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# The Comparison between Pollution Index and STORET Methods in Determining Post-Mining Lake Water Quality in Lati Petangis Forest Park, Paser, East Kalimantan after Reclamation

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## ABSTRACT

Lati petangis Forest Park is a post-mining forest park located in Paser, East Kalimantan, Indonesia. This area has been through the stages of reclamation and post-mining lake has been formed. Monitoring activities are needed to determine the success of post-mining management. This study aims to assess the water quality of post-mining lake in Tahura Lati Petangis based on the Pollution Index and STORET methods. The research was located at 3 observation stations, which were station 1 (Pit Lake I Saingprupuk Erai), station 2 (Natural Lake Gentung Dayo), and station 3 (Pit Lake II Saingprupuk Duo). At all observation stations, *in-situ* water quality observations were made in the form of Dissolved Oxygen (DO), pH, and water temperature at 4 points sites. Water sampling was also carried out at 4 sites in each station for *ex-situ* quality testing. The determination of water quality status based on the Decree of the Minister of Environment of the Republic of Indonesia No. 115/2003 with lake water quality standards following the Government Regulation of the Republic of Indonesia No. 22/2021. The results showed that the STORET method is more sensitive than the Pollution Index. Determination of general water quality status shows that station 1 and 2 are only usable for agricultural activities (class IV). Station 3 is unable to be used for all four designation classes based on DO, BOD, COD, phosphate, phenol, and zinc parameters that are not meeting the quality standards. The STORET method is recommended to be used in determining water quality based on periodic and time progression.

Keywords: Pollution Index, Post-Mining Lake, STORET

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## INTRODUCTION

Paser District is located in the southern region of East Kalimantan Province, Indonesia, making the mining sector one of the sources of regional economic income, especially coal mining. Coal production in 2017 reached 32,879,307 tons, and in 2018 the production increased to almost 2 million tons (BPS Kab.Paser, 2022). High production as a source of long-term economic income needs to be considered because it can have a negative impact on the environment.

Lati Petangis Forest Park (Tahura Lati Petangis) is nature reserve located in Paser District, East Kalimantan, Indonesia. The area was previously former coal mining concession of PT BHP Kendilo Coal Indonesia, which ended its operations in 2002. Reclamation and revegetation activities have been carried out based on the principle of an area borrow-to-use system (DLH Kab. Paser, 2017). The area borrow-to-use system is a way to grant permits to use forest areas for mining activities without changing the function and designation of the forest area by taking revegetation and reclamation steps after the permit expires, and it will be returned to the local government as the landowner. Post-mining activities, such as reclamation and revegetation are efforts to improve land functions and provide ecological and economic benefits (Pratiwi *et al*., 2021). The establishment of the Lati Petangis Forest Park (Tahura) was based on the Decree of the Minister of Environment and Forestry of Republic Indonesia No. SK. 4335/MenLHK-PKTL/KUH/2015 on September 08, 2015 (DLH Kab.Paser, 2017).

The impacts of mining activities cause major changes to the landscape and land use (Redondo-Vega *et al.*, 2021). Coal mining generates hazardous waste, such as heavy metal substances during production, washing, and several other processes. These hazardous wastes produce acid mine drainage with low pH and harmful for human consumption (Park *et al.*, 2017; Zhou *et al.*, 2020). Pollution from mining processes is an interaction between anthropogenic activities, hydrological activities and mineral rock weathering. The process that occurs will reduce the quality of waters and harm the living biota (Nyirenda *et al.*, 2016; Dan-Badjo *et al.*, 2019; Verma *et al.*, 2019; Zhu *et al.*, 2020; Punia *et al.*, 2021).

The condition of Lati Petangis Forest Park is diverse, consisting of natural forest areas, revegetation areas, open areas, native lakes and post-mining lakes. The natural lake is the largest lake in that area and there are seven post-mining lakes (DLH Kab.Paser, 2017). Post-mining lakes are formed from mining pit dredging activities, which are filled by groundwater, surface water flow, and rainwater (Sakellari *et al.*, 2021). Post-mining lakes are characterised by having an acidic pH, containing heavy metals, depths ranging from tens to hundreds of meters, so they have a dangerous risk of being used. Generally, the status of post-mining lakes is oligotrophic, although post-mining lakes have the potential to provide ecosystem and economic services (McJannet *et al.*, 2019; Lund *et al.*, 2020; Blanchette & Lund, 2021). Stability of post-mining lake water quality requires time that may range up to decades (Sakellari *et al.*, 2021).

The previous research in the Lati Petangis Forest Park showed differences water quality in each lake. Ammonia and phenol were identified to exceed the water quality standards in all lakes (DLH Kab.Paser & FPIK Unmul, 2020). The high ammonia is caused by incomplete nitrogen cycle. This can reduce water quality through increasing the organic load of waters (Risacher *et al.*, 2018; Nizzoli *et al.*, 2020; Qian *et al.*, 2021; Zhao *et al.*, 2021). In addition, as a post-mining lake, there is concern that it still contains dangerous heavy metals.

The potential development of post-mining areas is related to economic value, ecology, education, and ecosystem safety characteristics (Soni *et al.*, 2014). One of the considerations is water quality. Water quality is a condition of water quality that is measured or tested based on certain parameters and certain methods based on applicable laws and regulations (Government Regulation of Republic Indonesia No. 22/2021). Determination of lake water quality status is related to the function of its use class.

Based on the Decree of the Minister of Environment of Republic Indonesia No. 115/2003 about concerning guidelines for determining water quality status, the Pollution Index and STORET methods are recommended for determining the status of environmental pollution in Indonesia. Both methods are included in the Water Quality Index (WQI) method using the U.S. Environmental Protection Agency (US-EPA) value system. The use of the pollution index is only capable of describing water quality on temporary scale because it can be sourced from a single observation. The STORET method can be used to describe water quality consistently because the data is based on periodic development and time (Saraswati *et al.*, 2014; Barokah *et al.*, 2017). Comparison of water quality determination of the two methods may provide a suggestion of the suitable method to be used.

Terrestrial ecosystems and clean water, proper sanitation are two areas that need attention for the Sustainable Development Goals (SDG's). Some of the goals of these development sectors are to protect, restore and enhance the sustainable use of terrestrial ecosystems, restore land degradation, and ensure the availability and management of clean water (UNDP, 2015; Bappenas RI, 2021; Tyas *et al.*, 2021). Research that aligns with sustainable development goals can help formulate follow-up strategies for regional development (Gebrehiwot *et al.*, 2021; Thakur *et al.*, 2022).

Lati Petangis Forest Park as post-mining area with the function of forest park has been running for approximately 20 years. Therefore, it is necessary to monitor and evaluate the post-mining development. The focus of the study was on the quality of post-mining lake waters.

## MATERIALS AND METHODS

### Description of the Study Area

The research was located in the Lati Petangis

Forest Park (Tahura Lati Petangis), Paser District, East Borneo, Indonesia, which has an area of 3,445.37 Ha. Geographically, it is located from north to south between 116°3'40.996″BT - 116°6'21.502″BT and 2°2'30.786″LS - 2°9'24.983″LS. As regards the administrative division, Lati Petangis Forest Park located in three villages, namely Saing Prupuk Village, Petangis Village, and Teberu Simpang Damai Village, Batu Engau, Paser District, East Kalimantan. The area has eight lakes, consisting of one natural lake and seven former mining exploration lakes (pit lakes).

The focus of the research was on lakes located in the Saingprupuk Village administration, namely Saingprupuk Erai Pit Lake I (Pit Lake I) and Saingprupuk Duo Pit Lake II (Pit Lake II) as post-mining lakes. While one other lake is a natural lake Gentung Dayo which is not included in the reclamation area of PT BHP Kendilo Coal Indonesia (Table 1).

**Table 1.** Characteristics of research sites

| Station Number | Location Name | Coordinate Point | Size | Depth | Water Volume |
|---|---|---|---|---|---|
| Station 1 | Pit Lake I Saingprupuk Erai | 116°6’17.349″ E – 2°2’87.800″ S | 1,31 Ha | 10,5 m | 94.975,00 $m^3$ |
| Station 2 | Natural Lake Gentung Dayo | 116°5’48.730″ E – 2°3’49.080″ S | 12,74 Ha | 11,6 m | 1.153.383,59 $m^3$ |
| Station 3 | Pit Lake II Saingprupuk Duo | 116°5’50.558″ E – 2°4’32.902″ S | 5,79 Ha | 11,67 m | 898.438,90 $m^3$ |

Source: DLH Kab.Paser & FPIK UNMUL, 2020

The study was held in January 2023 at the three observation stations (Figure 1). Water sampling was taken by purposive random sampling, and the three lakes each had four observation sites. At each station, water quality was measured based on temperature, pH, and dissolved oxygen (DO). Water samples were collected to analyze Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Ammonia ($NH_3$-N), Nitrate ($NO_3$-N), Nitrite ($NO_2$-N), Total Phosphate, Phenol, Dissolved Zinc (Zn), Dissolved Manganese (Mn), Dissolved Iron (Fe), Dissolved Lead (Pb), Dissolved Copper (Cu), Sulfide as ($H_2S$), and Sulfate.

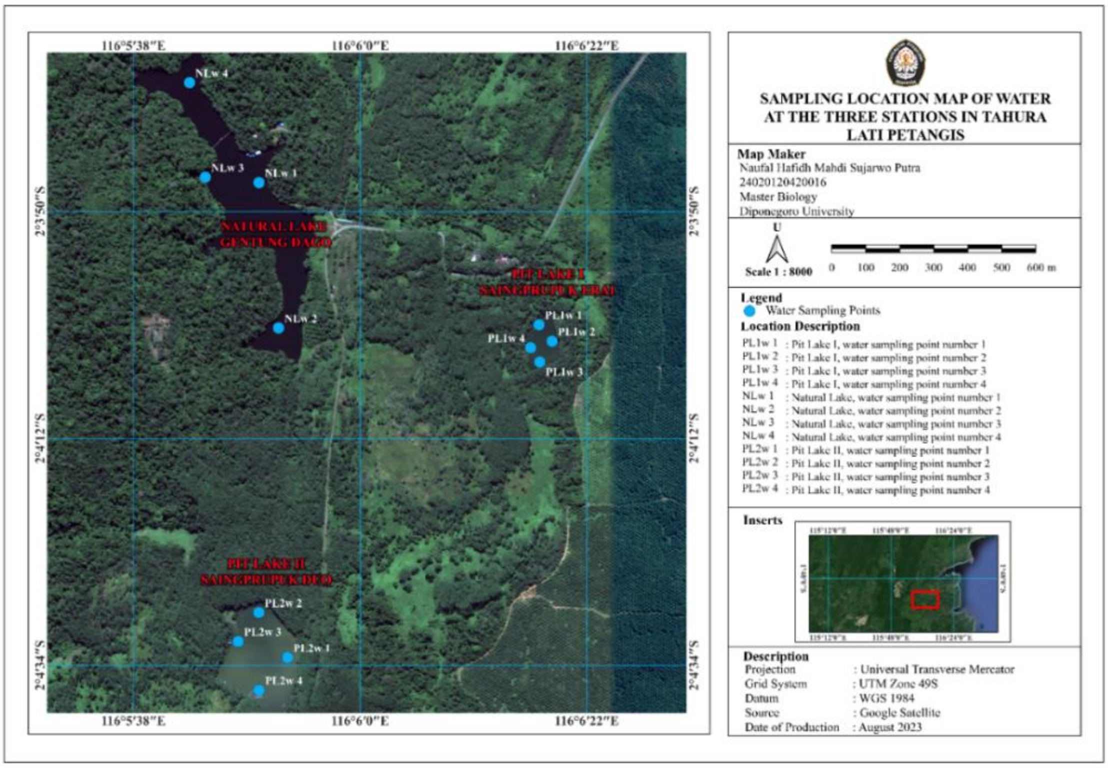

**Figure 1.** Research location of lakes in Lati Petangis Forest Park

## Data Analysis

*In-situ* water quality measurements of pH, temperature, and Dissolved Oxygen (DO). Ex-situ measurements were made by taking 5 litres of water samples on the lake water surface at each research stations with 4 collection points. Lake water samples were tested at the Laboratory of Samarinda Industrial Research and Standardisation Centre, East Kalimantan. The *ex-situ* measurement parameters and Indonesian Standard Test methods used are as follows (Table 2).

**Table 2.** *Ex-Situ* parameters and testing methods for water quality parameters of Lati Petangis Forest Park Lakes

| No | Parameters | Indonesia Standard Testing Methods |
|---|---|---|
| 1 | *Chemical Oxygen Demand* (COD) | SNI 6989.2.2019 (Spectrophotometry) |
| 2 | *Biological Oxygen Demand* (BOD) | SNI 6989.72:2009 |
| 3 | Ammonia ($NH_3$-N) | SNI 06-6989.30-2005 |
| 4 | Nitrate ($NO_3$-N) | SNI 06-2480-1991 |
| 5 | Nitrite ($NO_2$-N) | SNI 06-6989.9-2004 |
| 6 | Total Phosphate ($PO_4$) | SNI 06-6989.31-2005 |
| 7 | Phenol ($C_6H_6O$) | SNI 06-6989.21-2004 |
| 8 | Dissolved Zinc (Zn) | SNI 6989-84:2019 |
| 9 | Dissolved Manganese (Mn) | SNI 6989-84:2019 |
| 10 | Dissolved Iron (Fe) | SNI 6989-84:2019 |
| 11 | Dissolved Lead (Pb) | SNI 6989-84:2019 |
| 12 | Dissolved Copper (Cu) | SNI 6989-84:2019 |
| 13 | Sulfide as ($H_2S$) | SNI 19-6964.4-2003 |
| 14 | Sulfate | SNI 6989.20-2019 |

Source: Samarinda Industrial Standardisation and Services Centre, 2022

## Pollution Index

The Pollution Index method is an easy assessment method and is able to produce calculations of the level of pollution to water quality standards (Suriadikusumah *et al*., 2021). The formula of PI as follows:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}} \qquad \text{Eq (1)}$$

where: $PIj$ = pollution index for designation j; $Ci$ = concentration of water quality parameter i; $Lij$ = concentration of water quality parameter i listed in the standard for water designation j; $M$ = maximum; $R$ = average.

The maximum Ci/Lij is obtained from the Ci/Lij equation depending on the number of water quality parameters measured, and the value of the largest Ci/Lij is selected. The average Ci/Lij is obtained from the values of the Ci/Lij equation for each parameter summed up and divided by the number of water quality parameters measured.

Pollution Index was based on 17 water quality parameters, namely temperature, pH, and dissolved oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Ammonia ($NH_3$-N), Nitrate ($NO_3$-N), Nitrite ($NO_2$-N), Total Phosphate, Phenol, Dissolved Zinc (Zn), Dissolved Manganese (Mn), Dissolved Iron (Fe), Dissolved Lead (Pb), Dissolved Copper (Cu), Sulfide as (H2S), and Sulfate. The first step in determining water quality used the pollution index (PI) method to calculate the value as in Equation (1), then the evaluation of the PI value was included in Table 3.

**Table 3.** Status of water quality criteria in Pollution Index

| **Score Range** | **Water Quality Status** |
|---|---|
| 0 ≤ PI ≤ 1,0 | Meets quality standards |
| 1,0 < PI ≤ 5,0 | Lightly polluted |
| 5,0 < PI ≤ 10 | Moderately polluted |
| PI > 10 | Heavily polluted |

Source: Decree of the Minister of Environment of Republic Indonesia No. 115/2003

## STORET water quality index

STORET method principally compares water quality data with water quality standards in accordance with its designation. This method is usually through periodic measurements over time to form time series data. The way to determine the status of water quality is by using the value system from the US-EPA (U.S. Environmental Protection Agency) (Decree of the Minister of Environment of Republic Indonesia No.115/2003).

This research uses the calculation of water quality data for 2017, 2020, and 2023. If the measurement results meet the water quality standard value, the score is 0, and if the measurement results do not meet the water quality standard value, the score is given according to Table 4. Water quality parameters can be divided into physical, chemical, and biological parameters. The three types of parameters have different score systems.

**Table 4.** The water quality scoring system

| Number of parameter samples used | Value | Parameter<br>Physical | <br>Chemical | <br>Biological |
|---|---|---|---|---|
| < 10 | Maximum | -1 | -2 | -3 |
| | Minimum | -1 | -2 | -3 |
| | Average | -3 | -6 | -9 |
| > 10 | Maximum | -2 | -4 | -6 |
| | Minimum | -2 | -4 | -6 |
| | Average | -6 | -12 | -18 |

Source: Decree of the Minister of Environment of the Republic Indonesia No. 115/2003

The measurement of water quality parameters through maximum, minimum, and average values is compared with the quality standard value. The number of negatives (the calculation value does not meet the quality standard) of all parameters is calculated and the quality status is determined from the number of scores obtained using a score system. The values obtained are then classified into four classes of water quality status as follows (Table 5).

**Table 5.** Water quality classification in STORET method following US-EPA grading system

| Class | Score | Characteristic of water quality |
|---|---|---|
| A | 0 | Meets quality standards |
| B | -1 to -10 | Lightly polluted |
| C | -11 to -30 | Moderately polluted |
| D | ≥ -30 | Heavily polluted |

Source: Decree of the Minister of Environment of Republic Indonesia No. 115/2003

Determination of the designation of water quality standards is carried out by comparing the results of water quality measurements with the water quality standards listed in Government Regulation of Republic Indonesia No. 22/2021. Water quality classification is determined into four classes, namely:

1) Class I, water intended for drinking water raw water and or other designations that require the same water quality as these uses.
2) Class II, water intended for water recreation infrastructure / facilities, freshwater fish farming, animal husbandry, water for irrigating crops and or other designations that require the same water quality as these uses.
3) Class III, water intended for freshwater fish cultivation, animal husbandry, water for irrigating crops and or other uses that require the same water quality as these uses.

4) Class IV, water intended for irrigating crops and or other uses that require the same water quality as these uses.

## RESULTS AND DISCUSION

By referring to Indonesian water quality standards, this study generally determined that water quality of station 1 (Pit Lake I Saingprupuk Erai) and station 2 (Natural Lake Gentung Dayo) are only suitable for agricultural or irrigation activities (class IV), while station 3 (Pit Lake II Saingprupuk Duo) is not suitable for all four use classes based on Government Regulation of Republic Indonesia No. 22/2021. Parameters that have not met the general water quality standards were Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Phosphate, and Phenol. In addition, specifically for Dissolved Zinc (Zn) at station III (Pit Lake II Saingprupuk Duo) the value has not met the quality standards.

### pH

Station 1 and Station 2 had more alkaline water pH categories compared to Station 3 which was more neutral (Figure 2). Even so, the values shown from three observation stations meet the lake water quality standards for all classes. The pH value will increase along with the natural neutralization process and correlates with the age of the lake. An increase in the pH value of post-mining lake water is generally followed by decrease in the concentration level of aquatic minerals, and also increase in the concentration of aquatic nutrients (Oszkinis-Golon *et al.*, 2020; Pukacz *et al.*, 2020; Gąsiorowski *et al.*, 2021).

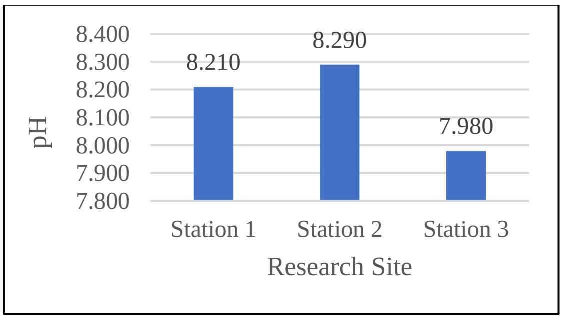

**Figure 2.** pH at three observation stations of lakes in Lati Petangis Forest Park

### Temperature

Temperature measurements showed that the lake water quality standards were met for the designation of all classes based on Government Regulation of Republic Indonesia No.22/2021 (Figure 3). Water temperature is very important in measuring water health and determining the process of nutrient release. Water temperature also supports the life and development of biota species in the environment (Peng *et al.*, 2022).

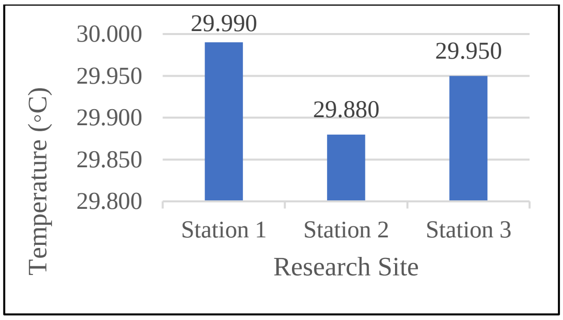

**Figure 3.** Temperature at three observation stations of lakes in Lati Petangis Forest Park

### Dissolved Oxygen (DO)

The DO values obtained from the three observation stations were only be used for fish farming and agricultural activities (class III and IV) (Figure 4). Dissolved oxygen (DO) is influenced by water temperature as one of the abiotic factors. Higher water temperature causes lower dissolved oxygen. The lower dissolved oxygen value, the worse the water quality. Dissolved oxygen plays a role in supporting metabolic processes of aquatic biota and biogeochemical processes (Wilson, 2010; Carey & Woelmer, 2020; Febiyanto, 2020; Handoko & Sutrisno, 2021).

### Chemical Oxygen Demand (COD) & Biological Oxygen Demand (BOD)

The COD values of the three observation stations meet the water quality standards for class II, class III, and class IV designations. BOD value for station 1 meets the quality standards for all classes, while the BOD values for stations 2 and 3 only meet the quality standards for class II, III, and IV designations (Figure 4). COD is a total organic water whose value is inversely proportional to dissolved oxygen (DO). COD is the level of water pollution by organic substances that can be oxidized, causing a reduction in dissolved oxygen content (Mafuyai *et al.*, 2020; Abdullahi *et al.*, 2021). COD values are always higher than BOD. Comparison of COD and BOD values can determine the number of organic compounds that are persistent and cannot be degraded by aquatic microorganisms. Thus, it is able to investigate the source of origin of organic contaminants (Mafuyai *et al*., 2020; Abdullahi *et al*., 2021; Qi *et al*., 2021).

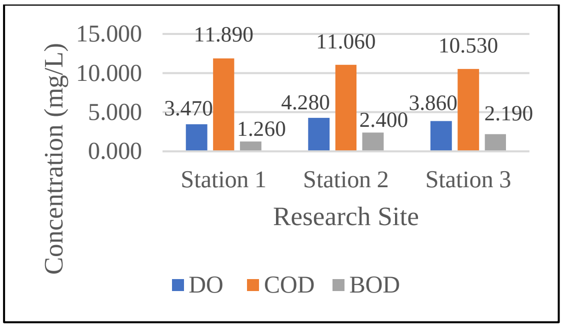

**Figure 4.** Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) at three observation stations of lakes in Lati Petangis Forest Park

## Ammonia, nitrite, & nitrate

Ammonia, nitrite, and nitrate in waters are generally other forms of compounds from the decomposition of nitrogen by microorganisms. Sources of high nitrogen concentrations in waters can come from anthropogenic activities as well as litter from plants around the waters (Baker *et al*., 2017; Roland *et al*., 2018; Zhang *et al*., 2022). Nitrate values are always higher than ammonia and nitrite, but ammonia and nitrite are much more toxic in waters than nitrate. The process of changing from ammonia to nitrite is much slower than the change of nitrite to nitrate. Nitrite concentrations in drinkable waters range from 0.01 - 0.1 mg/L and ammonia ranges from 0.05 - 0.5 mg/L (Schullehner *et al*., 2017; Spiridon *et al*., 2018; Monson, 2022). Nitrite and ammonia values at the three observation stations showed <0.5 mg/L (Figure 5).

## Total Phosphate & Phenol

Total Phosphate concentrations at three observation stations have not met the quality standards for classes I and II. At the phenol concentration, the value has not met the quality standards for classes I, II, and III, while at station III it has not met the quality standards for all four classes (Figure 6). The entry of phosphate into water bodies is heavily influenced by rainfall through water runoff (Rustiah *et al*., 2019; Wang *et al*., 2022). Phosphate is one of the parameters that trigger eutrophication. The concentration of phosphate in sediments is higher than phosphate in surface waters (Rustiah *et al*., 2019; Li & Zuo, 2020). Phenol entering waters can be caused by natural sources such as the decomposition of dead plants. The nature of phenol in waters can persist for a long time and very reactive to form toxic substances (Anku *et al*., 2017).

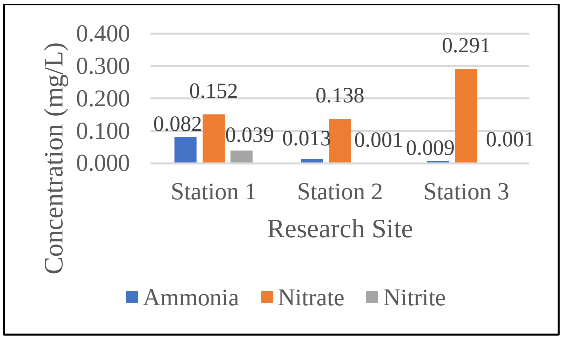

**Figure 5.** Ammonia, nitrate, and nitrite at three observation stations of lakes in Lati Petangis Forest Park

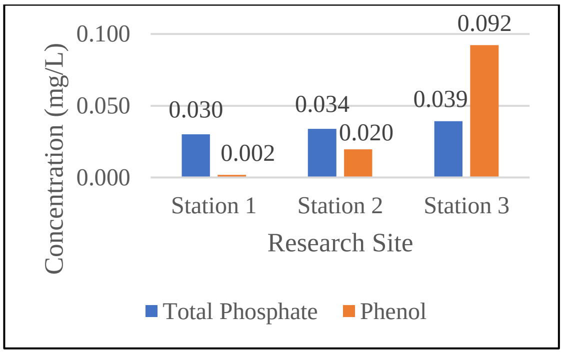

**Figure 6.** Total Phosphate and Phenol at three observation stations of lakes in Lati Petangis Forest Park

## Dissolved Zinc & Dissolved Manganese

Dissolved Zinc (Zn) concentrations for station I and station II meet all four quality standard classes. While for station III only meets the quality standards of class IV. In addition, measurements of Dissolved Manganese (Mn) concentrations at three observation stations met all four classes (Figure 7). Excess concentration of zinc (Zn) produces toxic compounds that can accumulate in the body of aquatic biota. Zinc (Zn) enters the water generally due to anthropogenic activities (Noulas *et al*., 2018; Li *et al*., 2019). Manganese (Mn) entering waters generally comes from anthropogenic activities and natural processes. Manganese (Mn) concentration strongly influenced by dissolved

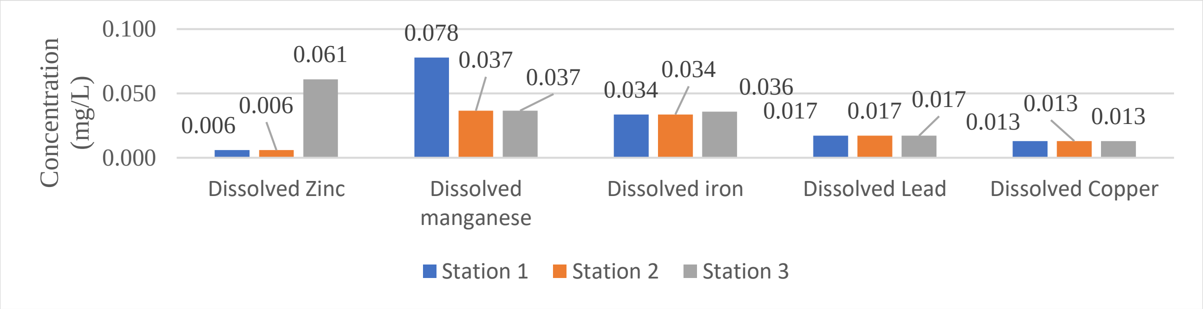

**Figure 7.** Dissolved Zinc, Dissolved Manganese, Dissolved Iron, Dissolved Lead, and Dissolved Copper at three observation stations of lakes in Lati Petangis Forest Park

oxygen, pH, sediment composition, and temperature (Neculita & Rosa, 2019; Kousa *et al*., 2021; Nkele *et al*., 2022).

### Dissolved Iron, Dissolved Lead, & Dissolved Copper

Measurements of dissolved iron (Fe), dissolved lead (Pb), and dissolved copper (Cu) at three observation stations met all four quality standard classes (Figure 7). The entry of dissolved iron (Fe) into waters comes from mining and industrial activities, rock weathering, and input from groundwater (Xiao *et al*., 2022). High concentrations of iron in waters cause health problems for those who consume it (Kumar *et al*., 2017). Lead in water becomes toxic and contaminates aquatic biota through bioaccumulation and biomagnification mechanisms (Kołodyńska *et al*., 2018; Li *et al*., 2021). The toxicity level of lead (Pb) in waters is influenced by other water quality parameters, such as pH, temperature, dissolved organic matter content, and water hardness (Zheng *et al*., 2017). Copper (Cu) is mostly found in water bodies and surfaces rather than in the bottom. Copper concentration dynamics are related to binding with organic matter (Rader *et al*., 2019; Yusni & Ifanda, 2020).

### Sulfide as $H_2S$ & Sulfate

Measurements of sulfide concentrations as $H_2S$ and sulfate at three observation stations met all four quality classes (Figure 8). Specific concentrations of organic matter decomposing into hydrogen sulfide are toxic in aquatic environments (Siang *et al*., 2017; Austigard *et al*., 2018). Sulfide as $H_2S$ in waters comes from the decay of plants and animals from bacteria or the direct reduction process of sulfate (Austigard *et al*., 2018). $H_2S$ as a gas in waters is observed to determine the potential for organic pollution of waters. High concentrations of sulfate are toxic and present serious risks to human health and ecological balance. Sulfate is widely sourced from industrial activities, agricultural runoff, rock weathering, and mining activities (Wang & Zhang, 2019; Zak *et al*., 2021).

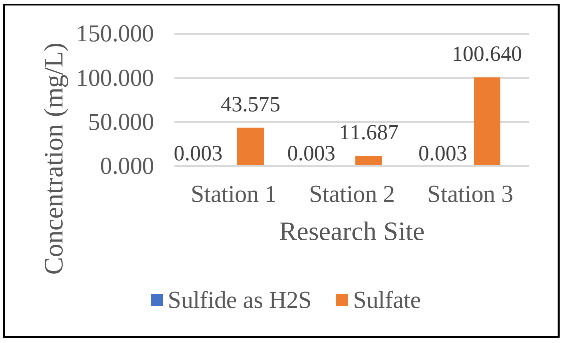

**Figure 8.** Sulfide as $H_2S$ and Sulfate at three observation stations of lakes in Lati Petangis Forest Park

### Water Quality Index

Based on Pollution Index (IP), station 1 meets the water quality standards for classes II, III, and IV, only class I is still lightly polluted. Station 2 is lightly polluted for water criteria classes I, II, and III. Only class IV has good condition criteria. Station 3 has moderate to lightly polluted criteria for all four water quality classes (Figure 9).

Physiochemical parameters used in STORET calculations were observed temporally. Time series data of pH, water temperature, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Ammonia (NH3-N), Nitrate (NO3-N), Nitrite (NO2-N), Total Phosphate, Phenol, Dissolved Zinc (Zn), Dissolved Manganese (Mn), Dissolved Iron (Fe), Dissolved Lead (Pb),

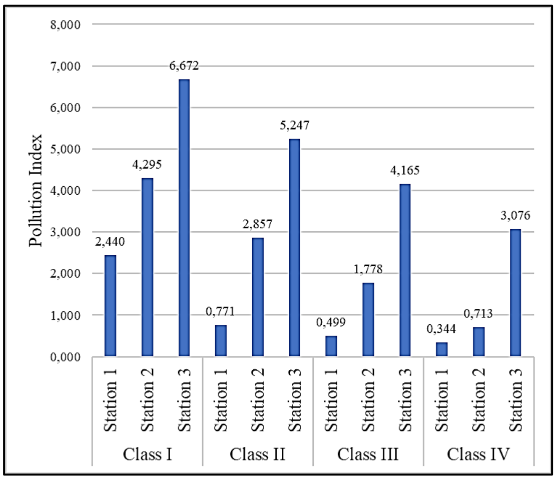

**Figure 9.** Pollution Index based on class categorized at each research station at Lati Petangis Forest Park

Dissolved Copper (Cu), Sulfide as ($H_2S$), and Sulfate of Lati Petangis Forest Park post-mining lake in 2017 (Sumargo, 2017) and 2020 (DLH Kab. Paser & FPIK UNMUL, 2020) combined with the data from this study showed that status of water lake at station 1 and station 2 only met the criteria for class IV. While the status of lake water at station 3 categorizes as heavily polluted for classes I and II, and moderately polluted for classes III and IV (Table 6).

**Table 6.** Water quality status of Lakes in Lati Petangis Forest Park based on STORET method

| Parameter | Measurement Unit | Min. | Max. | Average | Score Class I | Score Class II | Score Class III | Score Class IV |
|---|---|---|---|---|---|---|---|---|
| Station 1 (Pit Lake I Saingprupuk Erai) | | | | | | | | |
| Temperature | °C | 28,800 | 29,990 | 29,395 | 0 | 0 | 0 | 0 |
| pH | | 7,310 | 8,210 | 7,760 | 0 | 0 | 0 | 0 |
| Dissolved Oxygen (DO) | mg/L | 3,470 | 4,800 | 4,135 | -10 | -2 | 0 | 0 |
| Chemical Oxygen Demand (COD) | mg/L | 8,000 | 11,890 | 9,945 | -2 | 0 | 0 | 0 |
| Biochemical Oxygen Demand (BOD) | mg/L | 1,260 | 3,900 | 2,580 | -8 | -2 | 0 | 0 |
| Ammonia ($NH_3$-N) | mg/L | 0,057 | 0,082 | 0,069 | - | - | - | - |
| Nitrate ($NO_3$-N) | mg/L | 0,055 | 0,152 | 0,103 | - | - | - | - |
| Nitrite ($NO_2$-N) | mg/L | 0,039 | 0,087 | 0,063 | - | - | - | - |
| Total Phosphate | mg/L | 0,030 | 0,046 | 0,038 | -10 | -10 | 0 | - |
| Phenol | mg/L | 0,002 | 0,014 | 0,008 | -8 | -8 | -2 | 0 |
| Dissolved Zinc (Zn) | mg/L | 0,001 | 0,006 | 0,003 | 0 | 0 | 0 | 0 |
| Dissolved Manganese (Mn) | mg/L | 0,001 | 0,078 | 0,039 | 0 | 0 | 0 | 0 |
| Dissolved Iron (Fe) | mg/L | 0,034 | 0,080 | 0,057 | 0 | - | - | - |
| Dissolved Lead (Pb) | mg/L | - | - | - | - | - | - | - |
| Dissolved Copper (Cu) | mg/L | - | - | - | - | - | - | - |
| Sulfide as ($H_2S$) | mg/L | - | - | - | - | - | - | - |
| Sulfate | mg/L | - | - | - | - | - | - | - |
| STORET total score | | | | | -38 | -22 | -2 | 0 |

| Parameter | Measurement Unit | Min. | Max. | Average | Score Class I | Score Class II | Score Class III | Score Class IV |
|---|---|---|---|---|---|---|---|---|
| Station 2 (Natural Lake Gentung Dayo) | | | | | | | | |
| Temperature | ◦C | 29,600 | 29,880 | 29,740 | 0 | 0 | 0 | 0 |
| pH | | 6,220 | 8,290 | 7,137 | 0 | 0 | 0 | 0 |
| Dissolved Oxygen (DO) | mg/L | 4,280 | 7,600 | 5,940 | -4 | 0 | 0 | 0 |
| Chemical Oxygen Demand (COD) | mg/L | 8,000 | 19,830 | 12,963 | -16 | 0 | 0 | 0 |
| Biochemical Oxygen Demand (BOD) | mg/L | 1,900 | 6,700 | 3,667 | -16 | -16 | -4 | 0 |
| Ammonia ($NH_3$-N) | mg/L | 0,006 | 0,077 | 0,032 | - | - | - | - |
| Nitrate ($NO_3$-N) | mg/L | 0,017 | 0,138 | 0,064 | - | - | - | - |
| Nitrite ($NO_2$-N) | mg/L | 0,001 | 0,029 | 0,010 | - | - | - | - |
| Total Phosphate | mg/L | 0,034 | 0,086 | 0,059 | -20 | -20 | 0 | - |
| Phenol | mg/L | 0,008 | 0,020 | 0,014 | -20 | -20 | -16 | 0 |
| Dissolved Zinc (Zn) | mg/L | 0,001 | 0,010 | 0,006 | 0 | 0 | 0 | 0 |
| Dissolved Manganese (Mn) | mg/L | 0,001 | 0,037 | 0,016 | 0 | 0 | 0 | 0 |
| Dissolved Iron (Fe) | mg/L | 0,034 | 0,204 | 0,104 | 0 | - | - | - |
| Dissolved Lead (Pb) | mg/L | 0,010 | 0,017 | 0,014 | 0 | 0 | 0 | 0 |
| Dissolved Copper (Cu) | mg/L | 0,007 | 0,013 | 0,010 | 0 | 0 | 0 | 0 |
| Sulfide as ($H_2S$) | mg/L | 0,003 | 0,003 | 0,003 | - | - | - | - |
| Sulfate | mg/L | 11,100 | 11,687 | 11,393 | 0 | 0 | 0 | 0 |
| STORET total score | | | | | -76 | -56 | -20 | 0 |
| Station 3 (Pit Lake II Saingprupuk Duo) | | | | | | | | |
| Temperature | ◦C | 29,800 | 29,950 | 29,875 | 0 | 0 | 0 | 0 |
| pH | | 6,520 | 7,980 | 7,157 | 0 | 0 | 0 | 0 |
| Dissolved Oxygen (DO) | mg/L | 3,860 | 5,100 | 4,480 | -20 | -16 | 0 | 0 |
| Chemical Oxygen Demand (COD) | mg/L | 10,530 | 28,000 | 20,303 | -20 | -4 | 0 | 0 |
| Biochemical Oxygen Demand (BOD) | mg/L | 2,047 | 4,200 | 2,812 | -20 | -4 | 0 | 0 |
| Ammonia ($NH_3$-N) | mg/L | 0,009 | 0,053 | 0,034 | - | - | - | - |
| Nitrate ($NO_3$-N) | mg/L | 0,043 | 0,291 | 0,179 | - | - | - | - |
| Nitrite ($NO_2$-N) | mg/L | 0,001 | 0,010 | 0,004 | - | - | - | - |
| Total Phosphate | mg/L | 0,039 | 0,131 | 0,092 | -20 | -20 | -4 | - |
| Phenol | mg/L | 0,092 | 0,240 | 0,166 | -20 | -20 | -20 | -20 |

| Parameter | Measurement Unit | Min. | Max. | Average | Score Class I | Score Class II | Score Class III | Score Class IV |
|---|---|---|---|---|---|---|---|---|
| Dissolved Zinc (Zn) | mg/L | 0,001 | 0,061 | 0,025 | -4 | -4 | -4 | 0 |
| Dissolved Manganese (Mn) | mg/L | 0,001 | 0,037 | 0,016 | 0 | 0 | 0 | 0 |
| Dissolved Iron (Fe) | mg/L | 0,016 | 0,481 | 0,178 | -4 | - | - | - |
| Dissolved Lead (Pb) | mg/L | 0,010 | 0,017 | 0,014 | 0 | 0 | 0 | 0 |
| Dissolved Copper (Cu) | mg/L | 0,007 | 0,013 | 0,010 | 0 | 0 | 0 | 0 |
| Sulfide as ($H_2S$) | mg/L | 0,003 | 0,003 | 0,003 | - | - | - | - |
| Sulfate | mg/L | 49,233 | 100,640 | 74,937 | 0 | 0 | 0 | 0 |
| STORET total score | | | | | -108 | -68 | -28 | -20 |

Source: own study

The calculation and categorization of the water quality lakes status of Lati Petangis Forest Park using the Pollution Index (IP) and STORET showed differences. The STORET method shows more "polluted" than calculations using the Pollution Index (IP) method. The Pollution Index (IP) method bases the calculation on the maximum parameter value, which is obtained from the division of the most influential parameters against the quality standard. While the STORET method bases the assessment of all parameters used through the minimum value, maximum value, and average value. Determination of water quality status using the STORET method is able to see which parameters exceed or meet quality standards and more sensitive in describing the dynamic changes in water quality (Saraswati *et al*., 2014; Barokah *et al*., 2017).

Using the Pollution Index (IP) and STORET methods have their own advantages and disadvantages, as in the Pollution Index (IP), where the data source comes from a single observation (single sample), so it is only able to describe water quality in short moment. As for the STORET method, the data processed based on periodic development and time, so it is able to more fully and sensitively describe water quality. However, the STORET method needs to be careful in determining the water quality parameters, because the assessment is based on the accumulation of parameters that do not meet quality standards, so choosing the wrong water quality parameters can lead to errors in determining the conclusion of water quality status (Saraswati *et al*., 2014). Both the Pollution Index (IP) and STORET methods can be used in determining water quality status in Indonesia becauserecommended through the Decree of the Minister of Environment of Republic Indonesia No. 115/2003.

Based on measurements of water quality parameters, the source of pollution in three observed lakes is generally related to organic compounds in the waters, although in the station 3 there is an indicator of zinc (Zn) whose value exceeds the quality standard. The high concentration of zinc (Zn) in the waters can be attributed to the rock formations that make up the lake, which naturally through the process of erosion and sedimentation enter the waters (Rogozin & Gavrilkina, 2008). High organic compounds in the water are suspected to come from riparian vegetation through leaf litter and natural lake processes. Although this statement needs further study Meanwhile, the high organic compounds in the water are suspected to come from riparian vegetation through leaf litter and natural lake processes. Leaf litter will undergo decomposition, thus affecting the organic compounds of the waters (Mutshekwa *et al*., 2020). Although, this concern needs further research.

Indications of organic compound pollution at three research stations were supported by plankton data that was found in the research by DLH Kab. Paser & FPIK UNMUL (2020). Plankton can be used as bioindicators in determining water quality (Soeprobowati *et al*., 2021). Phytoplankton growth is influenced by nitrate and nitrite compounds (Idrus *et al*., 2017). Station 1 found many species of *Oscillatoria* sp. and *Navicula* sp. The presence of *Oscillatoria* sp. is associated with many organic compounds in the waters (Soetignya *et* *al*., 2021) and the presence of *Navicula* sp. is a warning of deteriorating lake conditions (Yusuf, 2020). Station 2 found many species of *Navicula* sp. and *Nitzschia* sp. Both of species are found in water conditions with moderate to heavy pollution categories by nutrients or organic compounds (Heramza *et al*., 2021). Station 3 found many species of *Nitzschia* sp. and *Synedra ulna*. *Synedra ulna* indicates the status of eutrophic waters (Heramza *et al*., 2021).

The pollution pattern shown earlier has been observed in 2020. Concentrations of COD, total phosphate, phenol were always observed as sources of lake water pollution in the last 3 years. The source parameters of lake water pollution are known from the STORET calculation of the three observation stations. Therefore, more attention can be focused on reducing the concentration of COD, total phosphate, and phenol as organic pollutants.

Determination of water quality status using the Pollution Index and STORET can provide advice on the proper method to use as needed. STORET is recommended because it is more sensitive (Barokah *et al*., 2017). On the other sides, the Pollution Index can also be used to obtain a quick overview of water quality.

The importance of determining the water quality status of post-mining lakes is to determine the potential for lake development. For example, the pit lake at Collie in Australia has developed into an aquaculture site for crustaceans. Rassnitz Pit Lake, Paupitzsch Pit Lake and Gremmin Pit Lake in Germany have developed into part of protected areas for nature conservation (Blanchette & Lund, 2016; Sakellari *et al*., 2021). Monitoring the water quality status of the ex-mining lake in Lati Petangis Forest Park is necessary to develop the potential of the area, as contained in the water designation class through Government Regulation of the Republic of Indonesia No. 22/2021. Knowing the source of water pollutants can facilitate the focus of remediation to help formulating the usage of lake water as drinking water, water recreation facilities, aquaculture activities, or agricultural activities.

## CONCLUSION

The determination of the water quality status at three observation stations based on the Pollution Index (PI) and STORET methods, shows that station 1 (Pit Lake I Saingprupuk Erai) and station 2 (Natural Lake Gentung Dayo) can only be used for agricultural or irrigation activities (class IV), while station 3 (Pit Lake II Saingprupuk Duo) cannot be used for the four classes based on the Government Regulation of the Republic of Indonesia No. 22/2021. The STORET methods shown more sensitive than Pollution Index. Furthermore, the pattern of pollution at three observation stations is related to water organic compounds, such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Phosphate, and Phenol. Thus, the value of Dissolved Oxygen (DO) is also affected. Comparison of the two methods of determining water quality status can provide advice on the suitable method according to their needs. Monitoring water quality can help determine the class of water designation.

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