Strategies of water flow treatment of Paringin Pit Lake to meet wastewater discharge compliance

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Abstract

Coal mining by the open-pit mining method creates the formation of a pit lake. The ex-mining site, over time, was gradually filled with contaminated water and must be returned to the water quality standard of compliance level. With proper treatment, the pit lakes have the potential for several benefits and subsequent uses. This study aimed to analyze the existing condition of the Paringin Pit Lake at South Kalimantan by identifying the quality of the water flow, and it is compliance with the parameter threshold values. The results showed that the pit lake water management had been carried out supported by good management of the catchment area and was indicated the stable category by geology technical study. The success of its revegetation processed in the area was shown by an erosion study in which the result was a very low-level category. No less important is the management of runoff water both in the quantity of water balance control and consistent water quality treatment to meet the quality standard values that have been set. The Paringin Pit Lake water management strategy is a form of activity that demonstrates compliance with good and responsible mining principles to support sustainable development that can serve as a good reference and example for other mining activities in terms of mine closure preparation.

Keywords:
compliance
pit lake
wastewater
water balance
water quality


Introduction

Coal mining by the open-pit mining method can change the existing environmental baseline condition. At the end of mining activities, it created the formation of a pit lake filled with contaminated water, which has the potential to pollute the surrounding area and cannot be utilized if not managed properly (Lima et al., 2016; Setiawan et al., 2018). Mining activity changes the physicochemical conditions of water to create some parameters be not comply with the quality standard values of applicable regulations. The ex-mining site,
over time, is gradually filled with runoff and groundwater (Bargawa et al., 2019).

The pit lake has the potential for several uses and considers some aspects such as appropriate mine closure planning, land degradation handling, the impact of changes in natural landscaping and compliance with water quality referred to the standard and utilization purposes (Nordström et al., 2015). In the termination phase of the mining process, more detailed technical studies are needed, such as morphometry, geology, hydrology, water quality, fill level, and biology, for the next references (Soni et al., 2014).

The efforts to manage the water quality are a must as an obligation. The water quality of the pit lake is categorized as good if the water can be used according to its utilization and compliance. The water conditions are maintained in accordance with quality standards and avoid contamination by materials or particles, or other substances in order to have good runoff water from the pit lake, and then it can ultimately be used, especially to support the aquatic life of biota (Bargawa et al., 2019). Utilization of compliance water from the pit lake during the mine closure period will provide further benefits after the mining activities cease to support industrial interests or surrounding community needs (McCullough and Schultze, 2018; McCullough et al., 2020).

Materials and Methods

Research location

The research area is in the mining site of PT Adaro Indonesia in the administrative Tanjung District, South Kalimantan Province, Indonesia, as shown in Figure 1.

PT Adaro Indonesia is one of the largest mining companies in Indonesia, which mainly runs coal mining operations in South Kalimantan and Central Kalimantan under a Coal Cooperation Agreement (CCA) with the Government of Indonesia. PT Adaro Indonesia (hereinafter referred to as “Adaro Indonesia”) began with the cooperation between Enadimsa, a Spanish company, and the Indonesian Government Company of Tambang Batubara in a coal exploration project in Tanjung Subdistrict, South Kalimantan, in 1982. The name “Adaro” is derived from the name of a Spanish family that was famous in the country’s mining industry. Adaro Indonesia started using the trademark “Envirocoal” in 1990 for their coal product with low ash, sulphur, and NOx content. In 1992, Adaro Indonesia commenced mining activities in a 385-square-meter mining concession area in Tabalong, South Kalimantan. No less than one million metric tons of Envirocoal 5000 were successfully extracted from the Paringin mining site and sold that year. Now, Adaro Indonesia products are known as Envirocoal E5000 and E4000 (Triwibowo et al., 2021).

Data compilation and description analysis

There were two groups of data used for this study, i.e., primary data that were observed directly at the research site and secondary data that were obtained from companies that have conducted previous and ongoing data collections. Relevant data needed are the condition of Paringin Pit Lake, catchment areas that contribute to water runoff entering the pit lake and monitoring of the water quality compared to the compliance parameter of applicable regulation. Data obtained were analyzed by simulating the amount of water that comes with the surface flow and water originating from within the pit lake itself to obtain a balance of the amount of water in the pit lake. The analysis of water quality obtained was compared with...
the parameter quality standard values referring to the central government regulation of the Minister of the Environment No. 113 of the year 2003 (pH: 6-9; Total Suspended Solid (TSS) <400 mg L\(^{-1}\), Total content of Fe <7 mg L\(^{-1}\) and Mn <4 mg L\(^{-1}\)) (Kepmen LH 113, 2003), and the regional government regulation of the Governor of South Kalimantan No. 036 of the year 2008 (pH:6-9; TSS <200 mg L\(^{-1}\), Fe <7 mg L\(^{-1}\), Mn <4 mg L\(^{-1}\), and Cd <0.05 mg L\(^{-1}\)) (Pergub Kalsel 036, 2008).

Results

Coal mine area characteristic

Referring to coal production for the last 10 years, from 2012 to 2022, Adaro Indonesia's average coal production is more than 50 million tons per year. Increased coal production causes increased land clearing and overburden (OB) removal. The active pit area and land for disposal reach 15,000 ha, with a total OB removal of more than 200 million annually. Potential challenging is acid mine drainage issues at Wara pit, and high TSS value’s at Paringin pit by an average of 3,000-4,000 mm of rainfall annually; consequence, the amount of mine wastewater to be managed is more than 350 m\(^3\) per year (Triwibowo et al., 2021).

Catchment area condition

The catchment area of the Paringin Pit Lake was a dumping area of overburden (OB) that has been completed in the reclamtion process. Geotechnical studies for the area have been carried out at several points, as presented in Figure 2, and the basic data is summarized in Table 1.

<table>
<thead>
<tr>
<th>Pit Wall Material Type</th>
<th>Height (m)</th>
<th>Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Wall Sandstone</td>
<td>16-36</td>
<td>45-70</td>
</tr>
<tr>
<td>High Wall Mudstone</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>Low Wall Sandstone</td>
<td>16-48</td>
<td>45-70</td>
</tr>
<tr>
<td>Low Wall Mudstone</td>
<td>16</td>
<td>40</td>
</tr>
</tbody>
</table>

The results of the slope stability analysis are safe by considering the safety factor (SF). The SF is the ratio between the retaining strength that keeps the slope stable and the driving strength that causes the landslide, where the result of evaluating the SF>1.5 means summarized is a safe category (Aubertin et al., 2016; McCullough et al., 2020; Redondo-Vega et al., 2021). The catchment area contributes to the accumulation of rainwater that comes in the direction of the water flow, as shown in Figure 3. The catchment area was revegetated in the year 2012 to 2014, covering 45.14 ha, 2014 of 0.98 ha, 2015 of 25.06 ha, and 2016 of 27.88 ha (Figure 4).

Figure 2. Geotechnical study location.
An evaluation study of tree planting in the area has been carried out with the methodology of plots designed with a calculated sampling area of 50 x 20 m by placing 5 (five) plots of 2 x 2 m with the position of one in the middle and others in the corner of sampling. Water volume can be predicted by rain intensity in the catchment area and other related factors. The initial survey showed that no woody plant was a pole (diameter 10<20 cm) or even a tree (diameter ≥20 cm). The existing woody plants were seedlings (height <1.5 m) or saplings (height 1.5 m with diameter <10 cm) and have been identified the species increase from year to year compared to the previous study (Soendjoto et al., 2014; Triwibowo et al., 2021). The updated species that have been planted are presented in Table 2. The catchment area has been reclaimed and revegetated.
Table 2. Tree species update list in the catchment area.

<table>
<thead>
<tr>
<th>No</th>
<th>Local Name</th>
<th>Scientific Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Angsana</td>
<td>Pterocarpus indicus</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>2</td>
<td>Angsana Keling</td>
<td>Dalbergia latifolia</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>3</td>
<td>Ekaliptus</td>
<td>Eucalyptus urophylla</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>4</td>
<td>Jabon</td>
<td>An throcephalus cadamba</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>5</td>
<td>Johar</td>
<td>Casia siamea</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>6</td>
<td>Ketapang</td>
<td>Terminalia catappa</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>7</td>
<td>Pulai</td>
<td>Aistonia scholaris</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>8</td>
<td>Salam</td>
<td>Syzygium polyanthum</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>9</td>
<td>Sengon Buto</td>
<td>Enterolobium cyclocarpum</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>10</td>
<td>Sengon Laut</td>
<td>Parasentianthes falcatoria</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>11</td>
<td>Septuadea</td>
<td>Spathodea campanulata</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>12</td>
<td>Trambesi</td>
<td>Samanea saman</td>
<td>Fast Growing</td>
</tr>
<tr>
<td>13</td>
<td>Belangeran</td>
<td>Shorea balangeran</td>
<td>Slow Growing</td>
</tr>
<tr>
<td>14</td>
<td>Beringin</td>
<td>Ficus benjamina</td>
<td>Slow Growing</td>
</tr>
<tr>
<td>15</td>
<td>Gofasa</td>
<td>Vitex cofassus</td>
<td>Slow Growing</td>
</tr>
<tr>
<td>16</td>
<td>Halaban</td>
<td>Vitex pubescens</td>
<td>Slow Growing</td>
</tr>
<tr>
<td>17</td>
<td>Mahoni</td>
<td>Swietenia acrophylla</td>
<td>Slow Growing</td>
</tr>
<tr>
<td>18</td>
<td>Sungkai</td>
<td>Peronema canescens</td>
<td>Slow Growing</td>
</tr>
</tbody>
</table>

Erosion is one indicator to assess the stability of the area. Erosion can be calculated by conducting direct experiments in the field and predictions using the USLE formula (Meyer and Moldenhauer, 1985). A study has been carried out to predict the level of erosion, with the result being very low (Novitasari, 2006; Soendjoto et al., 2014; Triwibowo et al., 2021), and the success revegetation area is shown in Figure 5.

The percent relative depth, \( RD \), is then defined as follows:

\[
RD = \left( \frac{z_{m}}{d} \right) \times 100\% = 0.05 \frac{z_{m}}{A_0} \sqrt{\frac{\pi}{A_0}}
\]

The natural lake has a relative depth of less than 2%, and pit lakes commonly have relative depths between 10 and 40% (Doyle and Shapiro, 1999; Sánchez-Españo et al., 2014; Cozzolino et al., 2018). This causes pit lakes commonly to become stratified, and the chemical characteristics of lake water can vary greatly with depth. The result of the calculation summarized that the pit lake area is 195,552.8 m², the depth maximum is 33 m, the depth relative is 6.6%, and the retention time is 303 days (Widara, 2022). Total dissolved solids and electrolyte conductivity tend to increase with depth that values near the bottom are often several times those at the surface. The hypolimnion (lower stratum) of a stratified lake has the tendency to lose dissolved oxygen if enough organic matter is present. The existence of a sub-oxic or anoxic layer in a pit lake can have significant effects on the lake’s chemical and biological characteristics and, thus, on its potential for remediation (Lawrence et al., 2015). The cross-section of Paringin Pit Lake is shown in Figure 6 where the average depth of water is 90 m and the surface water level at around 64 m asl (above sea level).

**Pit lake physical characteristic**

Pit lakes differ physically compared to natural lakes in having markedly higher relative depths. Percent relative depth is defined in terms of a lake’s maximum depth, \( z_m \), and its width, \( d \). Assuming an approximately circular lake (Soni et al., 2014; Tuheteru et al., 2021), the width is a function of surface area, \( A_0 \):

\[
d = 2\sqrt{\frac{A_0}{\pi}}
\]

**Paringin Pit Lake water balance**

The water balance is to determine the amount of water flowing into and out of the pit lakes. The parameters that make up the inflow of water are groundwater, direct rainfall, and runoff water from the catchment area then entering the pit lake. On the other hand, water discharge parameters include evaporation and groundwater in the pit lake.
In addition to the main parameters, the water flow can be pumping water from a nearby pit lake in some cases (Tong et al., 2021; Tuheteru et al., 2021). Water balance equation (Sánchez-España et al., 2014):

$$\delta V_L = V_p + V_R + V_{GW} + V_{pm} - V_E$$

where: $\delta V_L$ represents the changes in volume (m$^3$) per period, $V_p$ is precipitation (m$^3$), $V_R$ is runoff water (m$^3$), $V_{GW}$ is groundwater (m$^3$), $V_{pm}$ is the water pumping volume, and $V_E$ is the volume of water lost, i.e., volume evaporation (m$^3$). The water balance can be considered from the catchment area and the pit lake itself. The catchment area is direct rainfall and evapotranspiration, runoff, and groundwater parameters. The pit lake area is direct precipitation, evaporation, and overflow (Tuheteru et al., 2021). The figure of the water balance is illustrated in Figure 7. Simulations for calculating the pit lake water balance are presented in Table 3. The average annual water flow is 2.7 million m$^3$, and the overflow is 1.8 million m$^3$ to maintain the effective pit lake capacity of 2.1 million m$^3$ and a water level of 64.80 m above sea level (asl).
### Table 3. Calculation simulation of water in and out of Paringin Pit Lake.

<table>
<thead>
<tr>
<th>No</th>
<th>Month</th>
<th>Median Rainfall (mm)</th>
<th>Inflow (I) (m³)</th>
<th>Water Used (O) (m³)</th>
<th>Inflow-Water Used (I-O) (m³)</th>
<th>Effective Capacity (S) (m³)</th>
<th>Storage (S + (L-O)) (m³)</th>
<th>Water Elevation (Level) (m)</th>
<th>Overflow (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January</td>
<td>240.73</td>
<td>293,889.12</td>
<td>80,389.20</td>
<td>213,499.92</td>
<td>2,122,303.88</td>
<td>2,335,803.80</td>
<td>64.80</td>
<td>213,499.92</td>
</tr>
<tr>
<td>2</td>
<td>February</td>
<td>263.00</td>
<td>321,083.55</td>
<td>72,609.60</td>
<td>248,473.95</td>
<td>2,122,303.88</td>
<td>2,370,777.83</td>
<td>64.80</td>
<td>248,473.95</td>
</tr>
<tr>
<td>3</td>
<td>March</td>
<td>253.43</td>
<td>309,393.91</td>
<td>80,389.20</td>
<td>229,004.71</td>
<td>2,122,303.88</td>
<td>2,351,308.59</td>
<td>64.80</td>
<td>229,004.71</td>
</tr>
<tr>
<td>4</td>
<td>April</td>
<td>203.61</td>
<td>248,580.32</td>
<td>77,796.00</td>
<td>170,784.32</td>
<td>2,122,303.88</td>
<td>2,293,088.20</td>
<td>64.80</td>
<td>170,784.32</td>
</tr>
<tr>
<td>5</td>
<td>May</td>
<td>117.38</td>
<td>143,307.44</td>
<td>80,389.20</td>
<td>62,918.24</td>
<td>2,122,303.88</td>
<td>2,185,222.20</td>
<td>64.80</td>
<td>62,918.24</td>
</tr>
<tr>
<td>6</td>
<td>June</td>
<td>147.80</td>
<td>180,441.63</td>
<td>77,796.00</td>
<td>102,645.63</td>
<td>2,122,303.88</td>
<td>2,224,949.51</td>
<td>64.80</td>
<td>102,645.63</td>
</tr>
<tr>
<td>7</td>
<td>July</td>
<td>118.00</td>
<td>144,060.30</td>
<td>80,389.20</td>
<td>63,671.10</td>
<td>2,122,303.88</td>
<td>2,185,974.98</td>
<td>64.80</td>
<td>63,671.10</td>
</tr>
<tr>
<td>8</td>
<td>August</td>
<td>101.00</td>
<td>123,305.85</td>
<td>80,389.20</td>
<td>42,916.65</td>
<td>2,122,303.88</td>
<td>2,165,220.53</td>
<td>64.80</td>
<td>42,916.65</td>
</tr>
<tr>
<td>9</td>
<td>September</td>
<td>101.00</td>
<td>123,305.85</td>
<td>77,796.00</td>
<td>45,509.85</td>
<td>2,122,303.88</td>
<td>2,167,813.73</td>
<td>64.80</td>
<td>45,509.85</td>
</tr>
<tr>
<td>10</td>
<td>October</td>
<td>136.50</td>
<td>166,646.03</td>
<td>80,389.20</td>
<td>86,256.83</td>
<td>2,122,303.88</td>
<td>2,208,560.71</td>
<td>64.80</td>
<td>86,256.82</td>
</tr>
<tr>
<td>11</td>
<td>November</td>
<td>256.50</td>
<td>313,148.03</td>
<td>77,796.00</td>
<td>235,352.03</td>
<td>2,122,303.88</td>
<td>2,357,655.91</td>
<td>64.80</td>
<td>235,352.03</td>
</tr>
<tr>
<td>12</td>
<td>December</td>
<td>304.15</td>
<td>371,321.53</td>
<td>80,389.20</td>
<td>290,932.33</td>
<td>2,122,303.88</td>
<td>2,431,236.21</td>
<td>64.80</td>
<td>290,912.33</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td></td>
<td>2,738,483.55</td>
<td>946,518.00</td>
<td>1,791,965.55</td>
<td></td>
<td></td>
<td></td>
<td>1,791,965.55</td>
</tr>
</tbody>
</table>
Utilization of water overflow for fish pond

Water from the pit lake flows into a lower level. It can be used for fishery farming studies. Fish ponds are created after the pit lake and before the compliance point. The fish pond is designed in an area of one ha, which receives an overflow of about 900 m$^3$ every month. Eight fish ponds were prepared with dimensions of length: 35 m, width: 15 m and depth: 1.5 m each (Figure 8). Three fish ponds prepare for the mating process by combining 300 males and 900 females in each pond, and the result of this process is distributed and sent to the community surrounding for their next development as a community project (Triwibowo et al., 2021).

Figure 8. Fish pond construction next to pit lake.

In some areas of fish ponds are put the water hyacinth to see her role in reducing the water’s total suspended solid (TSS) and providing good living places for fish. Water hyacinth reduced the water’s TSS and reduced the alum material usage for water treatment to comply with the applicable regulation (Suhernomo et al., 2022). The structure of a macrophyte community plays a large role in determining the community composition of phytoplankton, zooplankton and fish in freshwater ecosystems that may be novel in ecosystems that otherwise lack floating vegetation (Arora and Mehra, 2003).

Water quality compliance data

Referring to the parameters that have been set by the government as a reference in managing coal mining liquid waste, namely the Minister of Environment Regulation No. 113 of the year 2003 as a national regulation and the South Kalimantan Governor’s Regulation No 036 of the year 2008 as a provincial regulation that liquid waste from coal mining must meet the threshold value. Observations on the content of metals in water such as Fe, Mn and Cd as compliance parameters did not show any issue, considering the content are very low. Its means that all are compliant. It is regularly sampled every three months (quarterly). It has been supported by better material handling during the reclamation process. The Fe and Mn observation in the pit lake compared with the content in the water that overflows in the compliance point is shown in Figure 9 for Fe and Figure 10 for Mn. Cd content during observation is very low and does not show in the graphic. The average of Fe and Mn values at the compliance point is mostly lower than at the pit lake. During water flow from the pit lake to the compliance, point has another potential process is precipitation. Both the value of Fe, Mn, and Cd at pit lake and at the compliance point comply with the threshold parameter value. Observation of pH and TSS was also conducted quarterly. The history data of pH starting the year of 2014 until 2021 shows in ranges of pH 6.5 to 8.5, which can be concluded that pH also has been met and comply with the threshold value (pH 6-9).

Figure 9. Data of Fe on pit lake and compliance point.
It can be supported by better material management where PAF (Potential Acid Forming) have been covered by NAP (Non-Acid Forming) material to reduce the formation of acid mine drainage (Noor et al., 2019) or if it has been formed, the swampy forest system can be applied to improve the pH combine with tree species selected (Noor et al., 2022). TSS is one of the critical parameters in Paringin Pit Lake. Observation of the TSS level of water shows varying values. It requires more focus on TSS monitoring. To reduce the level of TSS overtime, the water was treated with coagulant materials. The material name of Kuriflock PC-702 is commonly used to treat Paringin Pit Lake. Since the years 2016 to 2021, the average ratio of material usage is 0.82 kg L⁻¹ then the material used for the year 2021 only has been reduced to 0.77 kg L⁻¹. Total material usage was reduced in 2021 which was related to the transition pond for fishery treated by water hyacinth before coming to the compliance point. The water hyacinth is a passive treatment to reduce the total suspended solid (TSS) parameter value.

The observations of pH and TSS from 2014 to 2021 are shown in Figure 11. All data comply with the threshold value (national regulation). The water of pit lake then flowed to the settling pond prior of the compliance point. The result of pH and TSS monitoring on compliance points is shown in Figure 12 (comply with both national and provincial regulations).
Considering the water quality is good and complies with the regulation, Paringin Pit Lake may have a plan set for the recreation area and clean water distribution for the community. For recreational purposes, then need a proper plan considering it will involve more people in the surrounding community, especially in terms of visitor safety. Figure 13 shows the condition of Paringin Pit Lake with the facility to support this option.

Discussion

The successful reclamation process in the catchment area of Paringin Pit Lake has been more than five years revegetated, which shows the natural forest has been formed, which has supported the development aspect of recovering hydrological conditions (Soendjoto et al., 2014). Based on the results of the analysis carried out as well as field observations, satisfactory results were obtained from the implementation of post-mining reclamation, which was marked by a good revegetation condition, including the new plants being overgrown naturally. The area also showed a good level of plant fertility as an assessment indicator. In addition, the main thing that can be seen and supports the hydrological aspect is the more stable erosion and surface flow conditions (Novitasari, 2006; Soendjoto et al., 2014; Triwibowo et al., 2021).

Monitoring pit lake water quality is very important. The condition of pit lake water quality will greatly determine the final plan for how the mitigation is carried out to keep the compliance quality of water
consistently (Castro and Moore, 2000; Lund et al., 2018). One of the best ways to validate the accuracy of predictions is to compare the predicted concentrations with obtained water quality data collected through monitoring programs (Connon et al., 2012). The monitoring program also enables the stakeholders to evaluate the condition of the pit lake from time to time, prepare corrective actions to avoid unmanageable water quality and verify the achievement of the company, community, and regulatory objectives (Gammons et al., 2009).

Pit lakes are generally potentially stratified, and the chemical characteristics of the water can vary greatly with the depth (Sánchez-España et al., 2014). Total dissolved solids and electrolyte conductivity tend to increase with depth. The lowest value is often several times the surface value (Geller et al., 2013). The hypolimnion (bottom layer) of terraced pit lakes tends to lose dissolved oxygen. The presence of a suboxic or anoxic layer in a pit lake can have a significant effect on the chemical and biological characteristics of the lake and thus on its potential for remediation (Lawrence et al., 2015).

The material for the coagulation process is an aluminate compound which is optimum at neutral pH (Lothenbach et al., 2011). In a cartesian coordinate system, an open parabolic relationship is formed, so it requires the right materials in the water treatment process. The reaction causes the release of high levels of $\text{H}^+$ ions coupled with the presence of aluminium ions. The aluminium ion is amphoteric, so it depends on the environmental conditions that affect it. When these substances are dissolved in water, the salt dissociates into metal cations and anions. Metal ions will form a layer in solution with a lower concentration than water molecules, this is due to the strong positive charge on the hydration of the metal ion surface (Cherry et al., 2001). The mixing process of the coagulant material must be in liquid to have more effective. The hydrolysis reaction that occurs is usually used to calculate the change in alkalinity. In fact, the $\text{Al}$ ions in the coagulant solution are hydrated and depend on the $\text{pH}$ of the hydrolysis. The compounds formed are positively charged and can interact with impurities such as colloids.

Compliance point is the last place to ensure that the water quality has met the quality standard before release to public agencies. Proper and correct design for treatment pond of compliance point is an obligation to have enough retention time and water flow out as planned. The compliance point of Paringin Pit Lake, namely MP2, is shown in Figure 14. Active treatment is one of the efforts that can be done if needed to mitigate conditions that cannot be overcome with the installed design (McCullough et al., 2020; Noor et al., 2022). Monitoring system to set all-time to ensure the water quality has met the threshold value on all compliance points to cover all areas from the mine site. Another example of other compliance points for water treatment is shown in Figure 15. The compliance point has been designed to cover the quantity and the quality of water to manage. The design has been considering many aspects to anticipate the unpredictable situation. Fish farming represents a common and often unintended end-use for pit lakes where the water quality is reasonable to good. However, pit lake for fisheries requires more consideration than just water quality, with habitat and food sources being important determinants of successful sustainable fisheries. Water quality must support adequate life for the animals around it (Meerhoff et al., 2007) and can be used by the community for their needs and of course, it has to be in line with the mine closure plan document that has been prepared by the company, understood by the stakeholder and approved by the Government (Sufrianto et al., 2021).

Figure 14. Compliance point of Paringin Pit Lake.
Conclusion

Paringin Pit Lake is one of the good examples of a better preparation of mine closure stage by ensuring the pit lake physical character, better catchment area management by success revegetation, determining the accuracy of water balance, and keeping the water quality consistently to achieve the goals that have been mutually agreed upon to provide benefits for all parties.

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References


Kepmen LH 113. 2003. Decree of the State Minister for the Environment of the Republic of Indonesia Number 113 of 2003 concerning Wastewater Quality Standards for Coal Mining Business and Activities *(in Indonesian).*


Pergub Kalsel 036. 2008. Regulation of the Governor of South Kalimantan Province Number 036 of 2008 concerning Liquid Waste Quality Standards for Industrial, Hotel, Restaurant, Hospital, Domestic, Mining (in Indonesian).


