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POLLUTION INDEX AND ECONOMIC VALUE OF VANNAMEI SHRIMP (*Litopenaeus vannamei*) FARMING IN INDONESIA

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ABSTRACT

Shrimp farming has contributed a large share in Indonesia's aquaculture portfolio for at least a decade, and a national plan to increase shrimp production by 250% has been recently laid out. However, boosting shrimp productions could lead to unintended consequences in environmental and socio-economic negative impacts. The rapid development of vannamei farming in Java has increased coastline land clearings and demands of fertilizers, feeds, and chemicals to sustain the farming activities. Such pressures will eventually lead to a reduced environmental capacity and the farming efficiency itself. This study aimed to study the environmental impacts and business performance of intensive shrimp farming in Indonesia. The study was conducted in Aquaculture Business Center (ABC) in Karawang for four months, from July to October 2020. *In-situ* and *ex-situ* measurements of water quality parameters were done at six sampling stations directly post-harvest water discharge. The measured parameters consisted of temperature, pH, dissolved oxygen, ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), alkalinity, and salinity. Pollution Index (PI) was used as the primary method to determine the environmental impacts of the shrimp farming. The R/C Ratio was used to analyze the business performance of the company. The results showed that the water quality index in the ABC area was categorized as lightly polluted in station 1 (PIj 4.52) and station 5 (PIj 4.37), moderately polluted in station 2 (PIj 6.24), station 3 (PIj 6.72), and station 4 (PIj 6.13) and heavily polluted in station 6 (PIj 111.06). The determined R/C ratio was 1.10, meaning that the shrimp farming is classified as economically profitable. Although the shrimp farming's economic performance value is very good, the water conditions affected by waste from the shrimp pond culture will reduce the R/C ratio in the future if not properly managed.

KEYWORDS: pollution index; water quality; vannamei; R/C ratio; environment

INTRODUCTION

According to the Food and Agriculture Organization (FAO), Indonesia is the second-largest farmed-shrimp-producing country in ASEAN, slightly behind Vietnam (FAO, 2018). Indonesia's highly valued farmed shrimp is exported to international markets, contributing to Indonesia's significant foreign revenue (Hadie & Hadie, 2017; Tran *et al.*, 2017). Farmed shrimp products from Indonesia are mainly exported to the United States, Japan, and the European Union. In 2016, farmed shrimp production in Indonesia ranked third globally with 644,000 tons (FAO, 2018). It was slightly below Vietnam in second with 694,400 tons and China as the top producer of 1.600.000 tons (FAO, 2018). According to the Indonesian National Statistical Data in 2019, farmed shrimp commodity led the national fishery export products within the last five years (2013-2017). It grew at an average of 6.43% per year within the period (BPS, 2019).

Aquaculture is the fastest-growing food production system globally, bringing potential solutions and new challenges for marine and coastal sustainability (Partelow *et al.*, 2018). Aquaculture contributes 44.1% of the total world's fish supply of 167.2 million tons with an annual increase rate of 8% (Jayanthi *et al.*, 2018). Considering Indonesia has enormous potential resources with a total indicative land area of 17.2 million hectares suitable for aquaculture, it is estimated that aquaculture could contribute a direct economic value of 250 billion USD per year (KKP, 2018).

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The Indonesian government launched a revised target of increasing vannamei shrimp exports by 250% in 2024 (Kemenko Marves, 2020; KKP, 2020). This revised target means that the total value of farmed vannamei has to reach IDR 90.30 trillion (USD 6.45 million) by 2024 from IDR 36.22 trillion (USD 2.58 million) in 2019. In terms of production volume, the total shrimp production should increase from 517,397 tons in 2019 to 1,290,000 tons in 2020. As part of the effort, the Indonesian Coordinating Ministry of Maritime and Investment released a program to increase vannamei farming areas to 86.000 hectares until 2024 (Kemenko Marves, 2020).

As a result, shrimp farming has caused concerning socio-economic and environmental impacts (FAIRR, 2019; Galappaththi & Berkes, 2015; Mitro *et al*., 2014; Saha, 2017). For example, the Ministry of National Development Planning (BAPPENAS) in 2014 reported that many aquaculture business entities in Indonesia have not yet implemented Good Aquaculture Practices (Bappenas, 2014). The increase in land-based shrimp farming activities will eventually lead to the clearing of mangrove forests, increased use of feeds, fertilizers, and inappropriate application of chemicals that can negatively impact the environment (Boyd, 2003; De Lacerda *et al*., 2006; Tarunamulia *et al*., 2016).

In Bengkalis Kembung River, Indonesia, a massive shrimp pond development had degraded the water quality of the adjacent rivers in from of increased BOD_5, nitrate (NO_3), and phosphate ($PO4^-$) values (Harianja *et al*., 2018). In other areas of Indonesia, such as in Kawaru Beach and Losari Subdistrict, the establishment of vannamei ponds has changed the coastal landscape (Pinto, 2016) and increased the likelihood of harmful algal blooms (HABs) occurrences (Tarunamulia *et al*., 2016). In Andulang village-Sumenep East Java, Indonesia, the rapid development of shrimp ponds has impacted nearby agricultural land and released ammonia pollutants to the adjacent coastal area (Hidayatillah, 2017). Also, high protein feed in shrimp culture can release nitrogen pollutants and organic matter to the surrounding waters (Imamah *et al*., 2013).

The contradicting features of shrimp farming (its impact on the environment but profitable as a business) have attracted global attention from various stakeholders such as academics, practitioners and private businesses. In most cases, research related to shrimp cultivation have reported massive negative impacts of shrimp farming on the environment (Páez-Osuna, 2001). A new approach needs to be developed that strikes a balance between producing a high yield of shrimp and maintaining the quality and function of the environment. Therefore, this research aimed to analyze the environmental impacts and link them to the business performance of an Indonesian shrimp farming system.

MATERIALS AND METHODS

Research Site

The research was carried out for four months from July to October 2020 at vannamei ponds owned by the Aquaculture Business Center (ABC) in Karawang Regency-West Java, Indonesia.

Research Data

Water samples were collected at six stations, namely mixed channel A (1), mixed channel B (2), seawater receptacle (3), Ciwadas River (4), Cimunclak River (5), and outlet channel (6) (Fig 1). The water samples were collected shortly after the ponds' water was discharged post shrimp harvest. *In-situ* measurements of water quality parameters were temperature (YSI 550A-SNI 06-6989.23-2005), pH (pH meter-SNI 06-6989.11-2004), dissolved oxygen (YSI 550A-SNI 06-6989.14-2004), and salinity (refractometer). *Ex-situ* measurements of water quality parameters were ammonia (NH_3) (Spektrofotometer-SNI 06-6989.30-2005), nitrite (NO_2) (Spektrofotometer-SNI 06-6989.9-2004), nitrate (NO_3) (Spektrofotometer-SNI 6989.79-2011), phosphate (PO_4) (Spektrofotometer-SNI 06-6989.30-2005), and alkalinity (titrate) in Laboratorium of Aquaculture Business Center. The farming business analysis was taken through direct observation and interviewing pond managers.

Data Analysis

The measure of temperature, pH, dissolved oxygen, ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), alkalinity, and salinity. The results were then analyzed using Pollution Index (PI) method by referring to the Ministerial Decree of Environment No. 115 of 2003. The R/C Ratio analysis was applied to analyze the business process of the ABC company. All the data were processed and analyzed using Microsoft Office Excel 2007 software. The step-by-step data analysis can be explained as follows:

a. Pollution Index (PI)

An index that can determine the water quality status is the pollution index (PI). The classification of water quality using PI was first introduced by Nemerow & Sumitomo (1970) and incorporated in the Ministerial Decree No. 115 2003 as one of the standard methods to determine water quality level (Table 1).

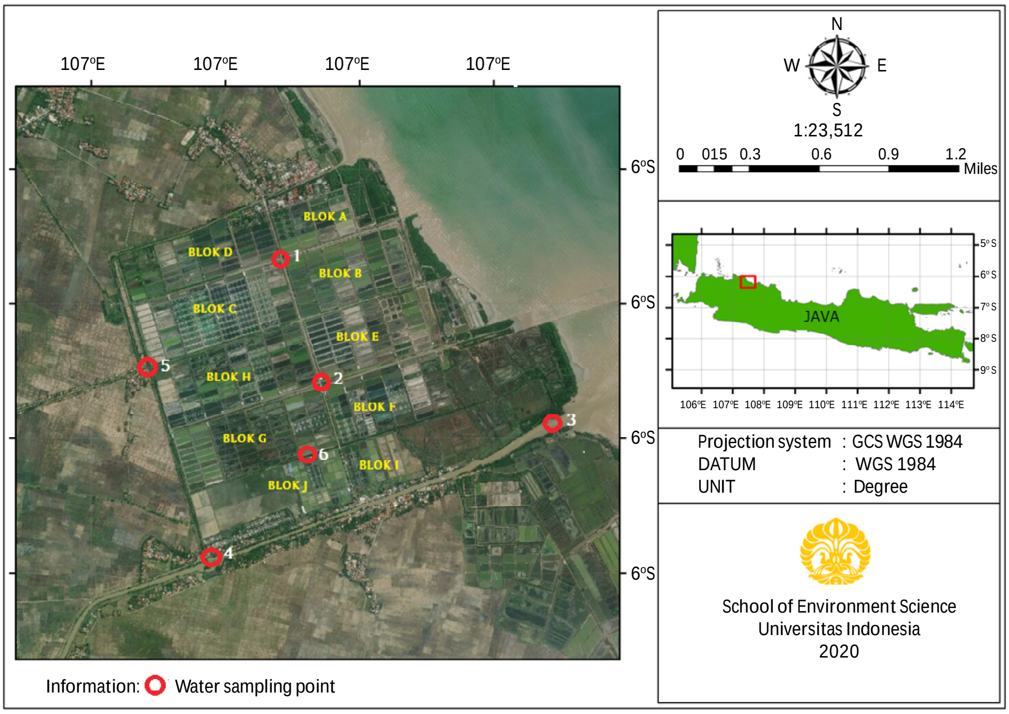

Figure 1. Location of sampling sites

This Pollution Index (PI) provides simple numerical categorization to decision-makers to assess whether the condition of a water body deteriorates due to the presence of pollutants. Pollution Index (PI) covers a variety of independent parameter groups. The Pollution Index is calculated using the formula as follows (Nemerow & Sumitomo, 1970):

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}} \quad ....(1)$$

Information:

PI_j = Pollution index for the-j designation

Ci = Concentration of the-i water quality parameter measured

Lij = Concentration of the-i water quality parameters listed in the-j designation quality standard (quality standard for marine biota)

$(Ci/Lij)_M$ = Maximum value of Ci/Lij

$(Ci/Lij)_R$ = Average value of Ci/Lij

b. Analysis of R/C Ratio

Revenue Cost Ratio analysis is a value obtained from the ratio between total revenue and total production cost. This analysis is used to determine the economic profitability obtained from an aquaculture activity using the R/C Ratio 2 equation below.

$$R/C = \frac{\text{Total revenue}}{\text{Total cost of production}} \quad ....(2)$$

With criteria:

R/C > 1, profitable business

R/C < 1, business loss

R/C = 1, effort at breakeven

RESULTS AND DISCUSSION

Pollution Index (PI)

The results of water quality measurements at six stations are presented in Figure 2.

The Aquaculture Business Center (ABC) area in Karawang is bordered to the north by the North Coast of Java, the south by Cimunclak Hamlet, and the east by Ciwadas River. Surrounded by the two water bodies, it is highly likely that the shrimp farming activity might have already impacted the surrounding waters. Cultivation activities throughout the year release a continuous discharge of waste particles into the water (Zhang *et al*., 2019). The ponds' wastewater contains pollutants from wasted feed, fertilizer, chemicals, and metabolites excretion (Anh *et al*., 2010). Dauda *et al.* (2019) argued that aquaculture waste is usually discharged in dissolved solids and dissolved nutrients such as nitrogen and phosphorus.

The water temperature in six sampling stations shows normal ranges between 28.1-29.6°C, meaning that the temperature is still the standard threshold of Government Regulation No 22 2021. No local external factors are affecting the water temperature, such as the cases in shrimp ponds in Indramayu Re-

Table 1. Determination of water categories according to Pollution Index (The Ministry of Environment No. 115 2003)

Value of water quality index	Category
$0 \leq PI_j \leq 1.0$	Water quality standards
$1.0 < PI_j \leq 5.0$	Lightly polluted
$5.0 < PI_j \leq 10$	Moderately polluted
$PI_j > 10$	Heavily polluted

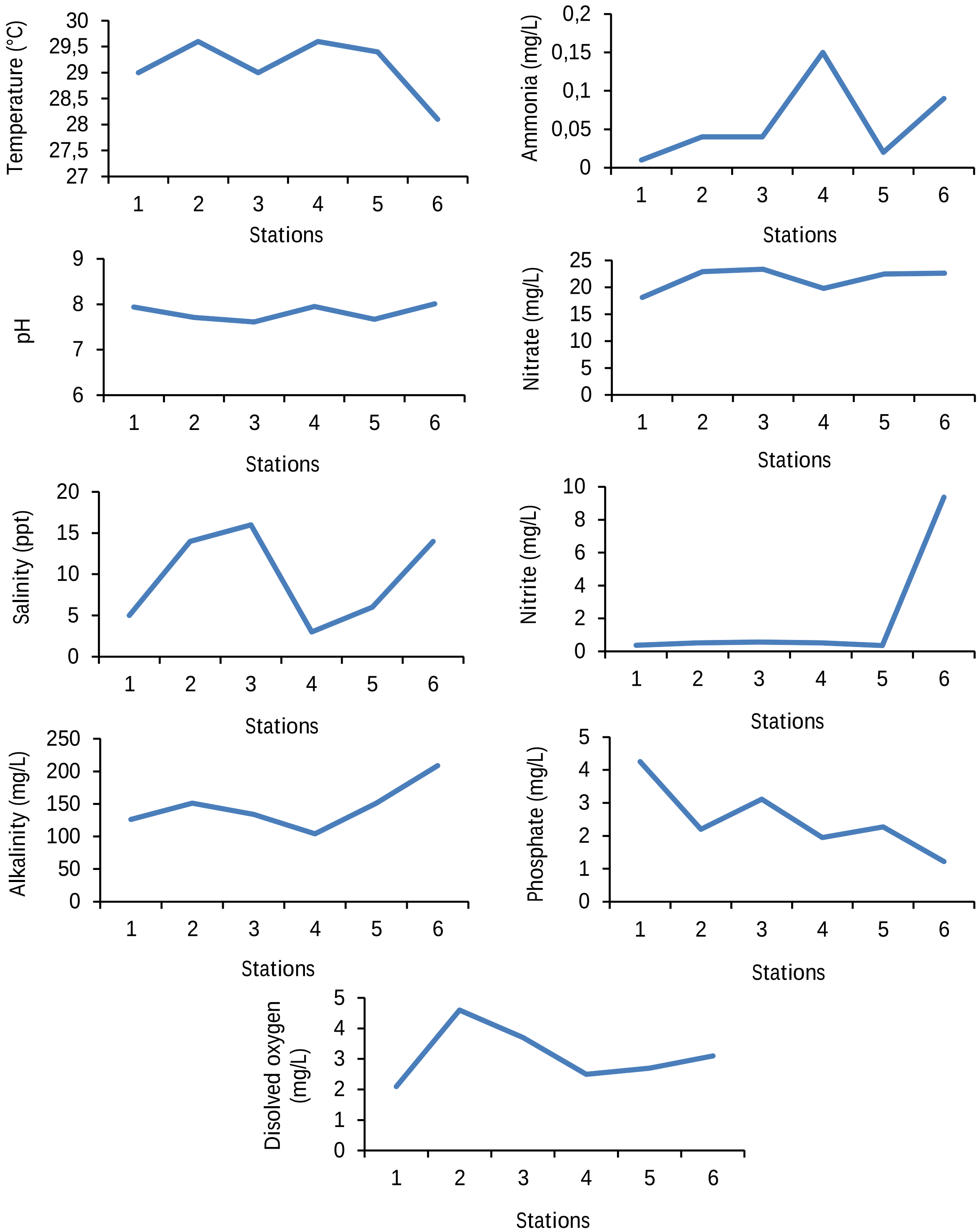

Figure 2. Water quality in ABC waters

Table 2. Collection data of water quality

Parameters	Quality standard*	Station					
		1	2	3	4	5	6
Temperature (°C)	28-32	29	29.6	29	29.6	29.4	28.1
pH	6-9	7.94	7.71	7.61	7.95	7.67	8.01
Salinity (ppt)	10-35	5	14	16	3	6	14
Alkalinity (mg/L)	80-150	126	**151**	134	104	**151**	**209**
Ammonia (NH_3) (mg/L)	< 0.5	0.01	0.04	0.04	0.15	0.02	0.09
Nitrate (NO_3) (mg/L)	20	18.09	**22.93**	**23.38**	19.8	**23.48**	**22.64**
Nitrite (NO_2) (mg/L)	0.06	**0.37**	**0.52**	**0.56**	**0.51**	**0.36**	**9.36**
Phospate (PO_4) (mg/L)	1	**4.25**	**2.2**	**3.11**	**1.95**	**2.27**	**1.22**
Dissolved oxygen (mg/L)	3	**2.1**	4.6	3.7	**2.5**	**2.7**	3.1

Explanation: * Government Regulation No 22/2021 (Attached VI)

Table 3. Pollution Index (PI) Calculation Results

PI calculation phase	Stations					
	1	2	3	4	5	6
$(Ci/Lij)_M$	6.17	8.67	9.33	8.5	6	156
$(Ci/Lij)_R$	1.68	1.65	1.8	1.69	1.48	18.24
$(Ci/Lij)_M^2$	38.07	75.17	87.05	72.25	36	24,336
$(Ci/Lij)_R^2$	2.83	2.73	3.25	2.85	2.2	332.81
$(Ci/Lij)_M^2 + (Ci/Lij)_R^2$	40.9	77.89	90.3	75.1	38.2	24,668.81
$\frac{(Ci/Lij)_M^2 + (Ci/Lij)_R^2}{2}$	20.45	38.95	45.15	37.55	19.1	12,334.4
$\sqrt{\frac{(Ci/Lij)_M^2 + (Ci/Lij)_R^2}{2}}$	4.52	6.24	6.72	6.13	4.37	111.06
Pij (PI Status)	Lightly polluted	Moderately polluted	Moderately polluted	Moderately polluted	Lightly polluted	Heavily polluted

gency, West Java (Utojo *et al*., 2013), Pati ponds in Central Java (Asaf *et al*., 2015), and Maros ponds in South Sulawesi (Utojo *et al*., 2011). This temperature range is the typical value range in most areas in a tropical country such as Indonesia. According to Alberto (2016), extreme temperature changes might affect an organism's metabolic rate, altering the spatial distribution of organisms both in the ocean and the freshwater ecosystem. Furthermore, the temperature also significantly affects the growth and life of aquatic biota (Alberto, 2016).

The water's pH (acidity level) of the ABC sampling stations is normal from 7.61-8.01 and still within the threshold of Government Regulation No 22 2021 where normal pH should not be out of the range of 6-9 for aquaculture farming. Another regulation, the Ministerial Decree of Marine Affairs and Fisheries No.28/2004, also recommends that the pH should not be out of range 6-9 for the discharged water pond effluents in shrimp culture. This is the same as the pH of the waters in the Indramayu and Maros ponds (Utojo *et al*., 2011, 2013) and the waters in the Pati ponds, Central Java (Asaf *et al*., 2015). This study finding is different from the study results by Yu *et al*. (2020), who showed that pH values of 6.5 and 9.5 had caused a significant reduction in shrimp growth. The pH is described as the number of hydrogen ions in water, which generally represents the acidity or alkalinity of water (Effendi, 2003). Changing in pH may affect the productivity of aquatic animals and plants.

Therefore, pH is often used to indicate whether or not the waters could support the life of the aquatic animal (Effendi, 2003).

In station 1 (mixed channels A), station 4 (Ciwadas River), and station 5 (Cimunclak River), the salinity values were 5 ppt, 3 ppt, and 6 ppt, respectively, which are below the suggested standard. These numbers indicate that the salinity at that stations is far below the threshold stated in the Government Regulation No 22/2021. The freshwater mass from the rivers influences the three stations' salinity levels. According to Supriadi (2001), salinity changes are often caused by rainfall and seawater masses' mixing with freshwaters, forming brackish water with unique physical characteristics.

For the alkalinity, only station Six has exceeded the threshold, where the value was 209 mg/L. Station Six is the outlet channel of the pond. Effendi (2003) defines alkalinity as a buffer capacity to decrease the waters' pH. Another water quality parameter, the ammonia content, is the main parameter in determining water quality concerning nitrogen concentration in waters. Ammonia values between 0.01-0.15 mg/L indicate that the water condition is still within the quality standard based on the PP. 22 of 2021 ammonia threshold 0.5 mg/L, while the standard quality value of the Decree of the Minister of KP No. 28 of 2004, is <0.1 mg/L. This finding is the same as the research results of Romadhona *et al*. (2016), who found the ammonia value ranges from 0.02–0.12 mg/L in their study sites. However, ammonia values <0.02 mg/L can inhibit growth and cause tissue damage in some fish species (Wahyuningsih *et al*., 2020). Putri *et al*. (2019) stated that industrial areas, agricultural land, and residential areas are the main contributors to ammonia. High concentrations of ammonia in waters can reduce dissolved oxygen levels that eventually affect physiological and metabolic functions such as respiration (Zhang *et al*., 2013).

Station Two, Three, Five, and Six have exceeded the allowable nitrate concentration. The nitrate concentration was 22.93 mg/L, 23,38 mg/L, 23,48 mg/L, and 22,64 mg/L, respectively. Based on the Government Regulation No. 22 of 2021, the nitrate threshold is 20 mg/L for shrimp farming, while the Ministerial Decree of Environment 2004 limits the nitrate threshold for marine biota to less than 0.008 mg/L (Harianja *et al*., 2018; Putri *et al*., 2019). Shrimp culture may increase nitrate amount due to the feed and fertilizers' leftover accumulated at the pond's bottom. For instance, Harianja *et al*. (2018) reported that about 457 tonnes of nitrate had entered the Kembung River in Bengkalis each year due to the shrimp cultivations and crops along the river. According to Nasir *et al*. (2018), agricultural, household, and aquaculture activities discharge large quantities of nutrients (N-P) along the Pangkep River, South Sulawesi. One of the factors that influence the presence of nitrate in water is the source of nitrate itself. Nitrate in water bodies can be derived from atmosphere diffusion, fixation, organic matter degradation, and organic waste disposal due to human activities (Effendi, 2003).

The concentration of nitrite has exceeded the allowable concentration as guided in the Government Regulation. In Station Six, the nitrite concentration was about 9.36 mg/L. Station Six is the outlet channel of ABC's ponds. According to PP No. 22 2021 and KEP.28/MEN/2004, the nitrite threshold concentration is between 0.06 mg/L-2.5 mg/L. As a comparison, Putri *et al*. (2019) reported that the concentration of nitrite in Banyuasin River Estuary ranged from 0.002 to 0.093 mg/L, while Nasir *et al*. (2018) reported nitrite concentration in Pangkep ranged from 0.004 to 0.006 mg/L. Pantjara *et al*. (2015) reported that nitrate content in seawater and reservoirs was about 0.040 ± 0.0416 mg/L and 0.045 ± 0.0439 mg/L, respectively. Therefore, the concentration of nitrite in the Aquaculture Business Center (ABC) area was the highest compared to other areas. This result indicates that the Aquaculture Business Center in Karawang has been contaminated with some organic pollutants. Nitrite (NO_2) is an oxidized form of nitrogen with an oxidation number of $+3$ and can be found in wastewater, river water, and drainage treatment plants. Nitrite is a critical parameter in determining water quality because it is toxic when it reacts with hemoglobin in the blood, blocking the blood from binding oxygen (Effendi, 2003).

The phosphate concentration at all stations has exceeded the allowable threshold ranged between 1.22-4.25 mg/L. Based on the Government Regulation PP No. 22 of 2021, phosphate's natural occurrences should not exceed 1 mg/L, and regulation of KEP.28/MEN/2004 limits the phosphate to not exceed 0.1 mg/L. The application of fertilizer during shrimp cultivation is the primary source of phosphate in the ponds. The leftover feed and fertilizer then released into the environment, increasing the phosphate and other organic matters to the river (Rawson *et al*., 2007). High organic matter may double the waters' primary productivity and eventually decrease dissolved oxygen (Ahmed *et al.,* 2010). The phytoplankton and bacteria in the bottom of the pond may reduce the phosphate concentration since they can absorb phosphate and use it in their metabolic process. The absorption of phosphate can also occur in the pond's bottom sludge if there is Ca_2^+ or Fe_3^+ that may help absorb the phosphate. The content of orthophosphate in water is often used to indicate the level of primary productivity of waters. Phosphate in inorganic form is assimilated by phytoplankton and circulates in estuary waters (Supriadi, 2001).

Dissolved oxygen (DO) contents in stations One, Four, and Five are the lowest DO level compared to the other stations. The DO concentration was 2.1 mg/L, 2.5 mg/L, and 2.7 mg/L, respectively. Based on the Government Regulation No. 22 of 2021 and KEP.28/MEN/2004, the limit of DO in aquatic farming should not exceed 3 mg/L. Interestingly, based on the results, the low DO contents occurred when the salinity concentration was low. This situation contradicts the study results conducted by Maicá *et al*. (2014), who found that the higher the salinity, the lower the dissolved oxygen. It is argued here that the water at the three stations, which are located in rivers and mixed water tanks, is consistently influenced by the low salinity freshwater from the river. The water also has substantial organic matter concentration where oxygen is used to break down the organic material, reducing dissolved oxygen. Low dissolved oxygen in water may affect biological functions, inhibit growth, or even causing death to some aquatic organisms (Rahman *et al*., 2020). The concentration of oxygen in a water body will decrease due to the organic element's decomposition (Rawson *et al*., 2007).

The Pollution Index (PI) method has been used to determine the water quality status of the ABC's shrimp farming based on the data provided in Table 2. The results of the PI calculation are presented in Table 3. These PI values refer to the Minister of Environment Decree No. 115 of 2003, which classify that the water quality of ABC shrimp farming is categorized as light to heavily polluted with the score of PIj > 10. This water pollution is caused by shrimp pond activities that contribute to the high nitrogen and phosphate concentrations disposed of directly without going through a treatment process (Kawasaki *et al*., 2016). The water pollution level in the study site could be attributed to the lack of sufficient wastewater treatment plants provided by the company.

Nowadays, water could become "an expensive and scarce item" since anthropogenic pollutants such as domestic wastewater, agricultural waste, and shrimp farming waste have contaminated and worsened the water quality. On the other hand, the shrimp economic activity also plays an essential role in the local's economy. Harianja *et al*. (2018) argued that the economy should not be put on top of the ecology's concern. For instance, fish farming uses a large amount of marine and freshwater. Since the water resources are open access where anyone can utilize them, a precautionary approach regarding the resources' use should always prioritize the minimal impacts to the resources.

Business Analysis

The business analysis of the vannamei farming was calculated based on one pond per cycle with total revenue IDR 102,880,719, total cost IDR 93,869,539, and benefit IDR 9,011,180. Therefore, the R/C ratio is 1.10, where R/C >1 meaning that the shrimp farming business is profitable or economically viable (Table 4). The highest cost component in the production of vaname is the cost of feed with an average price of IDR 13,000/kg. It contributes 46,1% of the total cost, followed by the electricity (20,5%), the cost of fry (17%), pond production facilities (13.5%), and labor (2.9%).

Table 4. Business analysis of shrimp farming

Components	Yield
Land area (ha)	0.45
Density (shrimp/m^2)	68
Amount of stocking (shrimp)	307,056
Amount of feed (kg)	3,054
Days of culture (DOC) (day)	70
Survival rate (%)	39.36
Survive (shrimp)	120,857
Main body weight (g)	13.18
Shrimp size (shrimp/kg)	76
Production biomass (kg)	1,593
FCR	1.92
Shrimp selling price (IDR/kg)	64,583
Revenue (IDR)	**102,880,719**
Cost (IDR)	**93,869,539**
Benefit (IDR)	**9,011,180**

CONCLUSION

Some organic pollutants have contaminated shrimp farming in the Aquaculture Business Center (ABC) area of Karawang Regency. The current pollution status water is classified from lightly to heavily polluted. Based on the R/C analysis, it can be concluded that shrimp farming is economically viable and profitable. However, this study suggests that the future profitability of the farm could be negatively affected if the level of water pollution in the area is not adequately addressed. Improving the capacity of wastewater treatment plants, efficient feeding management and following the general rules of Good Aquaculture Practices could extend the sustainability of the farming system.

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