pasangkayu Regency

Map of the level of suitability of ponds in each district is in Figure 2 for Sarjo Sub-district, Figure 3 for Bambaira Sub-district, Figure 4 for Bambalamotu Sub-district, Figure 5 for Pasangkayu Regency, Figure 6 for Pegongga Sub-district, Figure 7 for Dapurang Sub-district, Figure 8 for Tikke Raya Sub-district, Figure 9 for Lariang Sub-district, Figure 10 for Baras Sub-district, and Figure 11 for Sarudu Sub-district.

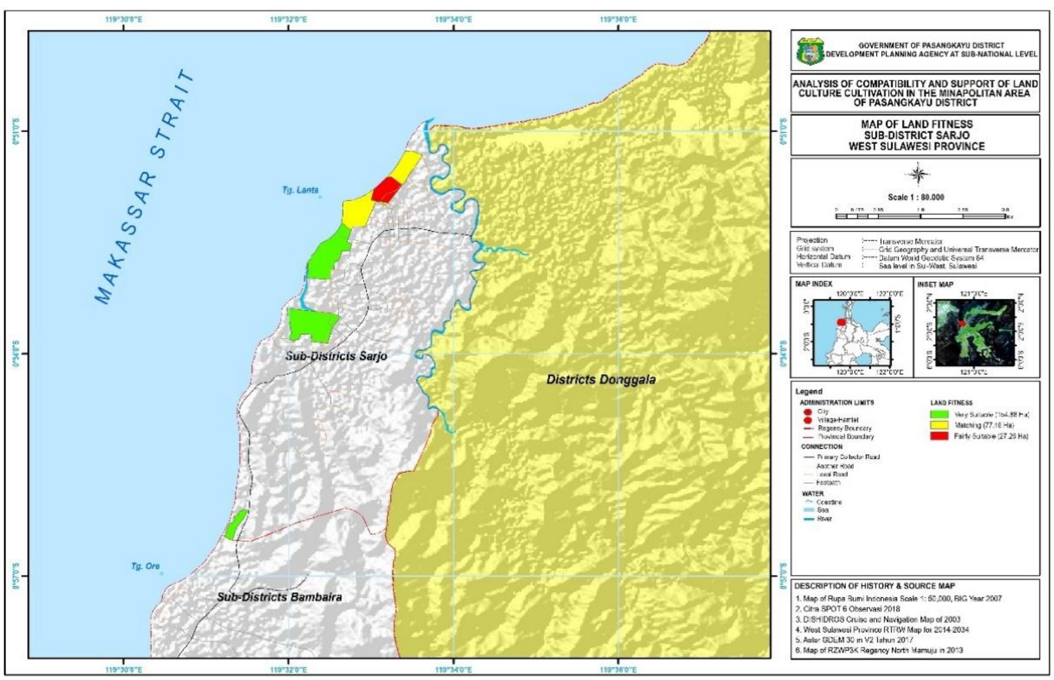

Figure 2:- Map of land suitability of ponds in Sarjo Sub-district

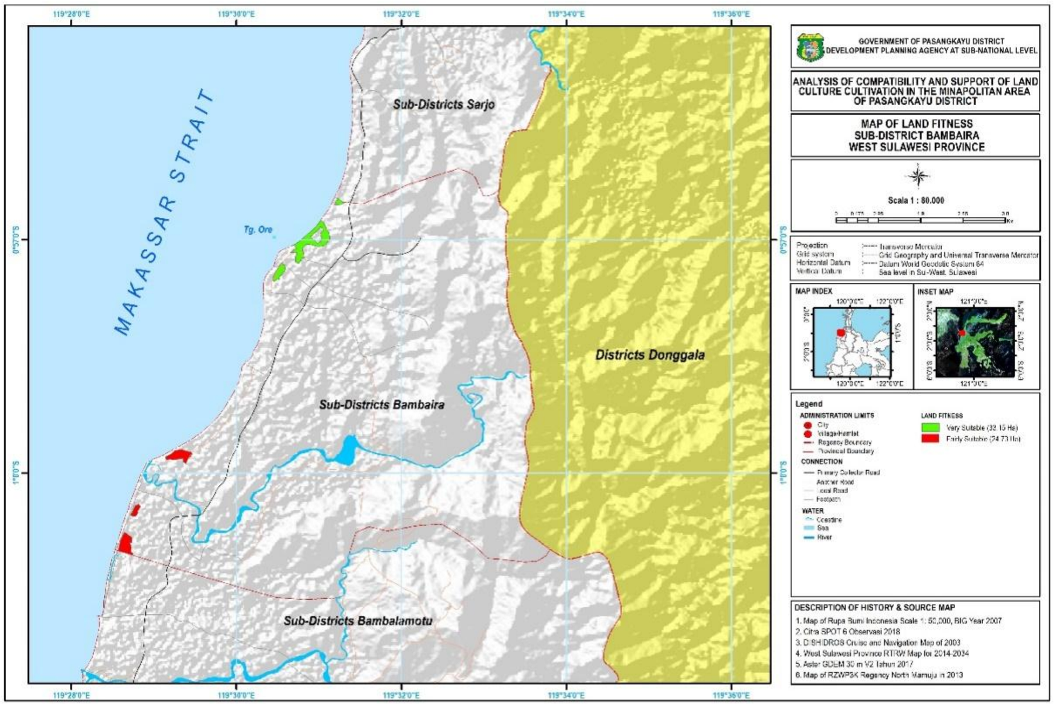

Figure 3:- Map of land suitability of ponds in Bambaira Sub-district

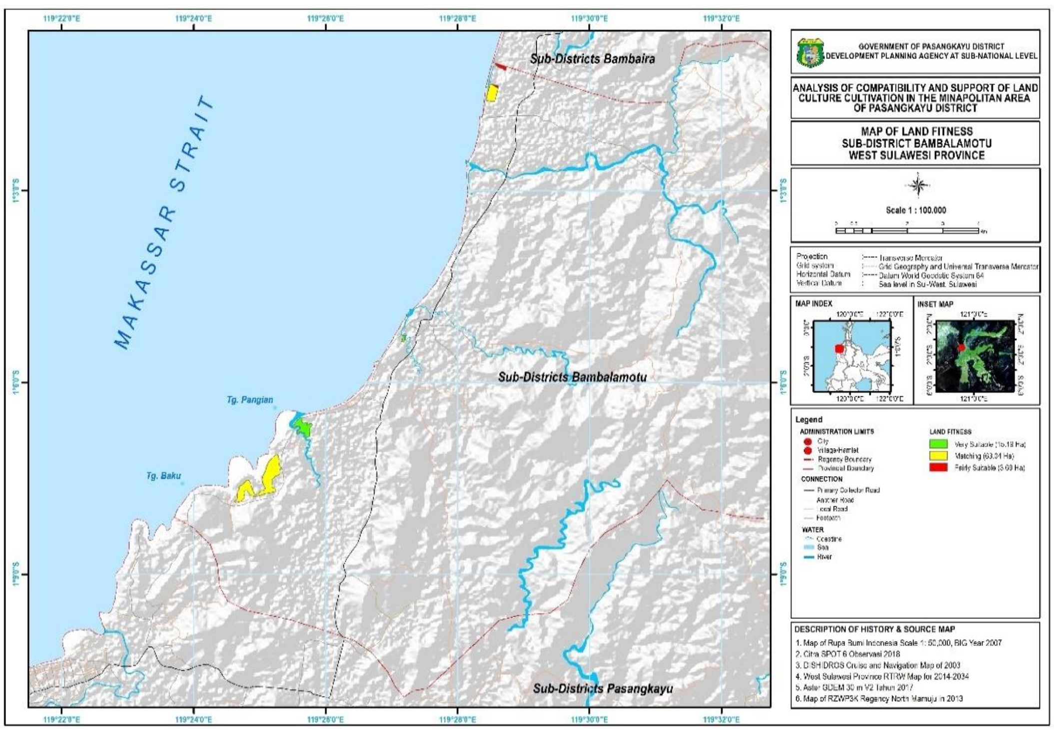

Figure 4:- Map of land suitability of ponds in Bambalamotu Sub-district

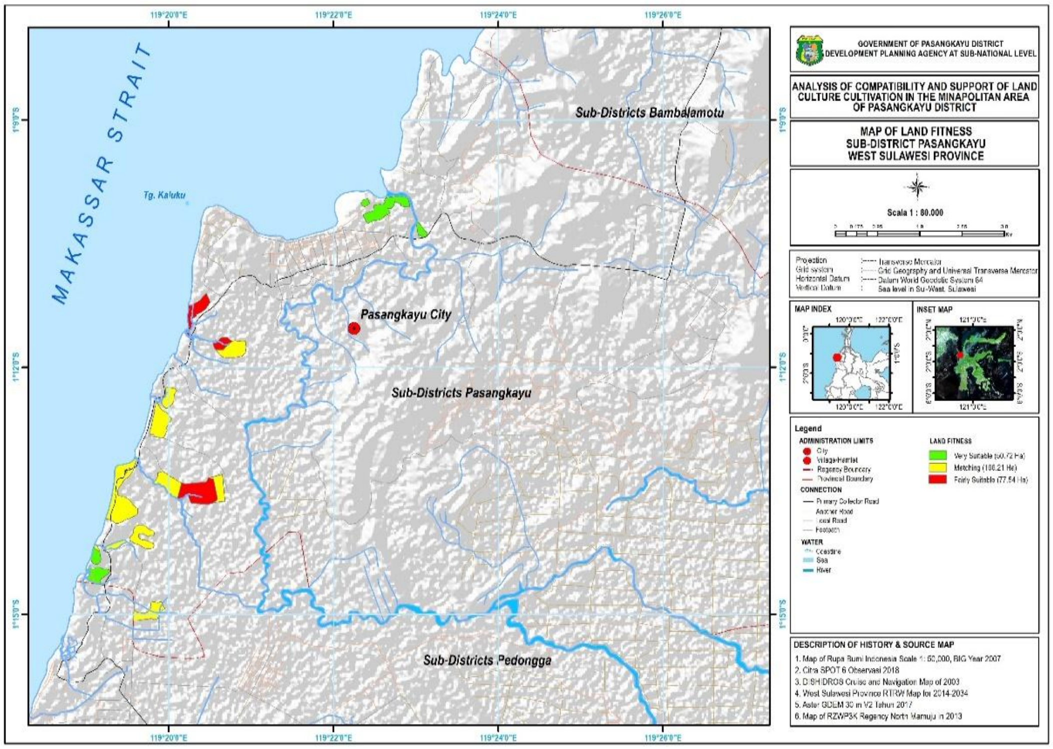

Figure 5:-Map of land suitability of ponds in Pasangkayu Sub-district

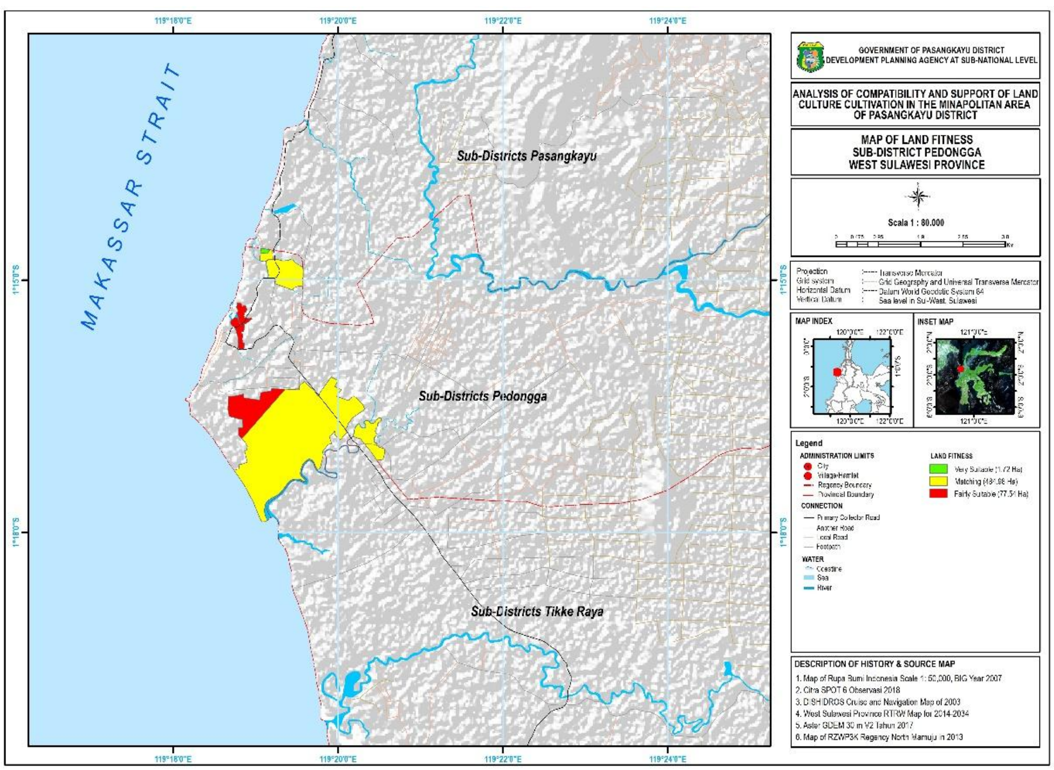

Figure 6:- Map of land suitability of ponds in Pedongga Sub-district

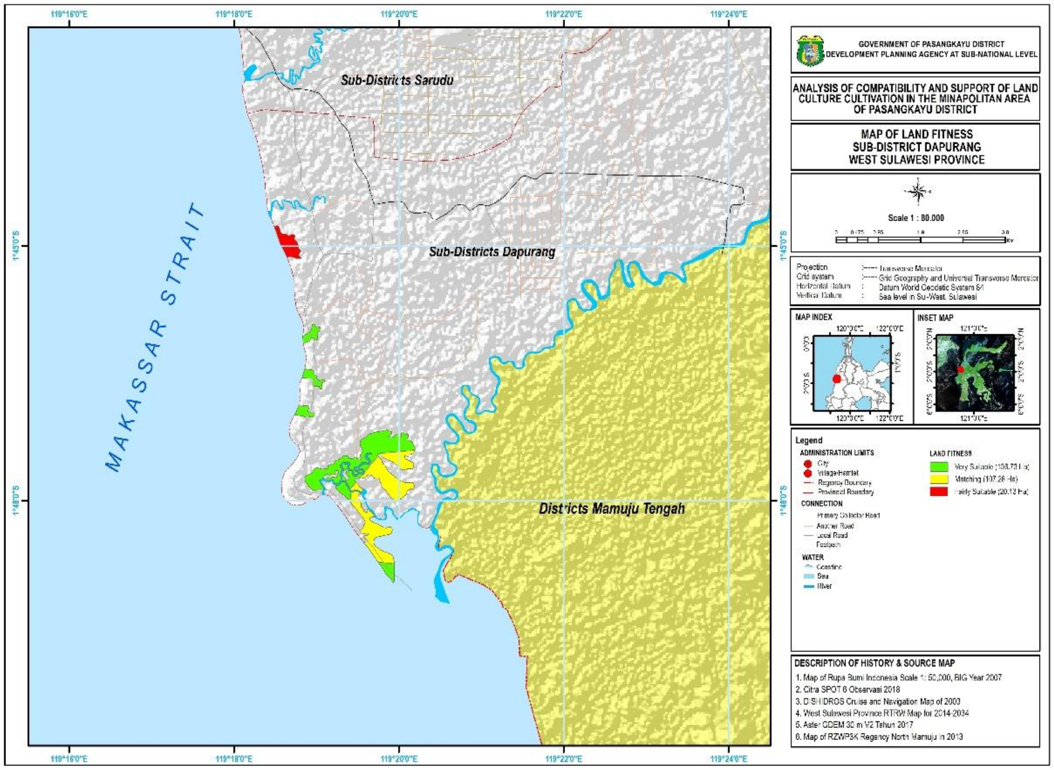

Figure 7:- Map of land suitability of ponds in Dapurang Sub-district

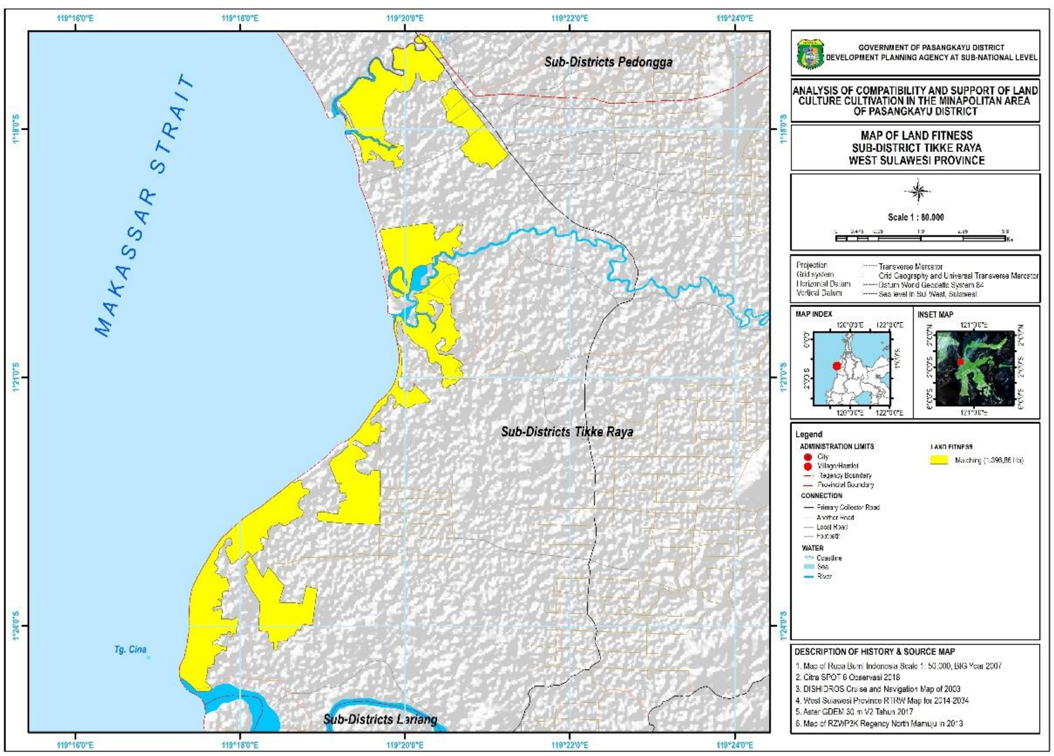

Figure 8:- Map of land suitability of ponds in Tikkeraya Sub-district

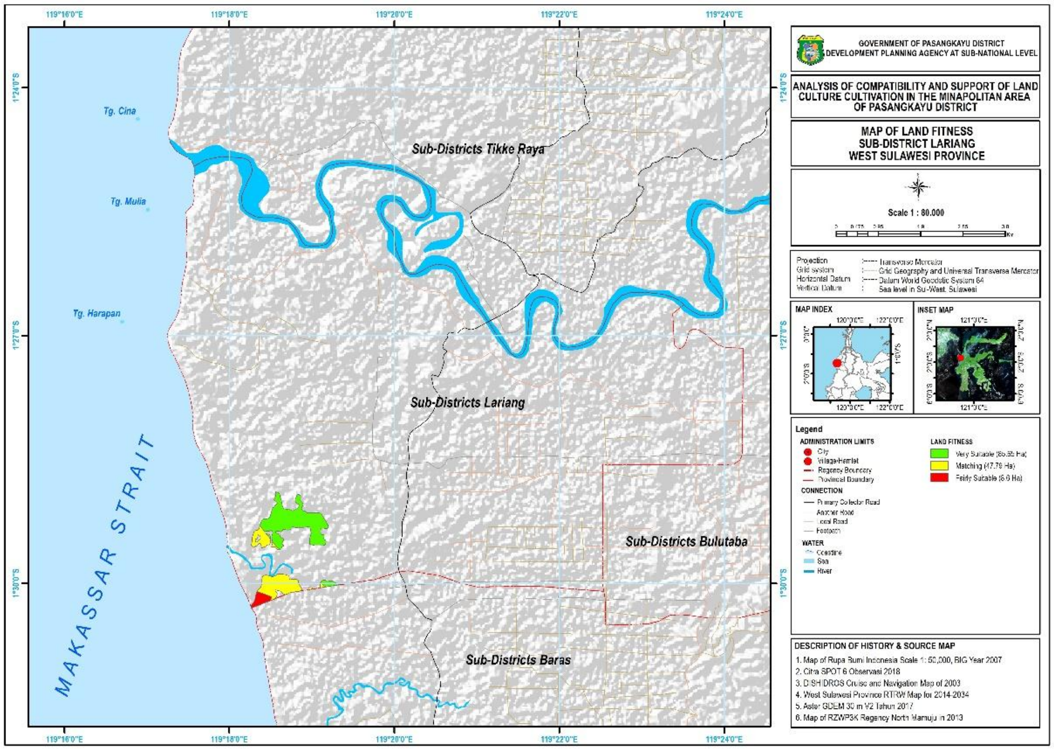

Figure 9:- Map of land suitability of ponds in Lariang Sub-district

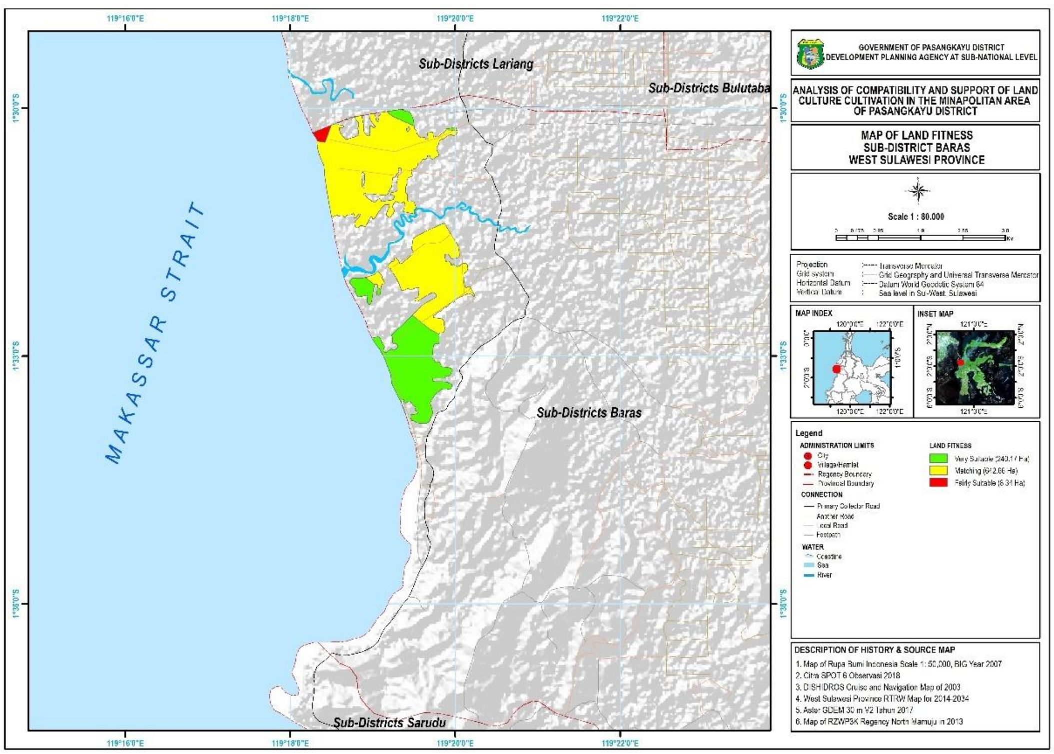

Figure 10:- Map of land suitability of ponds in Baras Sub-district

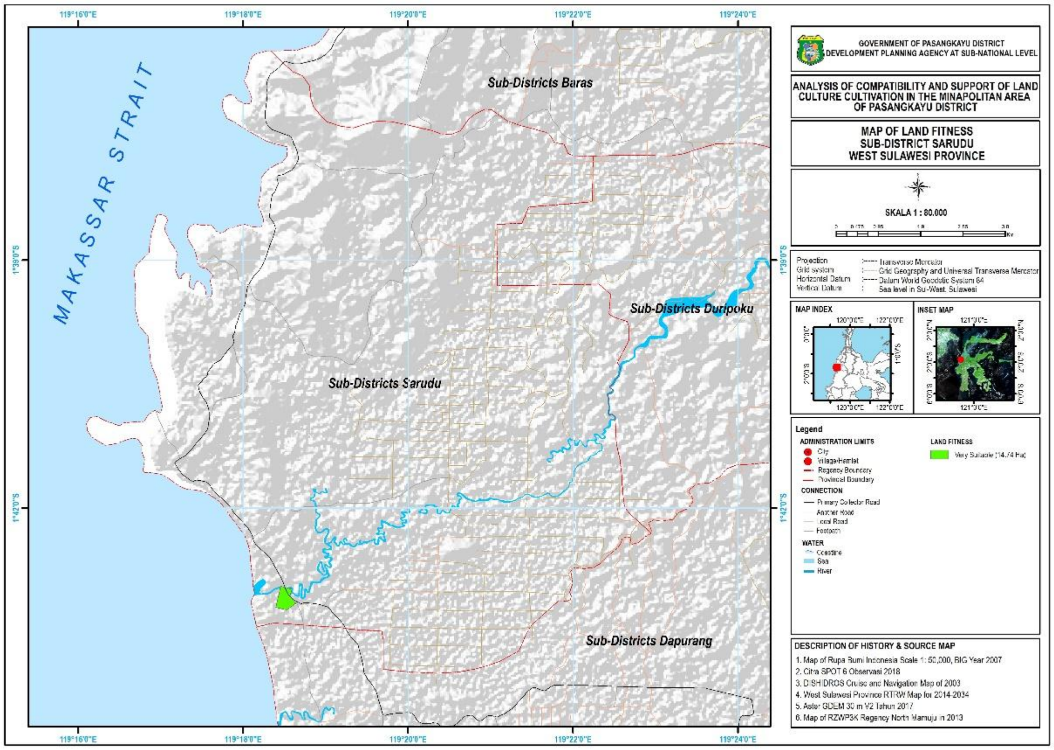

Figure 11:- Map of land suitability of ponds in Sarudu Sub-district

Assimilation Capacity and Carrying Capacity of Aquatic Environment:

The estimated carrying capacity of the environment for farming ponds was based on several aspects, including: (1) the volume of waste water recipient is 60 -100 times the volume of waste discharged to the beach; (2) the capacity of the available dissolved oxygen in the waters to decompose organic waste materials.

Based on the Volume of Water on the Beach and the Volume of Waste:

The result of the calculation of the volume of sea water available on the coast for farming ponds per day for the entire study area in accordance with formulas (1 and 2) is presented in Table 7.

Table 7:- Totala Volume of Water at the Coast, at the Pond, and Volume of Waste.

No.	Sub-district	Parameter		
		Total water volume at coast (m^3 hr^{-1})	Pond water volume (m^3)	Pond waste (m^3)
1	Sarjo	1,343,155.003	134.32	13.43
2	Bambaira	1,216,342.280	121.63	12.16
3	Bambalamotu	2,133,868.321	213.38	21.33
4	Pasangkayu	837,830.934	83.78	8.37
5	Pedongga	298,855.460	29.88	2.98
6	Tikke Raya	1887467.123	188.74	18.87
7	Lariang	492,753,399	49.27	4.92
8	Baras	1,587,481.500	158.74	15.87
9	Sarudu	1,280,171.650	128.01	12.8
10	Dapurang	1,485,974.410	148.59	14.85

The result of the the calculation in Table 7 was used as a basis for determining the area of farming pond based on the assumption of shrimp production capability for each technology used, including the 4 tons ha^{-1} MT^{-1} (Intensive Pond) of shrimp production; 2 tons ha^{-1} MT^{-1} (semi-intensive pond) of shrimp production; 300 kg ha^{-1} MT^{-1} (traditional ponds) of shrimp production. The potential carrying capacity of water to support intensive, semi-intensive and traditional farming ponds is presented in Table 8.

Table 8:- Potential of Area of Farming Pond to Remain Sustainable Based on Assumptions of Shrimp Production Capability.

No.	Sub-district	Pond Area		
		Intensive	Semi-Intensive	Traditional
		(4 ton ha^{-1} MT^{-1})	(2 ton ha^{-1} MT^{-1})	(300 kg ha^{-1} MT^{-1})
1	Sarjo	13.43	26.86	83.92
2	Bambaira	12.16	24.32	81.38
3	Bambalamotu	21.33	42.66	99.72
4	Pasangkayu	8.37	16.74	73.8
5	Pedongga	2.98	5.96	63.0
6	Tikke Raya	18.87	37.74	94.8
7	Lariang	4.92	9.84	66.9
8	Baras	15.87	31.74	88.8
9	Sarudu	12.8	25.6	82.66
10	Dapurang	14.85	29.7	86.76

Based on Table 8, the area of farming ponds remaining sustainable for intensive ponds was much smaller than that for semi-intensive and traditional ponds. . For example, in Sarjo district, there is a potential 13.43 ha for intensive ponds, 26.86 ha for semi-intensive ponds, and 83.92 ha for traditional ponds.

Based on the Availability of Dissolved Oxygen

Water carrying capacity based on dissolved oxygen content in water bodies was calculated based on the modification of the formula proposed by (Meade, 2012; Boyd) The results of the study of (B. J. J. I.-i. P. d. P. I. Widigdo), (Wedemeyer, 1996) concluded that the minimum level desired for farming ponds was 3 mg lt^{-1} (O_{out}). While the observations obtained the following average dissolved oxygen in coastal waters (O_{in}) in each sub-district: Sarjo Sub-district was of 5,9 mg lt^{-1}, Bambaira Sub-district was of 4,2 mg lt^{-1}, Bambalamotu Sub-district was of 5,95 mg lt^{-1}, Pasangkayu Regency was of 6,18 mg lt^{-1}, Pedongga Sub-district was of 4,55 mg lt^{-1} , Tikke Raya Sub-district was of 5,15 mg lt^{-1}, Lariang Sub-district was of 6,55 lt^{1}, Baras Sub-district was of 9,65 65 mg lt^{-1}, Sarudu Sub-district was of 5,6 mg lt^{-1} and Dapurang Sub-district was of 6,25 mg lt^{-1}. The observation was conducted for 24 hours, within one hour interval.

Based on the observations above, the difference between internal dissolved oxygen (O_{in}) and external DO (O_{out}) could be calculated. Sarjo Sub-district indicated a value of 2,9 mg $lt^{-1,}$ Bambaira Sub-district was of 1,2 mg lt^{-1}, Bambalamotu Sub-district was of 2,95 mg lt^{-1}, Pasangkayu Regency was of 3,18 mg lt^{-1}, Pedongga Sub-district was of 1,55 mg lt^{-1}, Tikke Raya District was of 2,16 mg lt^{-1}, Lariang Sub-district was of 3,55 mg lt^{-1}, Baras Sub-district was of 6,65 mg lt^{-1}, Sarudu Sub-district was of 2,6 mg lt^{-1} and Dapurang Sub-district was of 3,25 mg lt^{-1}. If the average volume of water available per day (V_t) for Sarjo District was of 1.343.155,003 m^3 hr^{-1}, the capacity of available dissolved oxygen in the waters was of 3.895,15 kg $O_{2.}$ In Sarjo Sub-district, the average volume of available water was 1,343,155,003 m3 hr-1, thus the capacity of oxygen available in the waters was 3,895.15 kg O2. Furthermore, to decompose 1 kg of organic feed waste, 0.2 kg oxygen is needed (Willoughby, 1968 referred by Meade, 1998). The carrying capacity of waters in Sarjo District in decomposing organic waste is of 19,475.75 kg. Complete result of the calculation of oxygen capacity and carrying capacity of the environment in assimilating waste throughout the coastal area Pasangkayu Regency, using the formulas 3-8, is presented in Table 9.

Table 9:- Total Coastal Water Volume, Oxygen Capacity, and Environmental Carrying Capacity in Assimilating waste.

No.	Subdistrict	Total water volume on beach (m^3 hr^{-1})	Oxygen capacity (Kg O_2)	Environmental carrying capacity in assimilating waste(kg)
1	Sarjo	1,343,155.003	3.895,15	19.475,75
2	Bambaira	1,216,342.280	1.459,61	7.298,05
3	Bambalamotu	2,133,868.321	6.294,91	31.474,56
4	Pasangkayu	837,830.934	2.664,30	13.321,51
5	Pedongga	298,855.460	463,22	2.316,13
6	Tikke Raya	1887467.123	4.076,93	20.384,64

7	Lariang	492,753,399	1.749,27	8.746,37
8	Baras	1,587,481.500	10.556,75	52.783,76
9	Sarudu	1,280,171.650	3.328,45	16.642,23
10	Dapurang	1,485,974.410	4.829,41	24.146,08

According to Table 7, the oxygen capacity in each coastal district was in the range of 463,22 Kg O_2 to 10.556,75 Kg O_2, with a range of environmental carrying capacity in assimilating waste at 2.316,13 kg to 52.783,76 Kg.

Analysis of Integration of Suitability and Carrying Capacity of Farming Land

The level of suitability of the farming land resulted from the analysis was categorized into 3 classes, including "highly suitable" (S1), "suitable" (S2), and "conditionallt suitable" (S3). The result of the suitability analysis were then integrated with the level of farming technology applied by the community. Local people have been running shrimp farming in coastal areas using traditional technology, with low investment, without windmills and water pumps. The land in the highly suitable category (S1) was the area for traditional farming, in the suitable category (S2) was the area for semi-intensive farming, and in the conditionally suitable category (S3) was an area for intensive farming. Area of ponds in each district is presented in Table 10.

Table 10:- Result of Analysis of Carrying Capacity of Farming Ponds in the Coastal Area of Pasangkayu Regency

No	Sub-district	Analysis Result (Ha)		
		Traditional	Semi Intensive	Intensive
1	Sarjo	154.88	77.16	27.26
2	Bambaira	33.15	-	24.73
3	Bambalamotu	15.19	63.04	3.69
4	Pasangkayu	50.72	166.21	77.54
5	Pedongga	1.72	484.98	77.54
6	Dapurang	136.73	107.28	20.13
7	Tikke Raya	-	1.395.86	-
8	Lariang	85.65	47.79	8.6
9	Baras	240.17	642.66	8.34
10	Sarudu	14.74	-	-
Total		732.95	2,984.98	247.83

Based on the result of the land suitability analysis and integration of the level of technology applied in the community, the area of land in the highly suitable category was for traditional farming, and was of 732.95 Ha, while the area in the suitable category is for semi-intensive farming, and was of 2,984.98 Ha, and the area in the conditionally suitable category was for intensive farming, and is of 247.83 Ha. The total area of farming ponds was 3,965.76 Ha.

Therefore, an area of 732.95 Ha of highly suitable land is prioritized for the use and management of traditional farming or by using traditional-plus technology. Whereas 2,984.98 ha of just suitable land and 247.83 ha of conditionally suitable land are allocated for investment development. With the pattern and direction of the use of farming land, the creation of sustainable resources and the sustainability of shrimp and milkfish farming businesses are expected to increase income, welfare, and standard of living of coastal communities and ultimately can increase regional economic growth.

Maximum utilization of farming land is expected to not exceed the carrying capacity of the aquatic environment based on the capacity to assimilate farming pond waste in the coastal districts of Pasangkayu Regency, as presented in Table 11.

Table 11:- Environmental Carrying Capacity Based on the Capacity in Assimilating Waste from Farming Technology in the Coastal Districts of Pasangkayu Regency.

Sub-district	Technology	Environmental carrying capacity in assimilating waste (kg MT^{-1})	Capacity of organic waste (kg ha^{-1})	Pond Area (ha)	Carrying Capacity of Production (Ton MT^{-1})

Sarjo	Intensive	19,475,747	117.27	166.07	42.63
	Semi intensive	19,475,747	32.58	597.85	153.49
	Traditional	19,475,747	1.46	13.342.08	3.425.31
Bambaira	Intensive	7,298,054	129.52	56.35	38.59
	Semi intensive	7,298,053	35.98	202.84	138.93
	Traditional	7,298,053	1.51	4.848.29	3.320.75
Bambalamotu	Intensive	31,474,557	73.84	426.26	67.71
	Semi intensive	31,474,557	36.92	852.51	135.43
	Traditional	31,474,557	1.23	25.621.57	4.070.15
Pasangkayu	Intensive	13,321,511	188.17	70.79	26.57
	Semi intensive	13,321,511	52.27	254.86	95.67
	Traditional	13,321,511	1.66	8.025.53	3.012.59
Pedongga	Intensive	2,316,129	528.52	4.38	9.46
	Semi intensive	2,316,129	146.81	15.78	34.07
	Traditional	2,316,129	1.94	1.191.53	2.573.50
Tikke Raya	Intensive	20,384,644	83.47	244.23	59.90
	Semi intensive	20,384,644	23.18	879.22	215.65
	Traditional	20,384,644	1.29	15.775.22	3.869.32
Lariang	Intensive	8,746,372	320.12	27.32	15.62
	Semi intensive	8,746,372	88.92	98.36	56.24
	Traditional	8,746,372	1.83	4.776.59	2.731.04
Baras	Intensive	52,783,760	99.24	531.86	50.38
	Semi intensive	52,783,760	27.57	1914.69	181.37
	Traditional	52,783,760	1.38	38.262.84	3.624.40
Sarudu	Intensive	16,642,23142	123.05	135.25	40.64
	Semi intensive	16,642,23142	34.18	486.90	146.31
	Traditional	16,642,23142	1.48	11.229.77	3.374.33
Dapurang	Intensive	24,147,08421	106.06	227.67	47.15
	Semi intensive	24,147,08421	29.46	819.62	169.73
	Traditional	24,147,08421	1.41	17.102.05	3.541.53

Based on the analysis result, the amount of waste discharged into the waters of the 10 coastal districts of Pasangkayu Regency per unit area (ha) of ponds during one planting season on average was 176.98 kg TSS ha^{-1} for intensive farming activities, and 50.79 kg TSS $ha^{-1,}$ for semi-intensive cultivation technology on average. While it was 1.34 kg TSS ha^{-1} for the average traditional farming. Based on this, caution is needed in shrimp farming activities for the waste becomes a burden on the aquatic environment, which can reduce the quality of the waters.

Conclusion:-

Based on land suitability calculation in terms of water quality using 7 parameters including Temperature, Salinity, DO, PO4, NO2, NH3, and pH levels, Pasangkayu area was in accordance with the water quality standard set for shrimp farming. Shrimp farming land in Pasangkayu Regency had an area of 3,965.76 ha, comprising respectively of 732.95 Ha of a highly suitable land, 2984.98 Ha of a suitable land, and 247.83 Ha of a conditionally suitable land. Based on the carrying capacity of the aquatic environment to accommodate organic waste, to ensure the development of shrimp farming sustainable, the area for intensive farming was much smaller than semi-intensive and traditional farming. Development of shrimp farming with high investment or intensive technology is directed at f lands with a level of suitability S2 and S3. For the land in level S1 (highly suitable), traditional or traditional-plus farming is designed.

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Conflicts of Interest:
The authors declare no conflicts of interest.

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