Morphometry and Water Quality Study of Pit Lakes in Coal Mines

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Abstract

After mining is completed, the remaining pits that cannot be restored to their original condition become artificial pit lakes. Pit lakes are used in reclamation efforts after mining activities. An in-depth analysis of the pit lake generated in a previously mined area is required, specifically concentrating on evaluating the water volume, morphometry, and water quality of the pit lake. Management strategies required for achieving sustainable development. Paringin Lake was found to have a surface area of 19.5 hectares, a maximum depth of 33 metres, and an underwater retention duration of 303 days. A 1.25 volume shift in the Paringin pit lake indicates a shallow bottom state. The Paringin pit lake is relatively stable and not prone to wind-induced churning, as indicated by the relative depth calculation of 6.6%. According to calculations using the Storet method, Paringin Pit Lake has minor contamination. The distant location of the Paringin pit lake is the cause of this. The results suggested that Pit Lake Paringin has the potential for utilization in aquatic tourism and aquaculture.

Keywords: morphometry, storet, pit lake

1. Introduction

One of the potential hazards after mining is the creation of residual voids that cannot be restored to their original state. Later, the former mine will serve as a storage area for runoff and rainwater. Generally, when the topography is poor, the soil structure becomes denser and less permeable to water. As the area develops, water accumulates and forms new bodies of water known as Pit lakes.

Pit lakes are the result of open pit mining excavations. Pit lakes are water bodies formed in former mining pits due to the accumulation of groundwater and surface runoff [1]. It is important to maintain high lake water quality so that pit lakes can be utilized. A lake is said to be in good condition if it can be used and is free from pollutants that can harm the organisms that live in it [2].

Pit lakes can facilitate sustainable development. Thoroughly analyzed former mining sites that have been converted into water resources, with a particular focus on the morphometry and water quality of pit lakes. The investigation was conducted in a former coal mining area. An in-depth examination of the pit lakes in Paringin is important to assess the scientific feasibility of using artificial water reservoirs and to determine the management strategies required for sustainable growth, especially in areas that have undergone ecological change.

In 1981, Hakanson [3] conducted a morphometric examination of Pit lake to assess the physical characteristics of lake waters. Lake morphometry is assessed by analyzing its physical characteristics, including depth and elevation. Lake morphometry relates to the physical features of a lake, such as surface area (A), volume (V), and average depth (Z). The terrain surrounding the lake may affect the physical characteristics of the lake. Indrayani, et al [4] defined bathymetry as the underwater topography that forms the landscape beneath a lake. Bathymetry maps show the underwater topography of the Pit lake using depth contour lines, aiding surface navigation in the lake. In addition, bathymetry can be utilized for sustainable water management and utilization.

Water quality criteria are critical to successful lake management. Ensuring ideal water quality is essential for the well-being of aquatic organisms. The Ministry of Environment has issued recommendations for the management of lake ecosystems, including elements that impact the condition of aquatic ecosystems in lakes. Lake water quality assessment is carried out using the Store methodology and the Pollution Index method as stated in the Guidelines for Determining Water Quality Status in the Decree of the Minister of Environment Number 115 of 2003 [5]. Government Regulation concerning the Implementation of Environmental Protection and Management. Number: 22. Year: 2021 [6].

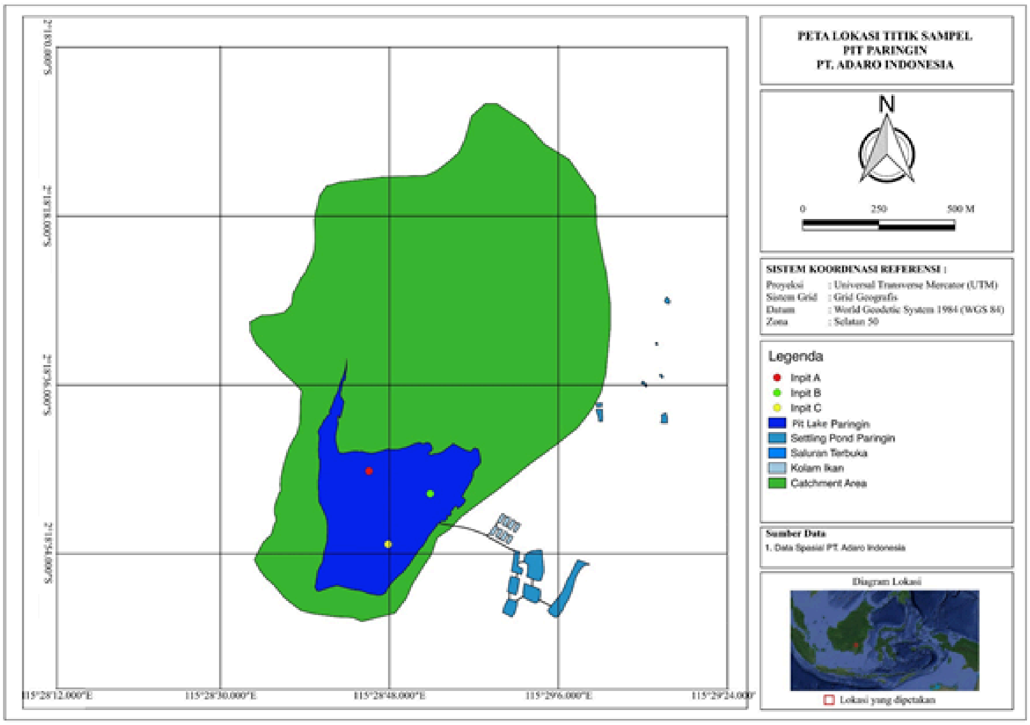

Figure 1. Map of Sample Point Locations

2. Methods

Pit Lake Morphometry

Pit lake morphometry is influenced by its elevation and depth. Pit lake morphometry relates to the size of the pit lake, including its volume (V), surface area (A0) and average depth (Z).

Pit lake volume is an important morphometric feature. Pit lake volume depends on catchment area and rainfall, and cannot stand alone. The main objective is to calculate the volume of water in the pit lake to assess whether it can meet the water demand.

Subsurface dimensions.

Subsurface dimensional measurements are cited by Hakanson [7] in Muhtadi [8]:

a. Surface area (Ao) refers to the area of the pit lake, which fluctuates with the seasons. Calculate the surface area of the depth map by determining the polygon area with QGIS software. Surface area can be expressed in Ha, Km^2 , or m^2 . The measurement uses the rectangular area formula:

$$Ao = Lmax \times Wmax \quad (1)$$

Description:

Ao = Lake surface

Lmax = Maximum length

Wmax= Maximum width

b. The average depth of the Mean ($\bar{z}$) is the result of : Volume divided by surface area, expressed in meters.

$$\bar{z}= \frac{V}{Ao} \quad (2)$$

Description:
V = Volume
A_O = Surface Area

c. The maximum depth (Z_{max}) indicates the deepest depth of the *pit lake*. Field measurements can be obtained directly using a weighted rope with weights, while indirect measurements can be obtained from depth contours on bathymetric maps. The quantity Z_{max} is expressed in meters.

d. The relative depth (Zr) is calculated by dividing the maximum depth of the excavation lake (Zmax) by the average diameter of its surface. The relative depth calculation is:

$$Z_r\ (\%) = 50.\ Zmax.\ \frac{\sqrt{\pi}}{\sqrt{Ao}} \quad (3)$$

Description:
A0 = lake surface area
Zmax = maximum depth

Wetzel [9] that most lakes have Zr values lower than 2, so lakes cannot shift. Lakes are classified into holomictic or meromictic. Lakes have specific mixing zones that are influenced by various elements including temperature, density, and depth. In holomictic lakes, water is completely mixed, but in meromictic lakes, water is only partially mixed. The deepest layer remains distinct due to its higher density caused by dissolved compounds or because it is protected from the influence of wind.

e. Volume development (VD) is a metric that characterizes the basic shape of a *pit lake* in a broad sense. The equation can be used to calculate VD:

$$VD = \frac{A_0 \times \bar{z}}{\frac{1}{3} x\ (Zmax\ x\ Ao)} \quad (4)$$

Description:
Ao = *Pit lake* surface area (m^2)
Z = Average depth (m)
Zmax = Maximum depth (m)

Since the VD magnitude is greater than 1, it can be concluded that the bottom of the pit lake is rather flat. If the VD value is less than or equal to 1, the water bottom is conical.

f. The total *pit lake* water volume (V) is calculated by multiplying the area (m^2) by the depth (m) of each contour in the *pit lake*. The *pit lake is* usually conical, which is calculated by considering the entire lake volume as the sum of each layer or contour.

$$V = \frac{L_1+L_2}{2} \times t \quad (5)$$

Description:
L_1 , L_2 = Cross-sectional area of sediment
t = Contour interval
V = Volume

g. Water residence time (Retention time, Rt) is the length of time water remains in the lake, measured in hours [10]:

$$Rt = \frac{V}{Q} \quad (6)$$

Description:
Rt = Water residence time (hour)

V = Total volume (m)^3
Q = Water discharge (m^3 /second)

h. The Schindler factor measures the impact of catchment area on a lake by determining the ratio of catchment area to lake surface and volume.

$$Schindler \text{ Factor} = \frac{Catchment\ area + Lake\ area}{Lake\ volume} \quad (7)$$

The Schindler factor is a statistic that assesses the vulnerability of a lake to damage by comparing the amount of water collected in the catchment with the volume of the mining lake [11]. The indicator used measures the impact of the lake on the ecosystem. There is a clear relationship between the Schindler factor and increased lake pollution. Waters with a ratio value of 2 or lower are resistant to pollution by pollutants entering from the surrounding environment [12].

Water Quality Status

The Minister of Environment issued Decree No. 113 Year 2003 which stipulates the Quality Standard for Wastewater and/or Coal Mining Activities of the Company. Wastewater from coal mining operations is water generated during coal mining and coal processing/cleaning processes. The Storet approach can be used to set water quality standards. The Storet method is a commonly used methodology for evaluating water quality. The Storet method allows identification of parameters that meet or exceed water quality standards. The Storet approach assesses water quality by comparing water quality data with water quality requirements.

The process of assessing water quality using the Storet method includes the following steps.

1) Get water quality information.
2) Compare the measurement data of each water parameter with the water quality standard value.
3) Attend aquatic classes. If the measurement findings are equal to or less than the water quality standard value, the weight is 0.
4) If the measurement findings exceed the water quality guidelines, the weight is set to 0. The values are shown in Table 1.
5) Negative values are generated for all parameters, and the quality status is assigned based on the overall score obtained from the scoring system. After assessing the water quality condition using the Storet method, the next step is to categorize the water into one of four classes based on the US EPA (Environmental Protection Agency) value system:
   - Class A: Very good, with weight = 0 meets quality standards
   - Class B: Good, with weight = -1 to -10 lightly polluted
   - Class C: Moderate, with weight = -11 to -30 moderate pollution
   - Class D: Poor, with weight > -31 severely polluted

Table 1. Determination of Value System to Determine Water Quality Status

Total Example	**Value**	**Parameters**		
		Physics	**Chemistry**	**Biology**
<10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
≥10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Average	-4	-12	-18

Source; KEPMEN LH No. 115 Year 2003

3. Results and Discussion

Morphometry and Bathymetry

The morphometric features of *Pit Lake were* assessed by analyzing surface and subsurface measurements obtained from the bathymetry map. Figure 2 shows the bathymetry map. Examining the bathymetry map data obtained from the field topographic map. The contour data comes from the boundary of the coal mining pit in Paringin pit. Produce a bathymetry map using the QGIS tool.

Table 2. Morphometry of Paringin Pit Lake

Parameters	Value
Surface Area (Ha)	19,55
Maximum depth (m)	33
Average depth (m)	14
Relative depth (%)	6,6
Volume (m)^3	2.692.235
Discharge (m^3 /s)	0,10
Retention time (days)	303
Volume development	1,25
Schindler Factor [m]$^{-1}$	0,55

To calculate the surface area of the bathymetry map, you need to determine the polygon area using QGIS software. Based on the surface area measurement (A0), the area of Lake Paringin is 195,552.8 m^2 and the maximum depth is 33 meters. The following are the results of the morphometric calculation of *Lake* Paringin *Pit*.

The area of Pit lake Paringin is 19.5 hectares. Pit lake Paringin has an average depth of 14 meters. This is evidenced by the largest lake depth of 33 meters and a relative depth of 6.6%.

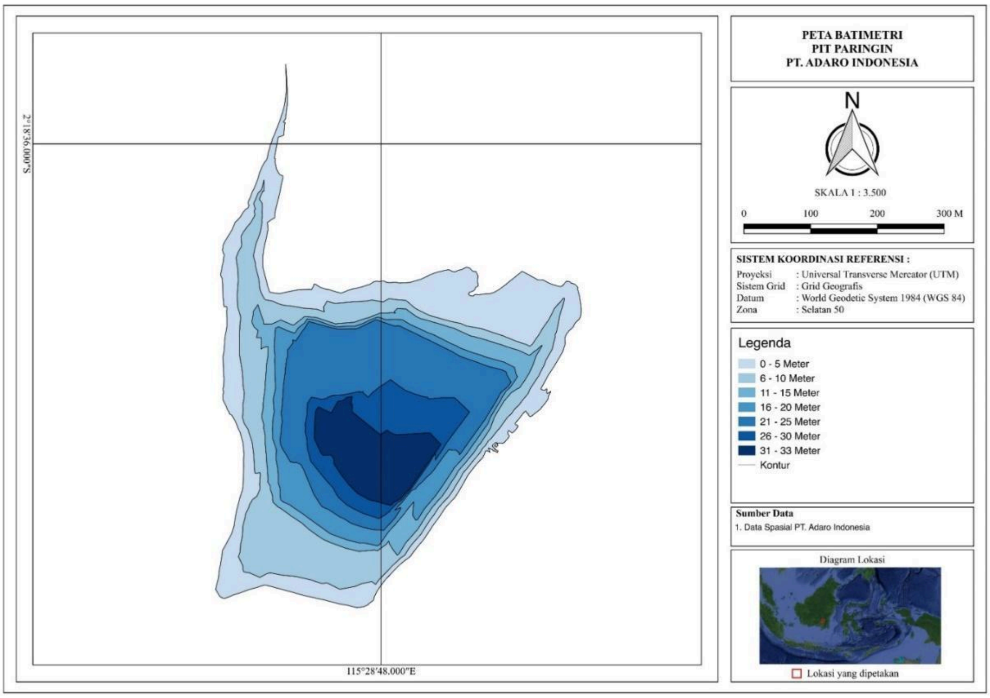

Figure 2. Bathymetry Map

The results of the average and maximum depth increases indicate that the Paringin *Pit lake is* resistant to wind stirring and has strong stratification stability. Wetzel [8] states that pit *lakes* with good stability usually have a Zr number of more than 4% and are resistant to wind-induced stirring. The depth of a pit lake has a significant impact on its water quality. This is related to the agitation of the lake as discussed by Barroso [12].

The water output of Lubang Paringin Lake is 0.103 cubic meters per second. The residence time of Lubang Paringin Lake water is approximately 303 days based on water discharge data. Water in Danau Lubang Paringin will experience a change every 303 days. This is also related to the rate of nutrient loss from the lake; incorporating nutrients will only last in the lake for 303 days. Straskraba and Tundisi describe that the criteria for the pit lake categorization system is based on the gradual release of water from the pit lake.

Pit lake with a retention time (Rt) of 20 days is included in the fast water flow category, while Rt between 20 to 300 days is included in the medium water flow category, and Rt above 300 days is included in the slow water flow. The Rt value indicates that the water discharge of Paringin Pit Lake falls into the slow water flow category.

Pratiwi [13] showed that the long duration of water retention in the *Pit lake* increases the likelihood of organic matter or nutrients accumulating within the lake. Therefore, the extended duration allows particulates suspended in the water to settle. Lubang Paringin Lake has a long water residence period, allowing suspended material to settle due to low mixing caused by strong stratification stability.

Pit lake Paringin has a volume development (VD) value of 1.25. Cole [14] explains that a VD value greater than 1 indicates a flat water bottom. Telaga Paringin has a flat bottom shape with a sparse contour map in the middle that does not intersect. The steep lake bed will be aligned with the contour graph in the center.

The Schindler factor has been determined to be 0.55. The Schindler factor is a parameter used to evaluate the vulnerability of mining lakes to damage. The Schindler factor is used. This indicator calculates the ratio between the total area of mining lakes and river areas and the volume of mining lakes [10]. The indicator used measures the environmental impact of lake mining. As the Schindler factor increases, pollution in mining lakes also increases. A lake or reservoir with a ratio value of 2 or less is not affected by pollution from its catchment [11].

Water Quality Status

The authors utilized the quality requirements of the Government Regulation of the Republic of Indonesia to classify the water quality criteria of pit lake. Table 3 displays the findings of the water quality status assessment.

Table 3. Quality Status of Water Quality According to the Storetical Value System for Class II designation

No.	Parameters	Unit	Quality standard	Measurement Result			Weight
				Max	Min	Average	
1	DO	mg/L	4	8,4	7,5	7,99	0
	Weight			0	0	0	
2	COD	mg/L	25	10	10	10	0
	Weight			0	0	0	
3	BOD	mg/L	3	2	2	2	0
	Weight			0	0	0	
4	in-situ pH		6-9	7,5	7	7,31	0
	Weight			0	0	0	
5	in-lab pH		6-9	6,92	6,62	6,74	0
	Weight			0	0	0	
6	Sulfur as H2S	mg/L	0,002	0,002	0,002	0,002	0
	Weight			0	0	0	
7	Hg (Mercury)	mg/L	0,002	0,00014	0,00005	0,000077	0
	Weight			0	0	0	

8	As (Arsenic)	mg/L	1	0,001	0,001	0,001	0
	Weight			0	0	0	
9	Cd (Cadmium)	mg/L	0,1	0,001	0,001	0,001	0
	Weight			0	0	0	
10	Sn (Tin)	mg/L	-	0,0092	0,005	0,0059	0
	Weight			0	0	0	
11	Pb (Lead)	mg/L	0,3	0,005	0,005	0,005	0
	Weight			0	0	0	
12	Nitrite	mg/L	0,06	0,001	0,001	0,001	0
	Weight			0	0	0	
13	Nitrate	mg/L	10	0,005	0,005	0,005	0
	Weight			0	0	0	
14	Ammonia	mg/L	0,2	0,78	0,05	0,16	0
	Weight			-0	0	0	
15	Total phosphate as PO4	mg/L	0,2	0,029	0,012	0,02	0
	Weight			0	0	0	
16	Temperature	°C	Deviation 3	23,4	21,2	22,36	0
	Weight			0	0	0,00	
17	TSS	mg/L	50	612	198	411,67	-5
	Weight			-1	-1	-3	
18	TDS	mg/L	1000	101	95	98,11	0
	Weight			0	0	0	
Total Weight							**-5**

Calculations using the Storet technique and US-EPA values classify the water quality of Paringin *Pit lake* as -5, indicating a "Class B" or lightly polluted status. Human and industrial activities can cause pollution in Paringin Lake, which now has a minimal level of pollution. The location of Paringin Lake in a coal mining area suggests that mining activities are the only source of pollution. This *pit lake is* very suitable for aquatic organisms.

4. Conclusion

Research results Pit lake Paringin has an area of 19.5 hectares, a maximum depth of 33 meters, and an underwater residency duration of 303 days. The volume change in Sangatin Pit Lake of 1.25 indicates that the lake bed is shallow. The calculation of the relative depth of 6.6% indicates that the Parigin Pit Lake is quite stable and resistant to relocation.

Analysis using the Storet method shows that Pit lake Paringin has a minimal level of pollution. Pit lake Paringin has relatively low pollution levels due to its remote location and distance from industrial operations.

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