

Determination of purification ratio of Lake Maninjau in epilimnion zone

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Abstract. This study aims to determine the purification ratio (reaeration and deoxygenation ratio) in the epilimnion layer of Lake Maninjau. The parameters studied were BOD, COD, and environmental parameters such as temperature, pH, DO, wind speed and water velocity. Sampling was taken at three sampling station at east- and west side of the lake at 0, 2, 4, 6 m depth, and at 10 m depth of the center of the lake in the rain and not rain condition. The water quality of Lake Maninjau showed that the organics parameters had exceeded the quality standard. The organic substances measured as BOD ranged in average 12 mg/L and COD ranged in average 193 mg/L in rain conditions, whereas under dry conditions the BOD were higher i.e. in range of 22 mg/L and COD 218 mg/L. The deoxygenation rate (K_1) during rain and dry were ranged in 0.047-0.371/day and 0.038-0.967/day respectively, whereas the reaeration rate (K_2) of those were in the range of 0.117-0.647/day and 0.161-0.691/day respectively. The overall value of the purification ratio (K_2/K_1) of Lake Maninjau was in the range of 1.282-5.048 in rain condition and 1.107-7.230 in dry condition. It indicated, that Lake Maninjau in the epilimnion zone still has self-purification ability to assimilate the organic pollutants.

1 Introduction

Lake Maninjau with an area of 9737.5 Ha located in Agam district, West Sumatera is one of the largest lakes in Sumatera. The lake is multipurpose, serving hydropower, as a means of fisheries, irrigation, and tourism. However, due to the aquaculture activity through fish cage has exceeded the capacity caused a decreased quality of Lake Maninjau. Regional Environmental Impact Management Agency reported that characteristics of Lake Maninjau in 2010 for the parameters BOD, COD, and DO were 1.8 mg BOD/L, 18 mg COD/L, and 8.2 mg DO/L respectively and decreases in 2011 to 18 mg BOD/L, 90 mg COD/L, 0 mg DO/L [1]. It is also reported by Marganoef [2] that the pollutant load for TSS, COD, BOD, and phosphate parameters has exceeded the assimilation capabilities of Lake Maninjau.

The lake has a natural purification capacity against pollutants entering the waters (self-purification), but excessive pollutant levels will inhibit self-purification. Self-purification of the waters can be measured through the ratio of reaeration and deoxygenation rate [3]. Deoxygenation rate (K_1) is the consumption of dissolved oxygen in natural streams, while reaeration rate (K_2) is the oxygen uptake rate into the waters from the atmosphere. Oxygen

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uptake from the atmosphere occurs in the epilimnion layer, which is the uppermost stratification layer of the lake. This layer had a higher light intensity, temperature and dissolved oxygen concentration than the layer beneath (hypolimnion) [4]. Lake Maninjau is a techno-volcanic lake that contains considerable amounts of sulfur and the input of organic carbon has increased hydrogen sulfide production in hypolimnion that can trigger a release of phosphorus from sediments [5]. Henny also revealed that the prolonged excess nutrients and carbon sources in this lake could affect a temporal changes of trophic status and the anoxic thickness of the hypolimnion layer that will continue to move upward pushing the epilimnion layer [5]. This condition may lead to a decrease of the lake purification capacity which is constantly burdened by an increase of fish cages as organic and nutrient sources.

Studies on self-purification have been conducted in several lakes such as Lake Oguta, Nigeria, where the value of deoxygenation (K_1) was 0.104/day, reaeration rate (K_2) was 0.104-0.111/day, and purification ratio of 1-1.07. The source of pollutants in Lake Oguta comes from agricultural activities, fisheries, and mining [6]. The lower reaeration rate K_2 was from a study on Lake Oshika, Nigeria i.e. 0.01 to 0.19/day with the pollution sources from settlements and agriculture [7]. Those values illustrate that the Lake Oguta and Lake Oshika were moderately polluted. However, those studies were conducted on medium-sized and low-velocity lakes, while studies on large lakes with high-speed winds such as Lake Maninjau are still limited. Meanwhile, Indonesia as a tropical country is dominated by two seasons, the rainy season and drought with rich sunlight that will affect deoxygenation- and reaeration rate of the lake [8]. Based on these reasons the ability of self-purification in Lake Maninjau through the ratio of the reaeration rate (K_2) and the deoxygenation (K_1) rate, especially in the epilimnion zone in rainy and not rainy conditions was investigated.

2 Methods

2.1 Sampling site, sampling and analysis method

The sampling locations were determined so that the samples can represent the characteristics of lake water. The sampling location was conducted at two locations, station 1 located in the eastern part of the lake representing floating net cages, and station 2 located in the western part of the lake representing pollutants from settlements taken at depth (0, 2, 4, 6) m, while the location in the center of the lake is used as a control, sample was taken at 10 m depth (Fig. 1). This depth represents the epilimnion layer of the lake based on the previous research, which is at a depth of less than 20 m [5]. The sampling distance of 0.5-1 km from the lake shore was considered as the average distance of floating net cage in Lake Maninjau, while the distance from the lake shore to the control site was 3.5 km.

Sampling was conducted in two conditions, rain (December) and dry condition (March) in the year 2013. Rainfall in western Sumatera is generally evenly distributed throughout the year. In certain months the rainfall rate is higher than the other months. The rainy time means that if the rain has fallen for three consecutive days, while the dry time is if the rain does not fall for three days. December represented a high rainy season, while March represented a low rainfall or dry season. Sampling was taken using a grab sample method. Water samples were taken using a vertical water sampler with a volume of 5 liters from a boat. Samples were prepared for laboratory analysis (BOD_5 and COD) and field analysis (temperature, pH, and DO). Samples for laboratory analysis were put into a 500 mL polyethylene bottle. The sample for BOD_5 analysis was stored in a cool box, while the a concentrated H_2SO_4 solution was added into COD sample until pH 2. Water flow velocity was measured at each sampling station by floating method. This method was chosen because it is simple, easy to do, and suitable for slow waters [9].

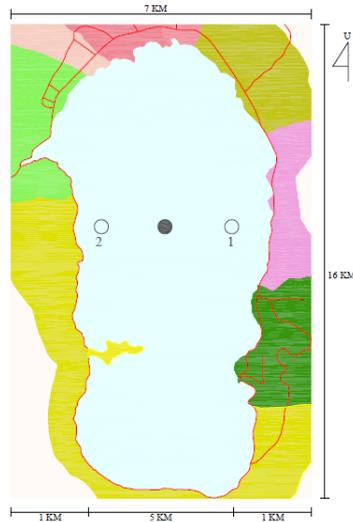


Fig. 1. Sampling site in Lake Maninjau. Station 1 located at Gasang (east side of the lake), station 2 located at Sigiran (west side of the lake). Control located in the center of the lake at 10m depth.

The measurements were performed simultaneously during water sampling. The light material was floated within 1m. The time was measured, then water speed was calculated [9]. Measurements were carried out three times. Wind speed of each sampling station at 50cm above the lake surface was measured using an anemometer Lutron AM-4205. Before wind speed measurement, the predominant wind direction was determined to represent the actual conditions. The anemometer's propeller was directed to the dominant wind direction. The number displayed on the anemometer was the wind speed value at the sampling site in m/s. Water samples was analysed using immediate and laboratory analysis. The immediate analysis was conducted for temperature, pH, and DO parameters. Temperature and pH were measured using a calibrated pH-meter equipment, while DO field used a DO-meter equipment. BOD₅ and COD analysis refers to Standard Methods for the Examination of Water and Wastewater [10].

2.2 Purification ratio calculation

The purification ratio of Lake Maninjau was determined based on deoxygenation rate (K_1), reaeration rate (K_2), and purification ratio (K_2/K_1). The rate of deoxygenation (K_1) was calculated using Thomas's slope method, via the least-squares treatment of the basic form of the first-order reaction equation [11].

$$\frac{dy}{dx} = K_1(L_a - y) = K_1L_a - K_1y \quad (1)$$

where dy = increase in BOD per unit time at time t , K_1 = deoxygenation constant, per day, L_a = first stage ultimate BOD, mg/L, y' = BOD exerted in time t , mg/L

The differential equation (Eq. 1) is linear between dy/dt and y . Let $y' = dy/dt$ to be the rate of change BOD and n be the number of BOD measurements minus one. K_1 was calculated using two normal equations:

$$a \sum y + b \sum y^2 - \sum yy' = 0 \quad (2)$$

$$n a + b \sum y - \sum y' = 0 \quad (3)$$

By eliminating Eq. 2 and 3, value b or K_1 was obtained. The reaeration rate (K_2) was calculated using Thomann and Fitzpatrick equations [12]:

$$K_2 \text{ (/day)} = 3,93 \frac{\sqrt{U_0}}{H^{\frac{3}{2}}} + \frac{0,728U_w^{0,5} - 0,317U_w + 0,0372U_w^2}{H} \quad (4)$$

where U_0 = horizontal flow velocity (m/s), H = lake depth (m), U_w = wind speed 50 cm above lake surface (m/s).

3 Results

3.1 Characteristics of Lake Maninjau

The water and environmental characteristics of Lake Maninjau are presented in Table 1. From the table, it could be seen that the temperature was in the range of 22.7-32.7°C, which at the surface had a slightly higher temperature (28.6°C) than the underlying layer (27.5°C).

Table 1. Water and environmental characteristics of Lake Maninjau.

Parameters	Unit	Rain	Dry	Standard Quality ¹	Annotation
Temperature	°C	22.2-29.7	24.4-32.7	Deviasi 3	-
pH	-	5.29-9.41	7.1-10.01	6-9	Exceeds
BOD ₅	mg/L	2.75-18.85	5.87-37.21	6	Exceeds
COD	mg/L	160-240	253.6-416	50	Exceeds
DO	mg/L	3.94-5.64	2.97-4.19	3	-
Wind speed	m/s	0.4-3.8	1.1-2.9	-	
Flow velocity	m/s	0.03-0.09	0.073-0.173	-	

¹Government regulations the Republic of Indonesia Number 82 the year 2001 on Water Quality Management and Water Pollution Control; Standard Quality Class 2.

The pH of Lake Maninjau waters was relatively high and tend to be alkaline (5.29-10.01). This alkaline pH value indicates that the lake has undergone eutrophication due to the activity of fish cages that enter the lake and disposal of residential wastewater [18].

The average of BOD₅ and COD concentrations when it rained were 12 mg/L and 193 mg/L, while those at dry were higher with 22 mg/L and 218 mg/L, respectively. The values are higher than BOD₅ and COD concentrations reported by Regional Environmental Impact Management Agency in 2011 with 18 mg/L and 90 mg/L. The values are also exceeded the standard quality of BOD₅ and COD with maximum of 6 mg/L and 50 mg/L. Accumulation of incoming wastes due to increasing human activity around the lake such as settlements, hotels, restaurants, and fish cage has increased the organic content of the lake. DO concentrations ranged from 3.94 to 5.64 mg/L during rain and slightly lower when it dry with 2.97 - 4.19 mg/L. Most of DO concentration of the lake is higher compared to the standard of 3 mg/L, indicating the lake still can support aquatic life. On the contrary, the organic content of the epilimnion layer does not meet the Government regulations PP No.

82 of 2001 [13] since the water was used for recreation facilities, fisheries, irrigation, and husbandry. Lake Maninjau had a flow velocity of 0.03-0.173 m/sec, where during rainfall the velocity could reach 0.1 m/sec. The wind speeds vary between 0.8-3.8 m/sec, where the wind speed can lead to ripple up waves in lake water.

3.2 Dissolved Oxygen (DO)

In Fig. 2a and 2b, it can be seen that the DO concentration was in the range of 4.37-5.17 mg/L in the rainy season, compared to dry season with a range of 3.11-3.35 mg/L. Meanwhile, in the center of the lake at 10 m depth, the DO concentration was not much different from other parts of the lake, which was 4.32 mg/L when it rains and 3.28 when it dry. This range indicated that the DO concentration at rainy days was higher than that of dry days. Generally, the value was above the standard, i.e. 3 mg/L. During the rainfall, the waters will be replenished by oxygen (reaeration) from the atmosphere due to wind [14]. Based on the depth, the DO concentration changes were not significant, except for station 2 at depths of 0 and 2 m (Fig. 2a) where there was an increase of DO from 4.69 to 5.17 when it rain. This condition probably due to a turbulence of waters, due to wind and rainfall on the surface of the lake that causes diffusion of oxygen to a certain depth [8]. However, during the observation, the wind speed at station 2 when it rained and not rained was 1.1 m/s, so the rainfall factor was more influential in increasing the DO concentration. Also, the upwelling can reduce levels of dissolved oxygen in the surface to some depth [15, 16].

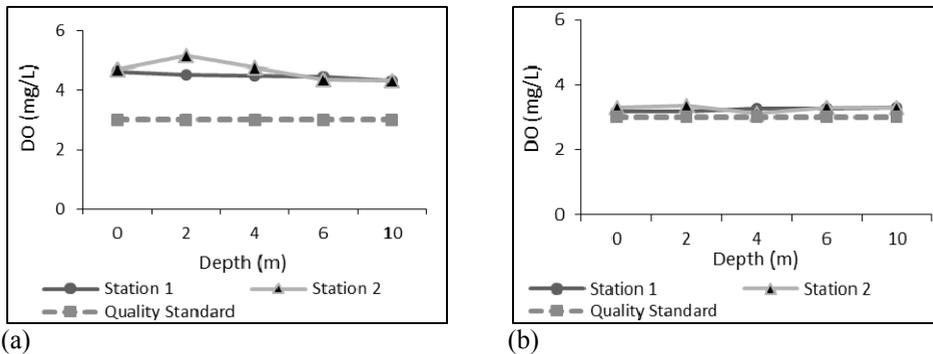


Fig. 2. DO concentration at various depth in a) rain, and b) dry season (sampling at 10 m located in the center lake, DO quality standard is 3 mg/L).

Another factor affecting DO levels on the surface was the presence of water hyacinth (*Eichhornia crassipes*) in some parts of the lake. Water hyacinth contributes to a reduction of the DO levels through photosynthesis [17] The lake has been greenish in certain depth due to the increase number of phytoplankton indicating that the eutrophication took place [18]. The maximum photosynthetic activity by algae and phytoplankton in dry days produced enough dissolved oxygen that was evenly distributed in this location, however, up to 6 m depth there was no anoxia indicated in the lake.

3.3 Biological Oxygen Demand (BOD)

The organic content measured as BOD₅ parameter against the sampling point and depth in rain or dry conditions can be seen in Fig. 3a and 3b. The organic pollution in rainy days was in range of 4.77-17.88 mg/L, whereas in the dry condition was between 16.43 to 29.87 mg/L. It seems in rainy days the BOD₅ concentration was lower than dry days, and the concentration of BOD₅ increases with depth. The oxygen uptake from the rainwater to the

surface of the lake and the pollutant dilution has lowered BOD₅ concentration [19]. However, when compared to the sampling station, the BOD₅ level is no different because the pollutant sources were evenly distributed discharged around Lake Maninjau.

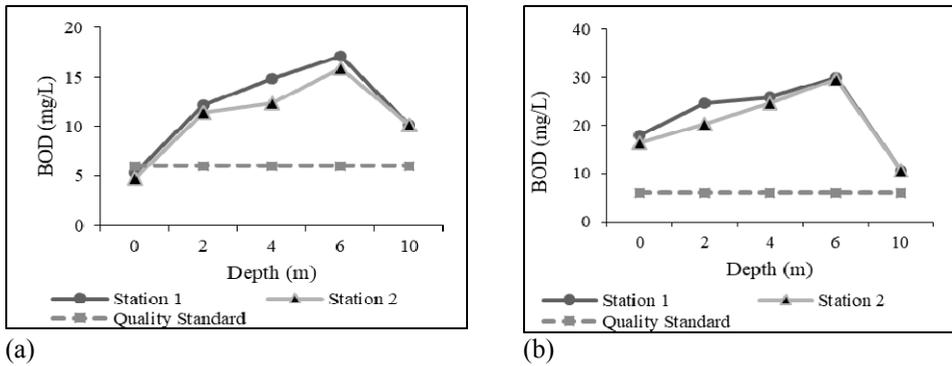


Fig. 3. BOD concentration at various depth in a) rain, and b) dry season (sampling at 10 m located in the center lake, BOD quality standard is 6 mg/L).

The BOD₅ concentration tends to increase with depth both in the rainy and dry seasons. The low oxygen concentration due to continuous decomposition of organic compounds, results in a reduction of DO in this location [20]. At 6m depth, the BOD₅ concentrations were higher than other depths with 15.93-29.87 mg/L. In a depth of 2-4 m the values were between 11.39 to 25.87 mg/L. In a relative stagnant water such as Lake Maninjau, some parts of organic wastes were stratified in several depths and some will settle and accumulate at the bottom of the water. This finding was supported by Boehrer's study [20].

3.4 Deoxygenation rate (K_1)

The deoxygenation rate (K_1) was calculated by the least square method using Eq. 2 and 3. The value of K_1 at station 1 (the eastern side of the lake) and station 2 (the western side of the lake) under rain and dry conditions can be seen in Fig. 4a and 4b. From Fig. 4a, it can be seen that the deoxygenation rate (K_1) of Maninjau Lake at various depths during rain was in range of 0.047-0.371/day (average 0.140/day), whereas from Fig. 4b K_1 the values around 0.038-0.967/day (average 0.273/day). K_1 of dry season was higher than rainy season. The high K_1 is related to the concentration of DO and BOD of the location. The average concentration of DO was 4.64 mg/L and BOD was 11.4 mg/L in rainy days, whereas when it dry, the DO was 3.24 mg/L and BOD was 21 mg/L in average. The rate of deoxygenation is influenced by temperature, microbiological activity, turbulence, and nutrients [21]. In the rainy season, the temperature drops to 27.5°C and dilution occur so that the organic content (BOD) was low, then the deoxygenation rate decreased. Conversely, when there was no rain with a temperature of 29°C and the organic content increased so that the deoxygenation rate also increased. This is supported by de Menezes study [22] that in summer, the high organic pollutant content is accompanied by higher deoxygenation rates to degrade organic compounds more rapidly. When compared with Eckenfelder's study [23], those value was classified in the 0.04-0.1/day range, that indicates the rate of oxygen depth at 2 and 10m equals to the oxygen rate of rivers with low pollutants up to biological treatment effluents. Overall the rate of deoxygenation showed that the epilimnion layer of the lake was moderately polluted.

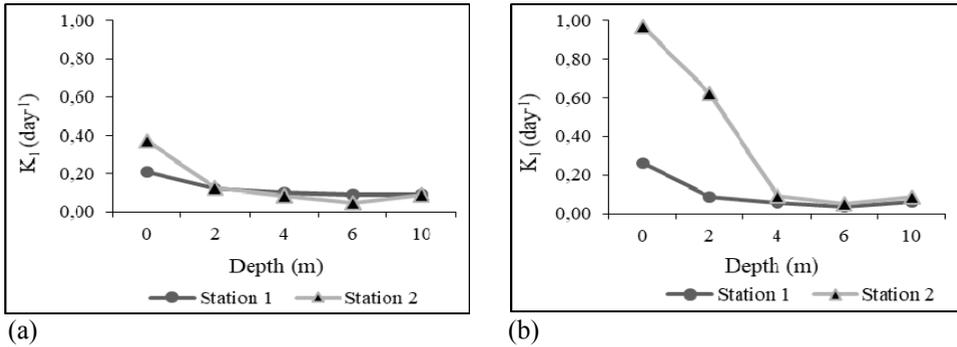


Fig. 4. Deoxygenation rate (K_1) at various depth in a) rain, and b) dry season (sampling at 10m depth located in the center lake).

3.5 Reaeration rate (K_2)

The value of reaeration rate (K_2) at sampling stations 1 and 2 under rain and no rain conditions is shown in Fig. 5a and 5b (calculated by Eq. 4). The value of reaeration rate (K_2) of Lake Maninjau waters to the sampling station and the depth during rain ranges from 0.117-0.647/day (average 0.30/day), whereas when it dry ranges from 0.161-0.691/day (average 0.37/day). As K_1 , the value of K_2 when dry was slightly higher than when it is rain. The high rate of reaeration is caused by wind speed and flow velocity in dry season higher than rain season. Wind speed value for Lake Lake Maninjau area in rainy days is in average 1.5 m/s while dry mean is 1.9 m/s, hence the value of flow velocity of those 0.07 m/s and 0.08 m/s in average. The high value of K_2 when it dry show that the oxygen uptake of the surface from the atmosphere was rapid, resulting in greater diffusion of oxygen into the water. Oxygen transfer rate is a function of temperature and turbulence. Turbulence is a function of flow velocity and flow depth for the specific stream [21]. At drought, since the temperature, wind speed, and flow speed were high, so the rate of reaeration.

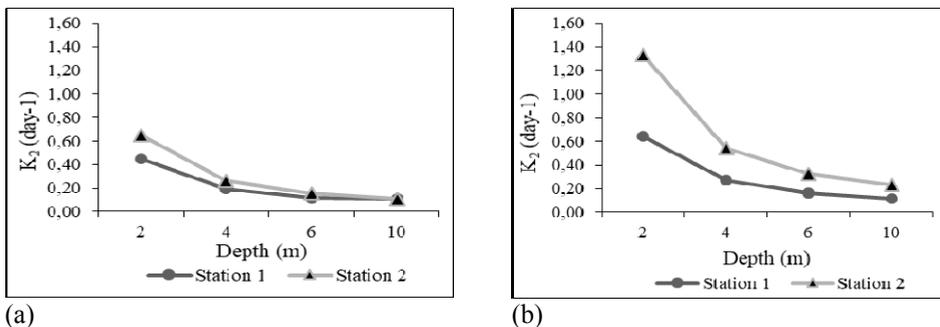


Fig. 5. Reaeration rate (K_2) at various depth in a) rain, and b) dry condition (sampling at 10 m depth located in the center lake).

The value of K_2 decreases with increasing depth. The decrease in the K_2 value for a depth of 2-6 m are 0.691/day to 0.117/day. It is also confirmed by Chapra [24] that the rapid and shallow water will produce a large reaeration. This condition was in line with the value of K_2 obtained in Lake Maninjau, since when it rain the K_2 value at a depth of 2 m is 0.647/day, while at 4 m depth is 0.262/day (Fig. 5a). There are not much different is also seen at a depth of 10 m (center), the K_2 obtained was smaller than the depth of 6 m. It shows that the influence of wind speed at a depth of 10m is almost non-existent. The value

of K_2 obtained for this depth ranges from 0.108-0.115/day, as well as at a depth of 6m, this depth is equivalent to the velocity of the small pool to provide dissolved oxygen from the atmosphere which is relatively slow [25], resulting in long-lasting self-purification. Overall, only up to the middle of the epilimnion layer of the lake has a rapid reaeration ability, while the deeper has decreased. Differences in purification ratio values at each location, due to differences in levels of organic pollutants, availability of dissolved oxygen, wind speed, and flow velocity obtained at each location.

3.6 Purification ratio (K_2/K_1)

Purification ratio value (K_2/K_1) for the Lake Maninjau can be seen in Fig. 6a and 6b. The purification ratio was in the range of 1.282 to 5.048 (average 3.067) at rainy season, while at the dry season from 1.107 to 7.23 (average 3.923). These values showed that the purification ratio of the dry season is higher than that of the rainy season. High temperature and wind speed in dry season increase the reaeration rate and purification ratio.

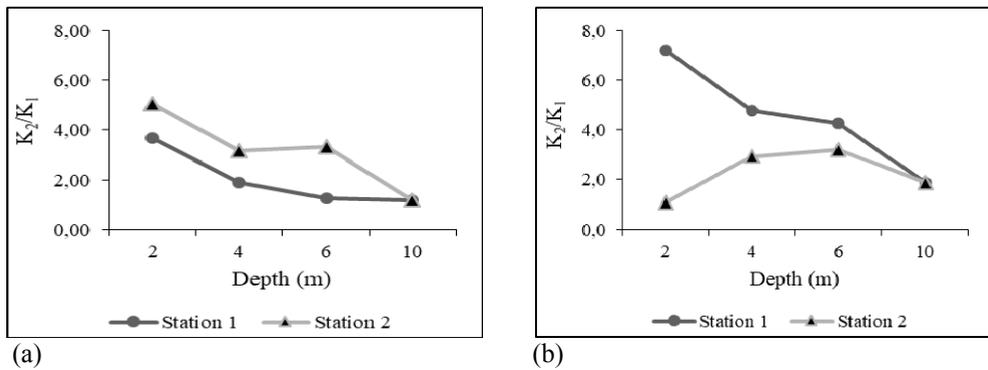


Fig. 6. Purification ratio (K_2/K_1) at various depth in a) rain, and b) dry season (sampling at 10m depth lake located in the center lake).

Purification ratio values decreased with depth, since at 2 to 6 m the ratio was ranging from 7.230 to 1.858 respectively. A reasonably high ratio of purification was measured on the lake surface. This value indicate a natural decomposition process is faster on the surface than other depths. The magnitude of the purification ratio depends on the reaeration and deoxygenation rates of each sampling station. The purification ratio of station 1 was higher compared to station 2 that was 1.858-7.230 (Fig. 6a). It is because the reaeration rate at this location was high, while the deoxygenation rate was low. Conversely, at the station 2 (Fig. 6b) the lower reaeration rate of 0.691/day and higher deoxygenation rate of 0.967/day resulting in a lower purification ratio of 1.107. A drastic decrease of purification ratio from 7.230 to 1.107 occurred from station 1 to station 2 at 2m depth. The deoxygenation rate at station 1 was 0.261/day, and lower compared to that of station 2 is 0.967/day, however the reaeration rate is quite similar. As the result, the purification ratio value from station 1 to station 2 on the lake dropped dramatically. The pollutants from floating net cages (station 2) tend to provide adequate nutrients compared to domestic waste (station 1) since nutrients can support photosynthesis especially at warm temperatures added with sunlight in dry season [18]. The purification ratio of the lake is much smaller compared to the purification ratio of Antokan River which located downstream of the lake [26], that indicates a low water quality. Nevertheless, the overall purification ratio in the epilimnion zone of Lake Maninjau was still in the range of self-purification since the purification ratio value was greater than 1 [3].

4 Conclusions

The quality of Lake Maninjau does not meet the Government regulations the Republic of Indonesia PP. No. 82 the year 2001 class 2 for water recreation facilities, fisheries, irrigation, and animal husbandry. The organic sources come from the aquaculture and other community activities. In the epilimnion layer to a depth of 10 m from the surface, deoxygenation rate (K_1) was between 0.038 to 0.967/day, which indicates the oxygen utilization rate for rapid decomposition in the lake. Reaeration rate (K_2) ranged from 0.108 to 0.691/day, which was high, so has a potential to decompose pollutants naturally. The purification ratio value (K_2/K_1) of the epilimnion zone ranged from 1.225-7.230, where the value at dry season is higher than that of the rainy season. High temperature, wind speed and flow velocity in dry season increase the reaeration rate, so the purification ratio. In general, the epilimnion zone of the lake Maninjau can still perform a self-purification.

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