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Loading Capacity of Water Pollution from Cage Aquaculture in South Kalimantan Rivers

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ABSTRACT

Decreasing of water quality and exceeding the loading capacity of water pollution are the main causes of the high mortality of cage aquaculture along the river in South Kalimantan province. The research objective was to analyze the river water quality profile, and to evaluate the loading capacity of water pollution around the cage aquaculture. The observations were made at 3 points (upstream, middle and downstream) along Harus river where is the center for the development of cage aquaculture in Banua Lawas District, Tabalong Regency. On each of these points, measurement of physico-chemical parameters of water and flow rates were carried out. Measurement and data collection were performed twice with intervals between measurements for 30 days. Water quality parameters analyzed were water temperature, pH, TSS, NH_3-N, NO_3-N, PO_4-P, BOD, COD, and DO. Based the eight water quality parameters measured, there were three parameters that tend to exceeding the loading capacity of water pollution on all the river segments, namely PO_4-P, (at middle = 16 kg day^{-1}, and downstream = 459 kg day^{-1}), BOD (at upstream = 301 kg day^{-1}, middle = 547 kg day^{-1}, and downstream = 2,086 kg day^{-1}) and COD (at upstream = 521 kg day^{-1}, middle = 380 kg day^{-1} and downstream = 1,249 kg day^{-1}). Exceeding the load capacity of BOD and COD were prone to cause depletion of DO in the river in which can potentially cause massive fish mortality.

Keywords: *cage aquaculture, the loading capacity, water pollution*

INTRODUCTION

The use of river for the cage aquaculture has been attempted by fish farmers in many rivers (Chitmanat *et al*., 2016; Alam et al., 2014; Lebel *et al*., 2013), because the economic contribution of this business is quite large (Ogwu, 2020). Although the threat of failure in the cage culture is quite large because of the high mortality of fish during cultivation. The use of the river for cage aquaculture has been done in South Kalimantan Province, especially in the Harus stream, Tabalong district. The cage aquaculture developed by fish farmers along the river are an intensive fish cultivation system by providing artificial feed. This causes the accumulation of organic waste from excretions and uneaten feed.

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According to McDonald *et al*. (1996), 30% of the amount of feed given is inedible and 25-30% of the food eaten will be excreted. So that there is a large enough organic matter (47.5% - 51.0%) to enter the water body and settle around the cage aquaculture or be deposited in the bottom waters of other fish cultivators' cages downstream. Leftover feed that is not eaten and excreted into water bodies during fish farming contains high levels of organic matter and nutrients (Johnsen *et al*., 1993; Buschmann *et al*., 1996; McDonald *et al*., 1996; Rachmansyah, 2005) which can affect the level of fertility (eutrophication) and the appropriateness of water quality for farmed fish life (Philips *et al*., 1993; Boyd *et al*., 1998).

The enrichment of organic nutrients in the waters will stimulate microbial activity which can reduce DO in the substrate and water

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column, increase BOD, COD, N, P, sedimentation and siltation, hypoxia, hypernutrification, changes in productivity and benthic community structure (Barg, 1992). Reducing dissolved oxygen levels to anaerobic conditions has spurred the formation of unstable compounds, such as ammonia, hydrogen sulfide, and nitrites which can be toxic to fish (Effendi, 2003 and Boyd, 1999) and changes in water quality to conditions that inhibit growth of fish and even causing massive mortality of domesticated fish (Boyd, 1990 and Machbub, 2010). The high intensity of cage aquaculture in the watershed area of the Riam Kanan River is one of the causes of the decrease in the carrying capacity of the waters for aquatic biota (Rahman, 2012). The same incident repeated itself in October 2014.

The mass mortality of cultured fish in cage aquaculture or floating net is a phenomenon that occurs repeatedly in Indonesia. Amount 1,042 tons fishes were died in floating net at Saguling reservoir in 1993, 1,039 tons in the Cirata reservoir in 1994, 1,560 tonnes in the Juanda-Jatiluhur reservoir in 1996 as a result of water fertilization originating from aquaculture (Krismono, 2004) and uncontrolled increase in the number of cage units (Machbub, 2010). This phenomenon tends to reoccured annually in reservoirs and lakes on the islands of Java and Sumatra. The same case has been experienced by cage aquaculture farmers in the Riam Kanan River at the end of 2012 which caused 2,340 tons of fish to die at a loss rate of Rp 42,402 billion (Marine and Fisheries Agency of Banjar Regency, 2012), the same incident repeated itself in October 2014. At the end of 2019 as many as 80 tons fish cage aquaculture died in Martapura River with a loss of up to 1.2 billion. The high density of cages is one of the causes of the decrease in the carrying capacity for aquatic organism (Rahman et al., 2017).

Research on the estimation of the carrying capacity of waters for aquaculture in freshwater lenthic habitats (inundated) has been investigated by Eley *et al.* (1972), Penczak (1982), Baveridge (1984), Pulatsu (2003), Azwar *et al.* (2004), Machbub (2010), Ndahawali (2011) and in coastal waters (Burhanuddin *et al*., 1994; Pongpasan *et al*., 2001; Rachmansyah *et al*., 2002; Rachmansyah *et al*., 2005). The environmental impact of cage fish culture on rivers is often overlooked, and is rarely the subject of research or observation (Lin *et al*., 2003).

MATERIAL AND METHODS

Study area and sampling site

This research was carried out in two watershed areas in the regency which are the centers for the development of cage aquaculture, ie. The Harus River, Tabalong Regency, South Kalimantan Province. Observations were done on 3 conditions of river water utilization which were used as research locations, namely 1) in the upstream part of the river (low-intensity cage aquaculture), 2) at the locations for placing cage aquaculture and 3) point in the downstream (see Figure 1). At each of these locations, observations were made on the physico-chemical parameters of water and flow rates. Sampling and measurement of water samples were carried out using the composite sampling method (combination of places) at three points for each sampling location. Measurement and data collection were performed for 2 times with 30 days time interval between measurements.

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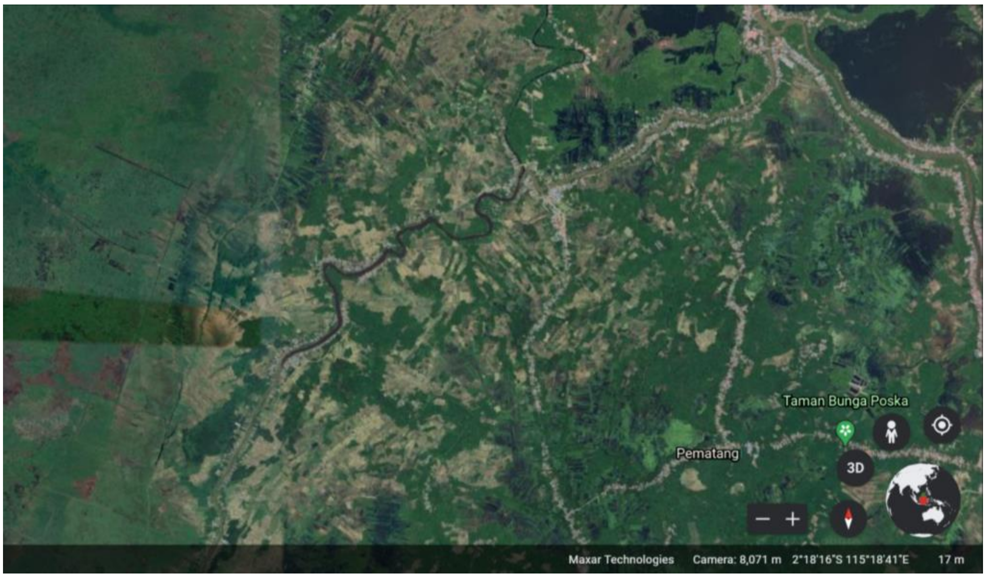

Figure 1. Research location

Water quality sampling procedure

The physico-chemical of water such as temperature, total suspended solid (TSS), pH, nitrate (NO3), ammonia (NH3), phosphates (PO4), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD). Water sampling was accomplished using a composite sampling method. Water samples that are volatile (temperature, pH, DO) were measured directly in the field (in situ), and for water quality parameters that are relatively stable and requiring standard equipment were analyzed in the laboratory. The volume of water samples taken is adjusted to the needs of the analysis.

Water samples taken for analysis in the laboratory were put in a glass bottle (reagent bottle) and then put in a container (cold box) with acidification and cooling treatment during transportation to the laboratory. The collection and measurement of water samples referred to the Indonesian National Standard. Water quality parameters measured, and the methods of taking and measuring water quality samples can be seen in Table 1.

Data Analysis

Flow rate measurements were carried out at 3 points (¼, ½ and ¾ of the river width) in ½ of the river depth at each point. The calculated flow rate was the instantaneous daily discharge which is determined by the following formula (Seyhan, 1977):

$$qn = \frac{1}{2} d_n (V_{vn}) (b_n + b_{n+1})$$

where:

qn = flow rate of river ($m^3.s^{-1}$);
Vvn = average flow velocity at n^{th} vertical ($m.s^{-1}$);
bn = vertical distance between measurement points n and n-1 (m);
dn = vertical depth to n (m).

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Table 1. Measured water quality parameters and analysis method

No.	Parameter	unit	Test method	Reference
1.	Temperature	ºC	Thermometric	SNI 06-2413-1991
2.	pH	-	Electrometric	SNI 19-1140-1989
3.	TSS	mg L^{-1}	Gravimetric	SNI 06-1135-1989
4.	NH_3-N	mg L^{-1}	Spectrophotometric-Nessler	SNI 05-2479-1991
5.	NO_3-N	mg L^{-1}	Spectrophotometric-brusin sulfat	SNI 06-2480-1991
6.	Total Phosphate (PO_4)	mg L^{-1}	Ion selective meter	SNI 06-2470-1991
7.	BOD_5	mg L^{-1}	Incubasi with 25 °C, 5 days	SNI 06-2503-1991
8.	COD	mg L^{-1}	Open Refluks	SNI 06-2504-1991
9.	DO	mg L^{-1}	Electrochemical	SNI 06-2525-1991

Determination of loading capacity of water pollution was determined by the mass balance method. The water pollution load capacity was calculated based on the water pollution load according to the water quality standard and the actual water pollution load. The determination of the actual water pollution load for a single flow was determined by the following equation:

$$BPs = Qs \times Cs(j) \times f$$

Where:
BPs = Single stream pollution load
Qs = River water discharge ($m^3. s^{-1}$)
Cs (j) = Concentration of pollutants (j) (mg L^{-1})
f = conversion factor = 86.4

The water pollution load capacity (WPLC) was determined using the following equation:

$$WPLC = PLQs – APL$$

Where:
WPLC = Water Pollution Load Capacity
PLQs = Pollution Load base on quality standards (according to Quality Act)
APL = Actual Pollution Load

RESULTS

Water quality profile

The results of water quality measurements show a trend of irregular changes between locations (upstream - middle - downstream) and the measurement period. The complete results can be seen in the Table 2.

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Table 2. The water quality at various measurement and periods.

Parameter	unit	Location and measurement period					
		Upstream		Middle		Downstream	
		I	II	I	II	I	II
Temperature	°C	27.3	27.4	27.1	27.3	27.4	27.3
TSS	mgL^{-1}	68	8	55	32	3	12
pH	-	6.62	5.98	6.18	6.21	6.57	6.31
Nitrate, NO_3	mg L^{-1}	0.3	0.5	0.9	2	0.2	0.5
Amoniak, NH_3	mg L^{-1}	0.1	0.05	0.2	0.1	0.15	0.05
Phosphate, PO_4	mg L^{-1}	1.03	4.46	0.91	0.28	1.84	0.17
DO	mg L^{-1}	6.02	6.12	5.94	6.05	6.01	6.04
BOD	mg L^{-1}	16.48	10.67	12.61	18.42	14.55	19.38
COD	mg L^{-1}	18.81	15.05	19.19	19.57	18.81	21.82

Upstream = Sungai Hanyar Village; Middle stream = Banua Lawas Village; Downstream = Bangkiling Village
I = 1st measuring period II = 2nd measuring period

The results measurement of water temperature, TSS, pH, NH_3-N, NO_3-N, PO_4-P, DO, BOD and COD in Sungai Hanyar, respectively: 27.10-27.40°C ($\bar{X}$=27.30±0.11°C); 3.00-68.00mgL^{-1}($\bar{X}$=29.67 ±26.87 mgL^{-1}); 5.98-6.62 ($\bar{X}$=6.31±0.24); 0.20-2.00 mgL^{-1}($\bar{X}$=0.73±0.67 mgL^{-1}); 0.05-0.20 mgL^{-1} ($\bar{X}$=0.11±0.06 mgL-1); 0.17-4.46 mgL^{-1} ($\bar{X}$=1.45 ±1.59 mgL^{-1}); 5.94-6.12 mgL^{-1}($\bar{X}$=6.03 ±0.06 mgL^{-1}); 10.67-19.38 mgL^{-1}($\bar{X}$=15.35±3.38 mgL-1); 15.05-21.82 mgL^{-1}($\bar{X}$=18.88±2.19 mgL^{-1}). Of the nine measured water quality parameters, most of them were still in ideal conditions for fish farming. Parameters that are not in ideal condition are BOD and COD. These parameters are derivative parameter to described DO.

Based on the data from the measurement of water quality, four parameters that have changed between measurement periods. There were TSS = 3.00-68.00 mgL^{-1}($\bar{X}$=29.67±26.87 mgL^{-1}), PO_4-P = 0.17-4.46 mgL^{-1}($\bar{X}$=1.45±1.59 mgL^{-1}), BOD = 10.67-19.38 mgL^{-1}($\bar{X}$=15.35±3.38 mgL^{-1}) and COD = 15.05-21.82 mgL^{-1}($\bar{X}$=18.88±2.19 mgL^{-1}). If related with deviation standard in measured water quality data, these four parameters are parameters that are vulnerable to changes between measurement times. Meanwhile, the other five parameters were measured with small variations between observation periods and between measurement locations (upstream-middle-downstream) with a standard deviation value <1.0.

Water Pollution Load Capacity

Water Pollution Load Capacity (WPLC) at each measurement location is obtained by calculating the actual pollution load (APL) and pollution load based on quality standards (PLQs). The difference between PLQs and APL is WPLC. The results of water pollution load capacity can be seen in Table 3.

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Table 3. Water pollution load capacity (kg d^{-1}) of the Hanyar River based on the water drainage area segmentation

Parameter	Upstream	Middle	Downstream
TSS	1,693.52	263.25	2,162.65
NO_3-N	266.18	346.28	1,730.12
NH_3-N	11.22	14.18	76.59
PO_4-P	7.48	-16.00	-458.66
BOD	-300.95	-547.36	-2,086.06
COD	-520.77	-379.89	-1,248.93

The results of the calculation of WPLC Sungai Hanyar which are calculated in kg day^{-1} (Table 3), there are 3 water quality parameters that have exceeded the WPLC, namely: PO_4-P, BOD and COD with the respective values: (-16.00 kg d^{-1}) - (458.66 kg d^{-1}); (-300.95 kg d^{-1}) - (-2,086.06 kg d^{-1}); (-379.89 kg d^{-1}) - (-1,248.93 kg d^{-1}). The pollution load capacity profile can be seen in Figure 2.

	TSS	NO3-N	NH3-N	PO4-P	BOD	COD
Upstream	1694	266	11	7	-301	-521
Middle	263	346	14	-16	-547	-380
Downstream	2163	1730	77	-459	-2086	-1249

Figure 2. The pollution load capacity profile at several river segments

Based on the results of these calculations, there is a tendency for the pollution load to be higher in the downstream. BOD and COD are the parameters that experience the largest pollution loads and have exceeded of water pollution loads capacity on all river segments. Meanwhile, the parameter with the smallest pollution load is TSS.

DISCUSION

Water Quality Profile

The results of water quality measurements (Table 2), there are four parameters that are not ideal for cage fish cultured, i.e.: TSS, phosphate,

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BOD and COD. The TSS value (3.00-68.00 mg L^{-1}, $\bar{X}$=29.67±26.87 mg L^{-1}) tend to be greater upstream and smallest downstream. The high TSS was a direct and indirect effect on fish. The direct effect can occur through attachment to the gill filaments, thereby reducing the ability to absorb oxygen. The indirect effect is the disturbance of sight in feeding. The TSS showed a tendency to exceed the ideal for fish life in the upstream and middle. The TSS predicted to rise in the rainy season, when debit increases (Kustamar and Wulandari, 2020).

The phosphate measured 0.17-4.46 mgL^{-1} ($\bar{X}$=1.45±1.59 mgL^{-1}) with the highest concentration in the upstream and the lowest in the middle. Phosphate is phosphorus in the form of particulates dissolved in water and is a nutrient needed by all organisms for the basic processes of life and is an essential element for higher plants and algae so that it affects aquatic productivity (Bahri, 2006). The loading of N and P that is wasted into the aquatic environment can be used to estimate the carrying capacity for the development of fish farming in public waters (Beveridge, 2004). Phosphorus in waters and sediments is in the form of dissolved phosphate compounds and particulate phosphates. Dissolved phosphate consists of organic phosphate (sugar phosphate, nucleoprotein, phosphoprotein) and inorganic phosphate (orthophosphate and polyphosphate) (Ambasankar and Ali, 2002). The presence of phosphate in the waters will break down into ionic compounds in the form of H_2PO_4, HPO_4^{2-}, and PO_4^{3-}, then it will be absorbed by phytoplankton and enter the food chain (Nwanna *et al*., 2009). Sources of phosphorus in waters and sediments are phosphorus deposits, industry, domestic waste, agricultural activities, phosphate rock mining, and deforestation (Asir and Pulatsu, 2008). Phosphate in waters naturally comes from weathering of mineral rocks and decomposition of organic matter. When the phosphate in water bodies is in excessive amounts, it will be re-deposited into the sediment pores through sedimentation, adsorption and precipitation processes. Thus, sediment in a waters has an important role in the eutrophication process because it acts as a source and reservoir of phosphate (Williams and Mayer 1972). In fresh and brackish waters, the release of phosphorus from aquaculture cage units can cause hypernutrification which can lead to eutrophication. The phosphate value showed that can trigger eutrophication. The EPA recommends that total phosphate (as phosphorus) levels should not be > 0.05mgL^{-1} in streams at the point of entry to lakes or reservoirs and not > 0.1mgL^{-1} in streams that do not enter a lake or reservoir directly (Murphy, 2007).

Ammonia is a nitrogen compound that is toxic to fish and other aquatic organisms and its presence is undesirable because it is toxic. It's produced from the decomposition of organic nitrogen compounds derived from living tissue or protein-containing materials under anaerobic or oxygen deficient conditions. Artificial feed given to domesticated fish for intensive fish farming such as fish culture in cages is a source of nutrient waste to the aquatic environment around the fish farming area. These nutrient wastes come from uneaten feed, urine and faecal (Asir and Pulatsu, 2008; Johnsen et al., 1993 and Rachmansyah et al., 2004). The entry of nutrient waste into the aquatic environment causes an increase of total-P and organic nitrogen which are the main nutrients associated with eutrophication of lakes and streams (Chun et al., 2010). The results of measuring ammonia value are 0.05-0.20mgL^{-1}($\bar{X}$=0.11±0.06mgL^{-1}) and are still supportive for fish life. Ammonia value of 0.25 - 0.5 ppm can cause stress for fish and more than 1.0 ppm can kill domestic fish (MacParland, 2008).

BOD measures the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water. COD measures the oxygen requirement to oxidize dissolved compounds and organic particles in water. BOD and COD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD and COD, the more rapidly oxygen is depleted in the stream. The consequences of high BOD and COD are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die. The BOD (10.67-19.38 mgL^{-1}, $\bar{X}$ = 15.35±3.38 mg L^{-1}) and COD (15.05-21.82 mgL^{-}

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1, $\bar{X}$ = 18.88±2.19 mgL^{-1}) has the potential to reduce dissolved oxygen. The high value of these two parameters indicate that the waters have been contaminated with organic matter (Pramaningsih *et al*., 2020) which can come from the aquatic environment (*authochtonous*) and come from outside the aquatic environment (*allocthonous*). These two parameters are closely related to dissolved oxygen concentration, the magnitude of the BOD and COD values will have an effect on reducing oxygen solubility in the waters which has the potential to cause hypoxic conditions which can cause mass death in fish in the waters, especially cultured fish (Hasim et al., 2017 and Zhang et al., 2012). Hypoxic conditions will become anoxia if nothing oxygen supply from the outside environment.

Water Pollution Load Capacity

Based on the data listed in Table 3, there are 3 parameters that tend to exceed the water pollution load capacity, namely PO_4, (middle = -16 kgs d^{-1}; downstream = -458.66 kgs d^{-1}), BOD (upstream = -301 kgs d^{-1}; middle = -547 kgs d^{-1}; downstream = -2,086 kgs d^{-1}) and COD (upstream = -521 kgs d^{-1}; middle = -380 kgs d^{-1}; downstream = -1.249 kgs d^{-1}). The increase of BOD and COD concentration mainly comes from the breakdown of organic matter in the waters. These organic materials can be sourced from outside the aquatic environment and within the waters themselves. Waters with high BOD and COD concentration indicate that the water is polluted by organic matter and can cause the death of aquatic organisms (Amira et al., 2021 and Iqbal et al., 2018). The of BOD and COD concentration in waters that are not contaminated with organic matter are less than 3 mgL^{-1} and 20 mgL^{-1}, respectively (Appendix 6 Government Regulation No. 22/2021). Fish farmers generally provide additional feed and artificial feed to fish farming in order to spur the growth of the fish they are raising. This activity is sometimes carried out without paying attention to the optimum feed dose, so that some of the feed is not consumed by the fish and settles on the bottom of the water and mixes with fish excrement. Excess feed and fish manure that settles on the bottom of the waters will naturally decompose. The nature of organic compounds is generally unstable and easily oxidized biologically or chemically to become self-stable, including CO_2 and H_2O. This process causes the dissolved oxygen concentration in the waters to decrease and this causes problems for aquatic life (Iqbal et al., 2018).

CONCLUSSION

a) The water quality profiles that tend to be not ideal for fish life are PO_4-P, BOD and COD, these parameters can be the cause of hypoxic conditions in water bodies that can cause mass fish mortality in a certain period (usually occurs at the peak of the dry season).

b) PO_4-P, BOD and COD are in a condition that exceeds the carrying capacity of the pollution load which indicates the dominance of organic pollutants which can be sourced from the aquatic environment (authoctonous) and outside the water / outside the cultivation location (allochtonous).

c) The excess load capacity of BOD and COD pollution is prone to cause depletion of dissolved oxygen in water bodies which can cause mass fish mortality if the dissolved oxygen supply is reduced.

Water pollution control related to efforts to reduce the burden of organic and inorganic pollution must be carried out in an integrated manner involving various government agencies / institutions. Because the problems faced are the result of contributions from various activities, so cross-sectoral handling is needed. This management body should have clear authority over the water body being managed.

An inventory and mapping of environmental conditions is needed to facilitate the management and direction of land use, which includes the unity of the area from upstream to downstream.

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