Dissolved oxygen and temperature stratification analysis for early warning system development in preventing mass mortality of fish in lake Maninjau, West Sumatera - Indonesia

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Abstract: Lake Maninjau is caldera lake which lies at Sumatera island, Indonesia. The objective of this paper is to analyse dissolved oxygen (DO) and water temperature (WT) stratification related to mass mortality fish. The WT and DO stratification were measured by logger version CTD profiler with a depth interval of 1 m in March 2018. Based on analysis at 12 stations of measurement from buoyancy frequency value showed various stratification. The top layer (epilimnion) had a thickness of 2 m and the concentration of DO was 4.8 mg/l – 13.5 mg/l. Meanwhile, the hypolimnion layer formed at various depths ranged from 9 - 20 m to the bottom of the lake with concentration of DO was close to zero. These two layers are separated by a thermocline (metalimnion), which acted as a buffer. When the surface temperature of the lake was cooler than the lower one, then the density was increased, the turnover occurred. Then, the concentration of DO at the upper layer of the lake decreased, caused mass mortality fish. The process of the mass water reversal was monitored through temperature stratification and DO measurements in real time, as criterion for early warning system of mass mortality of fish.

1. Introduction

Stratification of lake is a natural phenomenon and can change at any time, depending on the dynamics of local weather conditions. Changing stratification or stirring of water column is an ecosystem response to maintain flexibility and environmental capacity. In subtropical areas, the process of stirring lake water is more different clearly than that in the tropics. This stratification affects chemical and biological processes, such as nutrient dynamics, gas transfer and phytoplankton distribution in the water column [1, 2, 3].

Hydrodynamics of lake water are influenced by lake morphometry, inflow and outflow, air factors, water density, and Coriolis effects [4]. In case of Lake Maninjau, the density of water and weather are the dominant factors, especially in the stratification dynamics. The strength of stratification is affected by the transfer of heat energy from sunlight to the body of water, air temperature and wind strength. If the sun’s intensity is low and persist in a long time, the temperature of upper layer also decreases (the density of water increases), then the water is in the condition of the isotherm, thus facilitating the vertical diffusion process.
The seasonal variability of atmospheric conditions influenced fluctuations in air and water temperature nearly proportionally [5]. The results showed that increase of air temperature resulted in an increase of the epilimnion layer temperature [6] and changed the depth of the thermocline layer [7]. Stratification will disappear when solar thermal energy is not strong enough, then the kinetic energy of the wind can move warmer water from the upper to the lower layers [8]. There are several parameters used as indicators of the stability of lake water columns, including index stratification, buoyancy frequency, stability index, lake number, weederburn number and Schmidt stability. Research on the stability of lake water columns has been widely carried out, especially in subtropical lakes. But a few study tropical lakes, especially in Indonesia. Recent study at Lake Maninjau, West Sumatra, Indonesia showed that there was a dynamic stratification of the daily water column, which was positively correlated with the power of sunlight and the strength of stratification of the water column was reduced when there was an increase in wind stress [9].

Lake Maninjau is Caldera lake which has a height of about 464 m above sea level. In addition, water surface area, coastline length, maximum depth and catchment area are 9,737 ha, 52.7 km, 168 m and 13,260 ha, respectively. Based on this morphometry, wind has an influence on the movement of water, especially on the surface and penetration of oxygen in water [10]. The relative depth (Zr) is 1.508 and the Shore line development (DL) is 1.51 km/km² [11]. The Zr value means low stability, easy to experience stirring due to outside influences, such as strong winds. Lake has a high stability value of Zr > 4, and is a deep lake with a narrow surface area [12]. Meanwhile, the DL value shows that the waters of the lakeside areas do not support the productivity of their waters. The longer the coastline the greater the productivity [13].

At present, Lake Maninjau, not only for a power plant that generates annual energy of 205 GWH, but also used for floating net cages (KJA) which number more than 15 thousand plots. Every year, there are frequent mass mortality of fish that coincide with upwelling process. Research Centre for Limnology LIPI in collaboration with relevant agencies has been establishing online environmental parameter monitoring systems and developed into an early warning system for mass mortality fish. Therefore, this paper aims to examine the dynamics of temperature stratification and dissolved oxygen (DO) in Lake Maninjau for the basis of further development of early warning systems.

2. Materials and methods
The logger version CTD profiler with optical fast DO sensor RINKO-Profiler was used for our survey. Depth (semiconductor pressure sensor with ranged 0 to 600 m and resolution 0.01 m), temperature (thermistor with ranged -3 to 45°C and resolution 0.001°C) and dissolved oxygen/DO (phosphorescence with ranged 0 to 20 mg/L and resolution 0.001mg/L) were obtained at 61 stations. Measurements were carried out on March 12 – 17, 2018 with an interval depth of 1 m. The measurement station is presented in figure 1. Meanwhile, the data series of temperature profile and DO period starts from January to May 2018 obtained from e-most (monitoring on line) of Research Centre for Limnology station.
Figure 1. Stations of temperature stratification and DO at Lake Maninjau.

2.1. Determination of the stability of the water column

a. Buoyancy Frequency

Buoyancy frequency \( (N) \), is the frequency of oscillation of a water package in a stable layer of water column. This size is an indicator of water stability. The greater the frequency, the more stable of the water column. Buoyancy frequency, which is the local stability calculated by referring to [3].

\[
N = \sqrt{\frac{g}{\rho} \frac{\partial \rho}{\partial z}}
\]

where

- \( \rho \) : (kg/m\(^3\)) Water density for each depth layer (kg/m\(^3\))
- \( \frac{\partial \rho}{\partial z} \) : gradient density ((kg/m\(^4\))
- \( g \) : gravity acceleration (m/s\(^2\))

b. Stratification Index (SI)

The stratification index is the potential energy needed to mix the water column. If the water column has a large stratification index, then the large effort needed to mix the water column (water column is stable). Conversely, if the water column has a low SI, it will be easy to mix the water column. Next, the calculated index stratification refers to [14].
\[SI = - \int_{-h}^{0} (\rho - \langle \rho \rangle) g \, dz\]

where
- \(\rho\) : the density of water in each layer of depth (kg/m\(^3\))
- \(\langle \rho \rangle\) : average density of water for each layer of depth (kg/m\(^3\))
- \(g\) : gravity acceleration (9.8 m/s\(^2\))
- \((T_0 - T)\) : delta of water surface and air temperatures

3. Results and discussion

3.1. Stratification and distribution of water temperature

In general, the interaction process of physics, chemistry and biology in water is closely related to the function of temperature. Temperature is also an important parameter in determining the level of habitat feasibility for fish and other organisms. Water temperature plays an important role in the distribution of species [15], and the growth and survival of aquatic organisms, including phytoplankton and fish [16, 17, 18]. Water temperature also affects the reproductive time, development, growth, death and metabolism of most species, including fish [19, 20, 21, 22].

Moreover, water temperature determines the density of water (\(\rho\)), while \(\rho\) is the basic parameter in hydrodynamics. The difference \(\rho\) results in stratification of the water layer (epilimnion-metalimnion-hypolimnion) and prevents vertical mixing. According to [23], \(\rho\) is determined significantly by temperature, salinity, and total concentration of suspended sediments. However, according to [24], suspended sedimentary factors are important in ice lakes, while salinity factors only play an important role in high salinity lakes.

**Figure 2.** Water temperature profiling at Lake Maninjau.

For more detailed analysis, 12 stations were chosen from 61 stations which could represent both the aspect of space (horizontal distribution) and time (measurement in hours) and depth of the lake. The measurement results are shown in figure 2.

Figure 2 shows the water layer to a depth of 6 m, had a horizontal distribution of differences more than 1°C. Similarly, that at a depth of 10 m, 15 m and 20 m were 0.6°C, 0.3°C and 0.2°C, respectively. The smallest difference at 30 m depth, seemed evenly distributed throughout the lake. The temperature stratification at the 12 stations also showed the same pattern to a depth of 20 m. In addition, the fluctuation of water temperature decreased with increasing depth, indicating homogeneous and constancy of temperature in the deepest layer (table 1).
Table 1. Average and standard deviation of temperature (Temp) for each depth.

| Temp (°C) – Depth (m) | Standard deviation (σ) |
|-----------------------|------------------------|
| Temp 2 m              | 27.9 °C ± 0.348        |
| Temp 4 m              | 27.7 °C ± 0.296        |
| Temp 6 m              | 27.6 °C ± 0.298        |
| Temp 10 m             | 27.4 °C ± 0.188        |
| Temp 15 m             | 27.2 °C ± 0.115        |
| Temp 20 m             | 26.9 °C ± 0.106        |
| Temp 30 m             | 26.8 °C ± 0.024        |

Stratification of water layer based on temperature shows less clear boundaries, especially between the epilimnion and metalimnion, however the stratification for the hypolimnion layer was clearer (figure 3). This unclear stratification is common in tropical regions, so it is difficult to identify the epilimnion layer [25]. At a depth of 20 m, the water temperature of 26.8 °C showed insignificant differences, so this layer acted as a hypolimnion. The depth water of 1.5 m was very dynamic. Compared with a depth of 2 m, considered to be more stable, so the temperature difference with the hypolimnion layer also varies greatly, ranging from 0.6 °C (Stations 21-61 and Stations 29-104) - 1.6 °C (Stations 57-108) (figure 2).

In the hypolimnion depth, the density of water showed a value of 0.997 gr/cm³. The values of water density compared with water surface showed small values, ranging from 0.0003 - 0.0023 gr/cm³ (Station 3-113 ρ 0.9964 gr/cm³ and Station 47-137 ρ 0.9964 gr/cm³) (figure 4). The difference of ρ between the hypolimnion layer and the small above layer indicated no stirring of water mass. According to [24] the density with difference of 0.0003 is sufficient to prevent mixing. So, the measurement on March, the area of Station 47-137 has a very strong water period stratification compared to the Station area 3-113. This condition indicated uneven stirring occurred in whole lake area.

Figure 3. Water temperature stratification pattern at Lake Maninjau.
3.2. Stratification and distribution of DO

Figure 5 shows the variation of DO values on the lake surface had a large value and decreased followed the depth. At 10 m depth, the DO values have started to zero at some stations, and starting at a depth of 15 m, only a few stations whose values are close to 2 ppm (figure 5). At Station 21-61 DO at a depth of 2 meters around 3.8 ppm, and a depth of 4 m has decreased to 2.5 ppm. This area is KJA region, which requires quite a lot of oxygen, resulting in a decrease in DO. In the case of low DO content, it has caused disturbances in fish that DO conditions above 5 ppm for the growth of all aquatic organisms [26].
Figure 6. DO stratification pattern at Lake Maninjau.

DO stratification profiles have the same pattern as water temperature (figure 6). Based on 12 stations, it showed DO zero varies in water depth from 7-19 m to the bottom. At a depth of 2 m several stations have shown low DO values, such as Station 21-61 DO 3.7 ppm and even at Station 54-134 DO 2.6 ppm. It seemed that Lake Maninjau at a water depth of up to 19 m had a dynamic DO variation, while the water depth of more than 19 m DO have been zero throughout the lake.

3.3 Water column stability

Figure 7 shows the buoyancy frequency (St.45-144) and the lowest (St.57-108) at Lake Maninjau. The first maximum peak of the N curve at both stations was at a depth of 5 m and 15 m. The peaks of the curve showed that at this depth, there is a thermocline layer which can prevent the mixing and diffusion process. There was a peak variation of the N curve from the surface to 30 m. From a depth of 30 m to the bottom, the frequency was the same at each depth. It indicated the density of water in each layer of water was homogeneous. There was no density gradient indicating that there was no barrier to mixing and diffusion processes. It seemed the depth range of 20 m – 30 m, it was started for homogeneous layer until bottom of lake.

In addition to buoyancy frequency, the stratification strength of Lake Maninjau was also characterized by using the stratification index (figure 7.B). The calculation results showed that the sampling point of the measuring water column had SI ranging between 14.47 - 4103.86 Jm⁻². The greatest strength of stratification was in the middle (St. 45-144 and St.47-137), while the smallest in the south. This corresponds to the N curve, which was at St. 45-144 N curve had the highest peak compared to other stations. The high SI value at this point was caused by the amount of heat energy absorbed in the area and this condition corresponds to the high water temperature in the area. This situation causes the penetration of heat energy deeper and shifts the thermocline layer deeper. As a result, water stability will increase.
Based on the results above, there were variations in temperature and DO profiles both vertically and horizontally that vary from one location to another. The stirring process also varies, not simultaneously throughout the lake. This also shows that when the stirring occurred, only fish in the fish cage died, because the fish trapped in and could not look for locations that did not occur stirring/oxygen in the other places.

Figures 8 and 9 show the beginning of the year, the water temperature started at a depth of 4 m almost homogenous. This condition occurs most often in January around 12 days and decreased from February to May. At the same time, DO also dropped, it was close to zero and caused fish died, especially on fish cage. This stirring of water was also triggered by the cold air temperature in a few days earlier. In January, the difference in daily air temperature with the water surface ranged from 0.2 to 0.4 °C. Whereas in other conditions the daily temperature difference reaches 1.8 °C.

Figure 8. Daily temperature stratification pattern at Lake Maninjau (January-May 2018).
Figure 9. Daily DO stratification pattern at Lake Maninjau (January-May 2018).

Figure 10. Early warning system for mass mortality fish monitoring.

Figure 10 showed an early warning system that established by the Research Centre for Limnology LIPI at Lake Maninjau-West Sumatra. Principally, this system records the water temperature and oxygen from surface to a depth of 60 m with interval measurement 10 minutes. The measurement results in the field are immediately sent in real time to the server at the Cibinong-Bogor office. Data entered in server is processed and compared to certain criteria whether it is categorized as hazard, standby 1, standby and normal. Each change in status (hazard, standby 1, standby and normal) always gives a signal to the registered cell phone. The results of temperature monitoring and DO data can also be accessed through website [27].
4. Conclusion
Water temperature and DO stratification in Maninjau Lake are very dynamic, especially up to a depth of 6 m, which was characterized by horizontal (space) and vertical (depth) variations that had wide those vulnerable values. The hypolimnion layer started at a depth of about 20 m - 30 m which was evenly distributed throughout the lake, while the upper layer was difficult to separate between the epilimnion and metalimnion. By understanding the dynamics of temperature stratification and DO in detail, it can be used as a reference for the development of warning systems.

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