Post-mining pond water suitability for fisheries culture in West Aceh, Indonesia

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Abstract. Coal mining pools can be used as an abundant water resource. Water is a natural resource that is very important for the survival of all living things. The review of pond water quality is expected to help fish farmers determining the coal mines water physical and chemical suitability for farming ponds. Physical-chemical parameter testing was carried out by measuring the temperature, total suspended solids (TSS), turbidity, pH, dissolved oxygen (DO), ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), sulfuric acid (H_2S), iron (Fe) and manganese (Mn). The results showed that the water quality of previous coal mining ponds in the West Aceh area meet the quality standards for the parameters: temperature, DO, NO_3, NO_2, PO_4 and Mn, while for the TSS, turbidity, pH, NH_3, H_2S and Fe the requirements (based on the SNI 7550:2009) for the fish cultivation in calm water ponds are not met.
Key Words: water quality, after the coal mine pool, fish cultivation.

Introduction. In the past, the mining industry had a significant contribution to the economy, but nowadays the Acid Mine Drainage (AMD) mining operations were abandoned in Air Asam Tambang, due to changes not only in the mining industry, but also in the social and economic conditions (Matsumoto et al 2016; Kiswanto et al 2020a). On the other hand, the industrial development and the technological advances cause environmental damages. Industrial activities such as mining and fossil fuels burning contribute to the environmental degradation and climate change (Saviour 2012; Adejoke et al 2020). The open-pit mining activities cause pressure on the surrounding environmental ecosystem, due to changes in the physical and chemical quality of the surface water, especially by the heavy metal pollution and subsequent accumulation in the food chain (De Lima e Silva et al 2012; Guan et al 2014; Kurniawan 2017; Kiswanto et al 2018; Kiswanto et al 2020a). Several heavy metals, such as Pb, Zn, Mn, Fe, Cr, Cu, Ni, Sn, As, and Cd, were detected in former coal mining and tin mining sites (Ashraf et al 2012; Daniel et al 2014).

The coal mining activities at the PT. Mifa Bersaudara site use an open cast method with mine drainage and dewatering. The water sourcesare rains and runoffs flowing into the pond and released by pumping. On the northern side, an open channel will be built in order to prevent water going into the pit. During the rainy season, inundation and water overflow often occur on the ground floor of the mine, due to the well capacity limitations, which cannot accommodate the incoming water volume. Based on the analysis of rainfall data for 2005-2014, the rainfall forecast was of 74.27 mm day^{-1} and the intensity of rainfall was 25.75 mm $hour^{-1}$ with a 3-year rain return period and hydrological risk of 91.22% (Mifa 2014). The occurrence of pollution can be observed in both the inlet and outlet mine ponds. Coal mining activities at PT Mifa Bersudara, West Aceh Regency have an impact on the river surface water. The heavy metal content of Fe, Mn and Cd in the river body has exceeded the permissible threshold values, as in the PP No. 82 of 2001, namely: Fe<0.3, Mn<0.0440 ppm and Cd<0.1195 ppm. The high metal content of Fe, Mn and Cd does not rule out the possibility of containing other metals (Kiswanto et al 2018; Kiswanto et al 2020b).

The open-pit mine pond water has a pattern of physical and chemical characteristics that are determined by climatic, geomorphological and geochemical

conditions (Ashraf et al 2012). The condition of former open pit mining pond is influenced by the ecological succession changes over a long period of time (Urbanová et al 2011; Kurniawan 2017), with implications for the environmental factors, derived from complex chemical reactions between organic and inorganic compounds, including the heavy metals (Violante et al 2010). Characteristics of acid mine water need to be measured for parameters as temperature, pH, dissolved oxygen, turbidity, NH_3-N, NO_3-N, NO_2-N, PO_4-P, H_2S, Fe and Mn, except for hardness (Ekwule et al 2019; Kiswanto et al 2018; Hafids et al 2015). The AMD in open pit mining causes an industrial pollution that is of concern, due to a massive water pollution, especially with heavy metals like Cr, Mn, Fe, Ni, Co, Cu, Zn, Pb, Cd (Dlamini et al 2013; Ahmad & Sarah 2015). The water that flows from the activities of coal mining companies has not been optimally treated and it tends to be acidic, containing heavy metals, especially Mn and Fe, with total suspended solids (TSS), pH and Mn exceeding the river water quality standards (Kiswanto et al 2018; Gupta & Kumar 2016; Mansilha et al 2021).

Several studies analyzed acid water samples from coal mines for physicochemical parameters such as: pH, turbidity, hardness, magnesium, chloride, calcium, nitrate, sulfate, total dissolved solids, electrical conductivity, iron, dissolved oxygen (DO) and biochemical oxygen demand (BOD). The water quality index of the mine water samples was found to be of a very low quality, essentially due to the presence of iron, nitrate, hardness and sulfate in the water samples (Yadav & Jamal 2018). Pool water in coal mines is an important issue for the rural environment around (Yadav & Jamal 2018). As the use of conventional water sources such as springs and rivers is approaching the natural limit, alternative water sources, such as the mining ponds, become of an increasingly economic interest for the aquaculture (D'Souza et al 2004; Talukdar et al 2016).

The values of BOD, chemical oxygen demand (COD), DO, pH, TSS, total dissolved solids (TDS) and total solids (TS) in the mining pond waters are in the best optimum range for the crop cultivation and fisheries and can be tolerated for agriculture (Rahman et al 2021). Various alternatives have been developed to utilize mining pool water. Mine reclamation can be used as a reference for the development of tin mining lands and for productivity improvements (D'Souza et al 2004; Talukdar et al 2016). The quality of mining pond water is also influenced by the type of open or closed mine. Open pit mining pools have a better water quality and their heavy metals content is closer to the requirements for fish farming (Robin 2016).

Mining water quality parameters have not yet reached the maximum allowable concentration of heavy metals, in the waters used for fish farming or agriculture, according to the regulations in Indonesia (Semmens & Miller 2003). The formation of AMD water flows is a naturally occurring phenomenon that occurs in a suitable environment where the oxygenated water is in contact with sulfide minerals, in the presence of aerobic microorganisms. Acid mine pond water can be reclaimed into abundant water resources that can be utilized for clean water, recreation and freshwater fish farming for sustainable economic improvement (Semmens & Miller 2003). The water from the coal mine pond can be used for freshwater fish farming and can also be used for the clean water needs of the community around the coal mine by previous processing (Kiswanto 2020a; Kiswanto et al 2021). The study of physical and chemical parameters in coal mining pool water needs to be carried out in this study with the aim of compensating the lack of reviews on the quality of the mining pool water.

Material and Method

Description of the study sites. The research was carried out on a post-coal mining land used for fish farming in West Aceh Regency, Aceh Province. The research area consisted of the post-mining brownfields and ponds of the Sumber Batu Meureubo coal mine, in West Aceh.

Research tools and materials. The materials used are: H_2SO_4, HNO_3, HCl, NaOH, $HClO_4$, standard nitrate, standard phosphate, standard nitrite. The tools used in this

study are: thermometer, pH meter, DO meter, tools for titration (pipette, measuring cup), camera, plankton net, water sampler, scales, flask bottles, freezers, plastic bags, cold boxes, spectrophotometers, AAS, microscope, heating device (hot plate).

Sampling and data analysis. Water samples were collected to perform a general analysis of the water quality both in situ (directly) and ex situ (in the laboratory). The parameters analyzed in situ are: temperature, pH, DO, while the parameters analyzed in the laboratory are: turbidity, NH_3-N, NO_3-N, NO_2-N, PO_4-P, H_2S, Fe and Mn. Water temperature is one of the most important factors in regulating the metabolism and the spread of organisms, and it affects the physical andchemical properties of the waters. The temperature increase can reduce the oxygen content, causing waters toxicity. Each temperature change also affects many bio-chemical processes that occur in both plant and animal tissues.

Results and Discussion

Characteristics of coal mining pond water. Characteristic tests were carried out to determine the parameters of the coal mining pool water at the PT Mifa Bersaudara site, in Meureubo District, Aceh Barat. Based on the location of non-aerated, aerated, inlet and outlet samples, tests were carried out with the average results presented in Table 1.

Table 1

Analysis of water characteristics of coal mining ponds in West Aceh, Indonesia

No.	*Parameters*	*Units*	*Non-aeration*	*Aeration*	*Inlet*	*Outlet*	*Quality standards**
1	Temperature	°C	27	26.5	26.2	26.6	25-32
2	TSS		376	272	332	220	15
3	Turbidity	NTU	15	5.01	10.02	2.59	5
4	pH		5.2	5.7	5.3	6	6.0-9.0
5	DO	mg L^{-1}	4.1	4.4	3.8	4.6	>4

*PP no. 82 of 2001 (Class II).

Temperature (°C) affects the nature of the aquatic environment and the content of living things, substances, energy or other components. Water quality parameters include physical, chemical and biological parameters. The metabolism of organisms living in the waters requires oxygen. The oxygen demand increases when the ability of haemoglobin to bind oxygen decreases. High water temperatures will have a direct effect on physiological processes in some types of fish and reduce their abundance in the waters. An appropriate water quality and temperature will affect fish life and fish egg production. A good temperature is 28.5°C for physiological processes, increasing the fish abundance (Donelson et al 2010). The temperature should be in accordance with the SNI 7550:2009 quality standard requirements, which is 25–32°C (SNI 2009). Based on the current study observations of the temperature values at the point of non-aeration, aeration, inlet and outlet in the coal mining pool, the temperature value is still compliant. The usual water temperature in post-coal mine ponds is in the range of 26.2-27°C, a temperature range which still meets the required quality standards.

TSS can block the sunlight from entering the waters so that photosynthesis cannot run normally (stunted) which causes the production of low levels of DO. High TSS can also rise the water temperature, due to the heat absorption process and to the consequent evaporation increase and aquatic organisms' metabolism intensification, which increases the oxygen use. TSS content, at all sampling points in the post-coal mine pool in West Batu Sumber Aceh, is above the quality standard, where TSS levels in that location range from 220 mg L^{-1} to 376 mg L^{-1}. In addition to the consequences of a high TSS, it will result in a decrease in the depth of the photic or euphotic zone, resulting in a decrease in the depth of productive waters (Akan et al 2013; Kuriata-Potasznik et al 2016). The second effect is that it can directly interfere with the life of aquatic biota, such as fish because dissolved solids are filtered out by the gills. Based on the water

designation class meets PP No. 82 of 2001, the water quality in coal mining ponds in West Aceh has not met the quality standards for class 1 and class 2 water designations, which can be used for raw water sources for drinking and aquaculture (Kiswanto et al 2020a).

Turbidity is caused by organic or inorganic materials, both suspended and dissolved, such as debris, fine particles, soil, plankton, etc. This can come from the results of rock weathering, soil runoff (erosion) and anthropogenic influences (garbage, domestic, industrial or swamp water which is rich in organic matter). The level of water turbidity in post-coal mine ponds ranges from 2.59 to 10 NTU. This range is considered not to affect the supply of dissolved oxygen derived from photosynthesis. But if it exceeds the quality standard threshold, it can reduce the penetration of sunlight into the water column, thus affecting the photosynthesis process. The effect of increasing turbidity is the reduction of light penetration which results in a decrease of the primary productivity (such as phytoplankton and benthic macrophyta) and of the feed efficiency of the predatory fish. Hafids et al (2015) stated that plankton diversity and abundance were very low in post-coal mine ponds. Turbidity caused by suspended clay particles is generally highly undesirable in aquaculture activities (Ali & Cagauan 2007). Suspended clay particles can interfere with the eggs breathing during the incubation period, with the fish's vision while foraging and might physically cover the fish's gills, making breathing difficult (Maher et al 2002). In experiments with salmon (brook trout), the fish's reaction to the emergence of prey was slower as turbidity increased (Sweka & Hartman 2001).

The pH magnitude can be used as an indicator of the balance of chemical elements and nutrients which are very beneficial for the life of aquatic biota. In waters with low pH, many ionizable ammonium compounds are found (not toxic ammonium). In an alkaline atmosphere (high pH) more ammonium is found, which is not ionized and is toxic. The water pH at the sampling point in the post-coal mine pools ranges from 5.2 to 6 (Table 1), thus exceeding the required quality standard. The pH value on the outside of the pond is lower when compared to the inside of the pond. This is because in the inner pond there is still a process of stripping the soil ongoing, which causes pyrite to occur, while outside there is already a phytoremediation process taking place. Based on the water quality standard PP No. 82 of 2001 (class II), a good pH for freshwater fish farming activities ranges from 6 to 9. The ideal for freshwater biota life is between 6.8 and 8.5. A very low pH causes the solubility of metals in water to increase, which is toxic to aquatic organisms, whereas a high pH can increase the concentration of ammonia in water which is also toxic to the aquatic organisms (Zeng et al 2011).

The DO concentration in waters is determined by the rate of photosynthesis. The solubility of gases (especially oxygen) into the water is influenced by temperature, partial pressures and types of gases that are in the air or water and also by the salinity and compounds that are easily oxidized. Oxygen is essential for breathing and is one of the main components for the metabolism of fish and other aquatic biota. The analysis results of DO content in post-coal mine ponds are in the range of 3.8 to 4.6 mg L^{-1} (Table 1). Based on PP water quality standards No. 82 of 2001 (class II), the range of DO for fish farming activities is >4 mg L^{-1}. The results of measurements at four observation points showed that the highest DO was at the outlet with a value of 4.6 mg L^{-1}, while the lowest DO was at the inlet with a value of 3.8 mg L^{-1}. This shows that DO at four observation points in coal mine ponds in West Aceh, ranging from 3.80 to 4.60 mg L^{-1}, is very supportive for the continuity of fish farming activities, with values above the limit ruled by the water quality standard, the PP. No. 82 of 2001 (class II), which is >4 mg L^{-1} (Kiswanto et al 2020a; Abdel-Raouf et al 2012).

Ammonia (NH_3). Ammonia (NH_3) in waters comes from the breakdown of organic nitrogen (protein and urea) and inorganic nitrogen contained in soil and water; it can also come from the decomposition of organic matter (dead plants and aquatic biota), carried out by microbes and fungi.

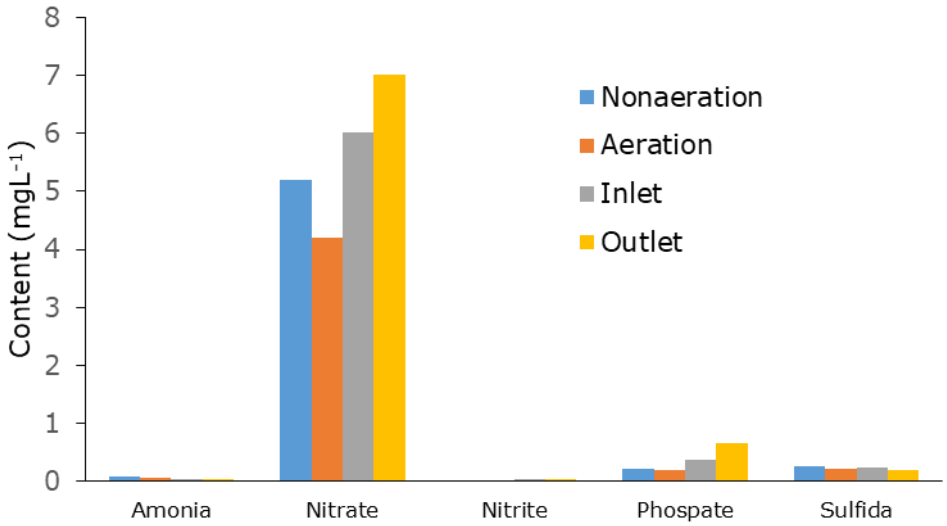

Figure 2. Results of water quality analysis.

Ammonia concentrations in post-coal mine ponds in Sumber Batu Aceh Barat are in the range of 0.03-0.09 mg L^{-1}. Ammonia levels detected in ponds after the Sumber Batu West Aceh coal mine exceeded the quality standard. The lowest level of NH_3 in the pond water was 0.021 mg L^{-1} and the highest level was 1.670 mg L^{-1}. Based on the requirements of SNI 7550:2009, the maximum limit of NH3 levels for fish farming activities is <0.02 mg L^{-1}. In general, by using nitrogen, aquatic organisms have a tendency to gradually and successively extract ammonia, nitrates and nitrites (Quirós 2003; Mihale 2015).

Nitrate (NO_3) is the main form of nitrogen in natural waters and is the main nutrient for plant growth and algae. Nitrates are very soluble in water and are stable. This compound is produced from the complete oxidation process of nitrogen compounds in the waters. Nitrification, which is the oxidation process of ammonia to nitrite and nitrate, is an important process in the nitrogen cycle and takes place under aerobic conditions. The oxidation of nitrite into nitrate is carried out by the Nitrobacter bacteria. Nitrates directly do no harm to fish. Nitrate levels in post-coal mine ponds are in the range of 4.2-7.01 mg L^{-1}. This range of values still meets the specified quality standard value, which is of 10 mg L^{-1} (quality standard for the Perda concerning the Water Quality Management and Water Pollution Control). The presence of nitrates in the waters can come from the decay of remaining plants and aquatic animals. Very high nitrate levels can cause a decrease in the water quality, a low dissolved oxygen, a decrease in fish populations, foul odors and bad taste. These results are compared with the water quality standards of government regulation No. 82 of 2001 (class II) for freshwater fish farming activities, is still very far from the specified limit of 10 mg L^{-1}.

The presence of nitrites (NO_2) illustrates the ongoing biological process of reforming organic matter in waters, where ammonia in the form of nitrogen is transformed by nitrosomonas bacteria into nitrite. High nitrite levels can cause the organism's immunity to decrease so that the organism is easily infected with the disease. The range of the nitrite value is still at the permissible limit based on the specified quality standard. The results of the analysis of NO_2 levels can be seen in Figure 8. According to the results of Quirós (2003), Michalski & Kurzyca (2006) and Mihale (2015), high nitrite levels can disrupt the balance between oxidants and antioxidants in *Macrobrium nipponense* shrimp. In addition, nitrite can also react with hemoglobin which causes the formation of methemoglobin so that blood cannot bind and transport oxygen to the body tissues. Based on the quality standards and classes of designation specified in the Regional Regulation of Aceh province, the water NO_2 content should be <0.6 mg L^{-1}. As it can be seen in the graph above, the water can be used for all designation classes (Class I-Class IV): recreation facilities and infrastructure, fish farming, animal husbandry, irrigation and for other designations that require the same water quality (D'Souza et al 2004; Semmens & Miller 2003; Rahman et al 2021).

Phosphate is a form of phosphorus that can be utilized by plants and is an essential element for higher plants and algae so that it can affect the level of productivity of the waters. The results of the analysis of phosphate levels in post-coal mine ponds used for aquaculture are in the range of 0.189-0.67 mg L^{-1}. Figure 2 shows that the PO_4 for the points of non aeration, aeration, inlet and outlet are still below the quality standard, so that PO_4 adjuvants can still be used for freshwater fish farming (Ma et al 2017).

H_2S levels in post-coal mine pools at the West Aceh location are in the range of 0.20-0.25 mg L^{-1}, exceeding the permissible standard threshold of 0.002 mg L^{-1}. The sulfidein post-coal mine ponds influences the sustainability of cultivation (Setiawan et al 2018), its detectionat the sampling location indicating the process of decomposition of organic matter, namely the process of sulfate reduction by bacteria in aerobic conditions. This compound is soluble, and it can cause foul odor of a significanttoxicity, if the levels are high. Figure 2 indicates that the dissolved Sulfide exceeds the quality standard. According to Akcil & Koldas (2006), sulfide in wastewater comes from the decomposition of organic substances in the form of hydrogen sulfide (H_2S) produced by decaying microorganisms from organic substances that are toxic to algae and other microorganisms. The decomposition of organic substances causes air pollution and odor. In addition, sulfide is corrosive in the form of hydrogen sulfide, which causes problems to the environment (Vaiopoulou et al 2005)

Fe and manganese (Mn). Iron and manganese are a metal that may be found in waters and sediments of coal mining ponds in West Aceh, Indonesia (Figure 3). Iron is the fourth largest element found in the earth's crust and is an essential element for living things. Iron is needed by plants and animals at significant concentrations.

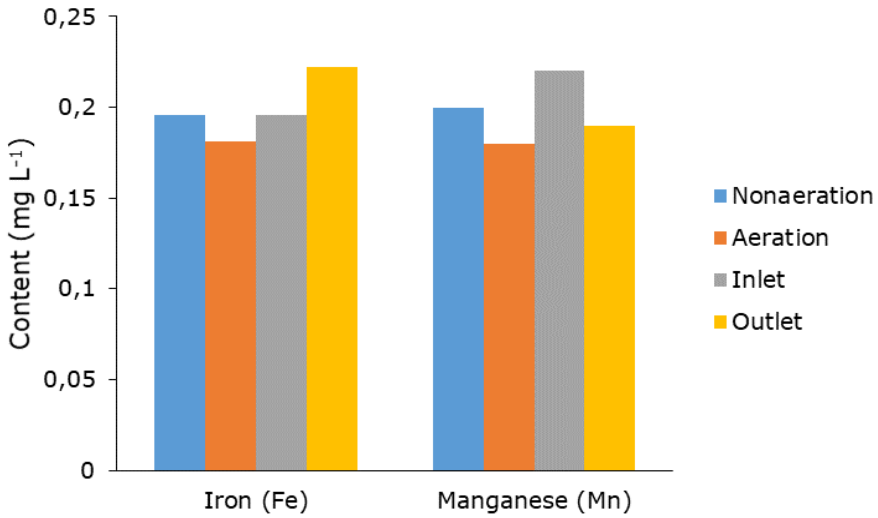

Figure 3. Iron and manganese content of coal mining ponds in West Aceh, Indonesia.

This research also found the local fish species such as repang (*Barbonymus schwanenfeldii*), puyau (*Osteochilus kappenii*), pepuyu (*Anabas testudineus*) and catfish or introduced fish, like the carp (*Cyprinus carpio*) can be reared in the coal mining ponds, being quite safe for consumption. In animals, iron is very important in oxidative metabolism and is a key component in hemoglobin. In plants, iron is an important element in the synthesis of chlorophyll, cytochrome and in the nitrogenase enzyme (Kurniawan 2017; Kiswanto et al 2020b). In plants, iron also plays a role in the enzyme system and electron transfer in photosynthesis. However, excessive iron levels can inhibit the fixation of other elements (Zhang et al 2014). The results of post-coal water analysis show iron content in the range of 2.78-8.24 mg L^{-1}. High iron content can endanger the life of aquatic microorganisms. Iron levels >1.0 mgl Lare considered to endanger the life of aquatic microorganisms (Daniel et al 2014), according to the PP water quality standard

No. 82 of 2001 (class II), but in the studied case the iron parameter is in the limits for freshwater fish farming (Kiswanto et al 2018).

Manganese is a tiny nutrient that is essential for plants and animals. Manganese plays a role in growth and is one of the important components of the enzyme system. Manganese deficiency can result in stunted growth, and the nervous system and reproductive processes become disrupted. In plants, manganese is an essential element in the metabolic process. Mačingová et al (2016) stated that although manganese is not toxic, it can control toxic substances in the waters, such as heavy metals. In natural waters, manganese content ranges between 0.1 and 1 mg L^{-1}. Higher manganese concentrations can be found in waters with low pH levels (Barkah et al 2008). The results of the analysis of acid coal liquid waste in the coal mine ponds show that the manganese content in void 1 has a value of 1.172 mg L^{-1}, in void 2 it is of 1.25 mg L^{-1} and in void 3 it reaches 1.24 mg L^{-1}, levels which are still dangerous to the environment and health, so a continuous management and monitoring needs to be performed.

Conclusions. The analysis of the physical water quality indicated that the temperature was still in accordance with the standard, while the turbidity is quite high. The results of the chemical water quality analysis showed parameters that exceeded the quality standard, namely the pH, TSS, NH_3, H_2S and Fe. The post-coal mine ponds that are used for fish farming businesses need to be monitored, so that aquaculture products can be sustainable. The temperature, brightness, pH and the dissolved oxygen at the location of fish farming in the former coal mining pond create good conditions for the fish farming development, with reference to the water quality standard PP no. 82 of 2001, concerning the water quality management and the water pollution control class II, local fish species such as *B. schwanenfeldii*, *O. kappenii*, *A. testudineus* and catfish or introduced fish, like *C. carpio* can be reared in the coal mining ponds, being quite safe for consumption.

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Conflict of interest. The authors declare no conflict of interest.

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