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Environmental Condition and Trophic Status of Lake Rawa Pening in Central Java

Kondisi Lingkungan dan Status Trofik Danau Rawa Pening di Jawa Tengah

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Abstract

Due to continuous problems of eutrophication, Lake Rawa Pening has been included into the 15 priority lakes in Indonesia to be saved from damage. This study aimed to clarify the current environmental conditions and trophic status of Lake Rawa Pening as a basis to control the eutrophication. Sediment loads, water quality, and nutrient concentrations were measured in the tributaries of lake inflow, within the lake, and at the point of lake outflow. The study was conducted in May, June, July, and August 2013. Water transparency, temperature, pH, turbidity, conductivity, and dissolved oxygen were measured in situ. Nitrogen, nitrate, total phosphorus, orthophosphate, TSS, and chlorophyll-*a* parameters were analyzed using standard method procedures. The Trophic State Index was used to determine the trophic state level. Hydro-climatological conditions showed that seasonally, fluctuation of water volume and discharge of lake followed the pattern of rainfall fluctuation. The sediment loads and nutrient concentration in the tributary inflow were more abundant than those in the lake and lake outflow. The results indicated that Lake Rawa Pening acts as sediment and nutrient sinks. Spatially and temporally, Lake Rawa Pening showed high variation of water quality. High concentration of nutrients observed during the wet and dry seasons indicated that the nutrients in the lake originated not only from external but also from internal sources. The overall results show that Lake Rawa Pening is a eutrophic lake, in which phosphorus seems to play a major role in causing eutrophication and massive growth of water hyacinth.

Keywords: Lake Rawa Pening, sediment, nutrient, water quality, eutrophication.

Abstrak

Danau Rawa Pening merupakan satu dari 15 danau di Indonesia yang menjadi prioritas untuk diselamatkan dari kerusakan karena mengalami masalah eutrofikasi. Tujuan penelitian ini adalah untuk mengetahui status terkini lingkungan perairan danau dan tingkat eutrofikasi sebagai dasar pengendalian eutrofikasi di Danau Rawa Pening. Muatan sedimen, kualitas air, dan konsentrasi nutrien diamati di aliran air masuk ke danau, di perairan danau, dan di saluran air keluar dari danau. Pengamatan dilakukan pada Mei, Juni, Juli, dan Agustus 2013. Parameter kejernihan, kekeruhan, temperatur, DO, pH, dan konduktivitas diamati secara langsung di perairan danau. Parameter nutrien, TSS, dan klorofil-*a* dianalisis di laboratorium dengan metode standar. Indeks Status Trofik digunakan untuk menentukan tingkat eutrofikasi danau. Kondisi hidroklimatologi menunjukkan secara musiman fluktuasi volume dan debit air keluar danau mengikuti pola fluktuasi curah hujan. Muatan sedimen di saluran air masuk ke danau lebih tinggi daripada di dalam danau dan di alur air keluar danau. Hal ini mengindikasikan bahwa Danau Rawa Pening berperan sebagai penampungan dan pengendapan sedimen serta nutrien dari sungai di sekitarnya. Secara spasial dan temporal kondisi kualitas air di danau menunjukkan variasi yang tinggi. Konsentrasi nutrien yang tinggi di danau pada musim hujan dan kemarau mengindikasikan bahwa sumber nutrien tidak hanya berasal dari luar tetapi juga dari dalam danau itu sendiri. Hasil penelitian ini menunjukkan Danau Rawa Pening merupakan danau eutrofik dan fosfor diduga sebagai faktor utama penyebab eutrofikasi dan pertumbuhan eceng gondok.

Kata kunci: Danau Rawa Pening, sedimen, nutrien, kualitas air, eutrofikasi.

Introduction

Water eutrophication has become a worldwide environmental problem in recent years (Yang et al., 2008). In Indonesia, most of major lakes are also facing environmental problems such as eutrophication, sedimentation, and a decline in surface area. Indonesia has determined that 15 lakes become national priority to be restored and preserved (State Minister of Environment, 2011). As a global environmental issue, eutrophication is characterized by high nitrogen and phosphorus concentrations in water bodies, resulting in excessive growth of aquatic plants (Liu et al., 2010).

Lake Rawa Pening has been facing an invasion of macrophytes indicated by a massive growth of water hyacinth that covers more than 40% of the lake surface (Suprobowati et al., 2012). Lake Rawa Pening receives water from the springs of the mountains and from eight tributaries (UNEP, 1999). The tributaries in the watershed of the lake flow through the intensively used catchment area for agriculture and urban development which is suspected as sources of increasing sediment load and nutrient content in the lake. According to Wuryanta & Paimin (2012), the catchment area of Lake Rawa Pening is used for rare forest (12,661.65 ha), dense forest (593.48 ha), agriculture (8,974.48 ha) consisting of irrigated and non-irrigated agriculture, human settlement (3,304.44 ha), plantation (480.30 ha), brushwood (529.55 ha), and water resources (1,517.46 ha). Non-irrigated agriculture for vegetable cultivation in the catchment area has caused erosion and sedimentation in the lake (Wuryanta & Paimin, 2012). Fertilizers from agricultural runoff and domestic wastes constituted factors affecting water quality and nutrient contamination in the tributaries, and stimulated the eutrophication process in the lake (Knoll et al., 2003; Sulastri et al., 2008, 2009; Suprobowati, 2012).

Lake Rawa Pening has been exploited for fish cage culture by local people since 2007. The area of cages for fish culture increased from 2.21 ha in 2007 to 3.781 ha in 2010 (Department of Husbandry and Fisheries of Semarang Regency, 2007). The use of fish pellets to feed the fish in the cage culture has also been suspected to cause nutrient accumulation in the lake that increased eutrophication. Several efforts have been made to reduce the invasive macrophyte coverage such as flushing the water hyacinth out of the lake outlet (Tuntang Canal), harvesting the water hyacinth as material to make handicrafts, removing the water hyacinth as physical control, and introducing herbivorous fish *Ctenopharingodon idella* as biological control. The coverage of water hyacinth on the lake surface increased from 60% to 70% between 2004 and 2005, and increased to 85% in 2006 due to its fast growth rate which reached 7.1% a year (Suprobowati, 2012; Department of Husbandry and Fisheries of Semarang Regency, 2007)

Eutrophication caused water quality degradation and reduced lake carrying capacity resulting in a loss of its ecosystem services such as water supply, recreation, and fishing activities. The study aims to determine the current environmental conditions and eutrophication status of Lake Rawa Pening, as a first step to control eutrophication.

Methodology

Sampling Location

Lake Rawa Pening is located in Central Java at 110°24’46” E–110°49’06” E and 7°04’S–7°30’S (Suprobowati et al., 2010). Based on its typology, Lake Rawa Pening is classified as tecto-volcanic lake. In the early 1900s the outlet of the lake (Tuntang River) was impounded for hydroelectricity, irrigation, and fisheries. Then, Lake Rawa Pening became a semi-natural lake (Suprobowati et al., 2012). The area of the lake varies seasonally from 800 ha (dry season) to 2,700 ha (wet season) with the water surface from 461.5 m above sea level to 463.9 m above sea level respectively. The maximum capacity of the lake is 65 million m^3 (UNEP, 1976). The deepest part of the lake ranged from 12.2 m to 18 m and the shallowest part in the littoral zone fluctuated between 2.0 and 8.1 m (Suprobowati et al., 2012).

Sediment Load

Sediment load was measured in the tributaries flowing into the lake and at the lake outflow in Tuntang River in May 2013 (Figure 1 and Table 1). Sediment load was calculated based on the data of discharges, while the value of suspended solids (SS) was measured from the inflow and outflow of the lake. In the cross section of the lake inflow and outflow, the flow velocity was measured using a currentmeter. Velocity was measured at point segments depending on the width of the lake inflow, lake outflow, and wet perimeters. These parameters were used to calculate the volume of discharge.

The flow velocity and the wet perimeters were calculated using the formula Q = VA, where
Q : discharge ($m^3 \cdot s^{-1}$)
V : flow velocity ($m \cdot s^{-1}$)
A : wet perimeters (m^2)

At the same sites and times, water samples were collected to further analyze the suspended solids (SS) parameter in the laboratory using gravimetric method (APHA, 1992). Sediment load calculations were based on the discharge and suspended solids following the formulation of Gray and Simöes (2008):
Qs = Qw.Cs.k, where
Qs : suspended-sediment discharge, in $kg \cdot year^{-1}$;
Qw : water discharge, in $m^3 \cdot s^{-1}$;
Cs : mean concentration of suspended sediment in the cross-section in $mg \cdot L^{-1}$;
K : a coefficient based on the unit of measurement of water discharge that assumes a specific weight of 2.65 for sediment, and equals 0.0027 in inch-pound units, or 0.0864 in SI units.

Physical and Chemical Parameters

Physical and chemical parameters were measured in the lake inflow, within the lake, and at the lake outflow (Table 1). Observations of physical and chemical parameters in the inflow and outflow of the lake were conducted at 8 stations in May 2013, while in the lake, observations were carried out in May, June, July, and August 2013 at four stations. The names of the stations and parameters measured at each station are presented in Figure 1 and Table 1.

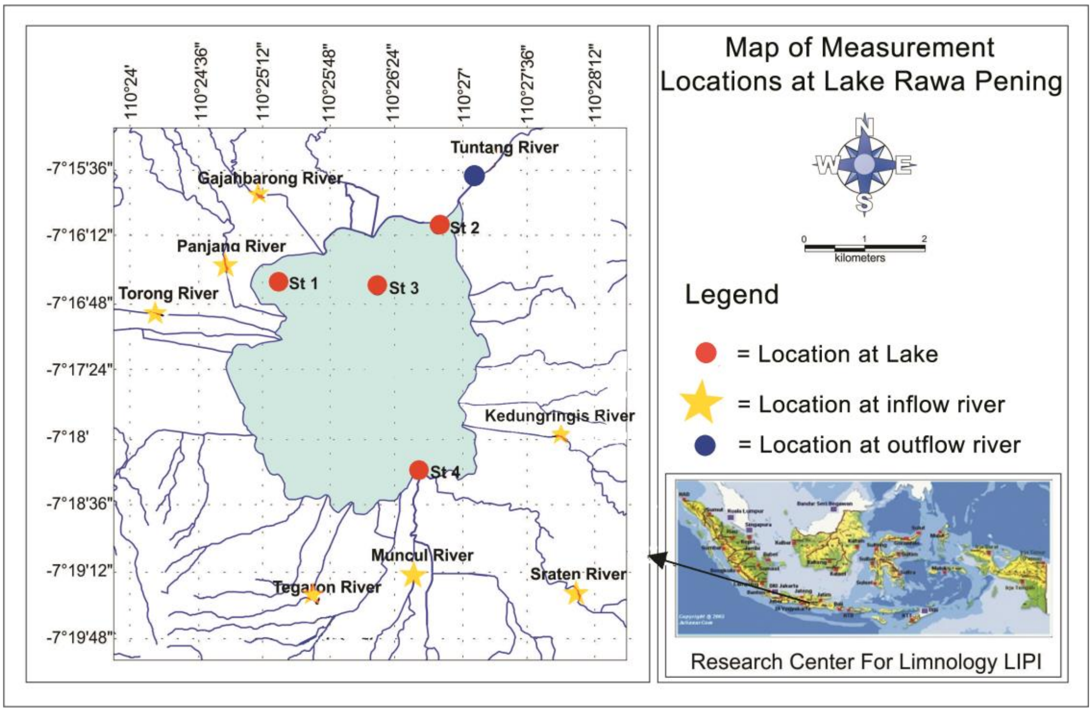

Figure 1. Research sites of sediment load and water quality of Lake Rawa Pening.
Gambar 1. Lokasi penelitian beban masukan sediment dan kualitas air Danau Rawa Pening.

Physical and chemical parameter data from both inlet and outlet points of the lake were taken from the water surface, while physical and chemical parameter data from the lake were taken from the surface water and the Secchi Depth (SD). Water samples for nutrient analysis were collected using Snatch Water Sampler. Water quality measurements included temperature, pH, turbidity, conductivity, Dissolved Oxygen (DO), TSS, and transparency (Secchi Depth). The measurements were conducted using Water Quality Checker (WQC, Horiba U), except for TSS, which was analyzed in the laboratory using gravimetric method. Water samples for analysis of total nitrogen, nitrate, total phosphorus, orthophosphate, and chlorophyll-*a* were preserved by adding sulfuric acid and a saturated $MgCO_3$ solution respectively and analyzed in the Hydrochemistry Laboratory, Research Centre for Limnology, according to standard method procedures (APHA, 1999). Methods for analysis of nutrients and other parameters are outlined in Table 2. Statistical analysis using Principle Component Analysis was done using the environmental parameter data to classify the research stations and to determine the relationships among environmental parameters.

The Trophic State Index (TSI) of the lake was calculated using the equations from Carlson and Simpson (1996) as follow:

TSI(SD) = 60 – 14.41 ln (SD)
TSI(CHL) = 9.81 ln (CHL) + 30.6
TSI(TP) = 14.42 ln (TP) + 4.15, where
TSI : Trophic State Index
SD : Secchi Depth
CHL : Chlorophyll-*a*
TP : Total Phosphorus

Table 1. Name of stations and physicochemical parameters observed at each station.
Tabel 1. Nama stasiun dan parameter fisika-kimia yang diamati di setiap stasiun.

Name of station	Physical description	Parameter observed
Panjang	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
Gajahbarong	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment , DO, pH, TN, N-NO_3, TP, P-PO_4
Torong	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
Teragon	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
Muncul	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
Sraten	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO , pH, TN, N-NO_3, TP, P-PO_4
Kedungringis	Inlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
Tuntang	Outlet of the lake	temperature, conductivity, TSS, turbidity, discharge, sediment, DO, pH, TN, N-NO_3, TP, P-PO_4
St 1	Littoral area of the lake and area for fish culture in cages	temperature, conductivity, TSS, DO, pH, TN, N-NO_3, TP, P-PO_4 and chlorophyll-*a*.
St 2	Littoral area of the lake, near outlet (Tuntang River), dense with water hyacinth	temperature, conductivity, TSS, DO, pH, TN, N-NO_3, TP, P-PO_4 and chlorophyll-*a*
St 3	Middle part of the lake, open area	temperature, conductivity, TSS, DO, pH, TN, N-NO_3, TP, P-PO_4 and chlorophyll-*a*
St 4	Littoral area of the lake, near mouth of Muncul Tributary	temperature, conductivity, TSS, DO, pH, TN, N-NO_3, TP, P-PO_4 and chlorophyll-*a*

Table 2. Methods for water quality analysis in the laboratory.
Table 2. Metode analisis kualitas air di laboratorium.

No	Parameter	Method	Reference
1	Nitrate (N-NO_3)	Brucine	APHA (1992)
2	Total N (T-N)	Predigested by peroxodisulphate and analysis by Brucine	APHA (1992)
3	Total P (T-P)	Predigested by peroxodisulphate and analysis by ascorbic acid	APHA (1992)
4	P-PO_4	Ascorbic acid	APHA (1992)
5	Suspended solid	Gravimetric	APHA (1992)
6	Chlrophyll-*a*	Colorimetric	APHA (1992)

Hydrological and climatological conditions including discharge of outflow, water volume of the lake and precipitation were analyzed from the secondary data obtained from the Department of Public Works in Tuntang, Ambarawa, and BMKG Semarang. The data for precipitation, water volume, and discharge were obtained from daily measurements.

Results

Climatological and Hydrological Conditions

Based on the average of daily rainfall from 2012 to 2013 (Figure 2), the dry season around Lake Rawa Pening lasted from June to September, while the wet season was from October to May, with average of daily rainfall of 85 mm in January, February, and October.

The maximum and minimum volumes of lake water occurred during the wet season in April and the dry season in early October respectively. The maximum and minimum water discharge occurred during the wet season in April and the dry season in August (Figure 3). The daily average of lake water volume showed a similar pattern to the ouflow water discharge. This might be due to the fact that the water discharge at the outflow follows the same pattern as the water level of the lake. The fluctuating pattern of water volume and water discharge in Lake Rawa Pening followed rainfall fluctuation. The average value for maximum water volume was 48,337,667 m^3, while the average of water discharge was 21.04 $m^3 \cdot s^{-1}$.

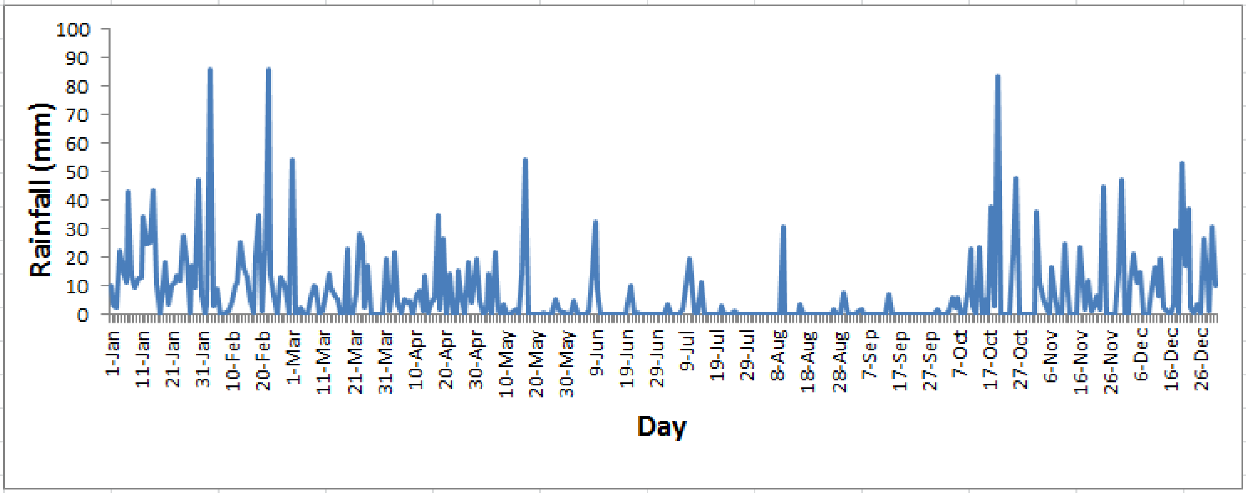

Figure 2. The average of daily rainfall around the study site from 2012 to 2013 (Source: BMKG Semarang, www.bmkg.go.id, accessed April 9, 2015).
Gambar 2. Curah hujan harian rata-rata di sekitar lokasi penelitian dari tahun 2012 sampai 2013 (Sumber: BMKG Semarang, www.bmkg.go.id, diakses 9 April, 2015).

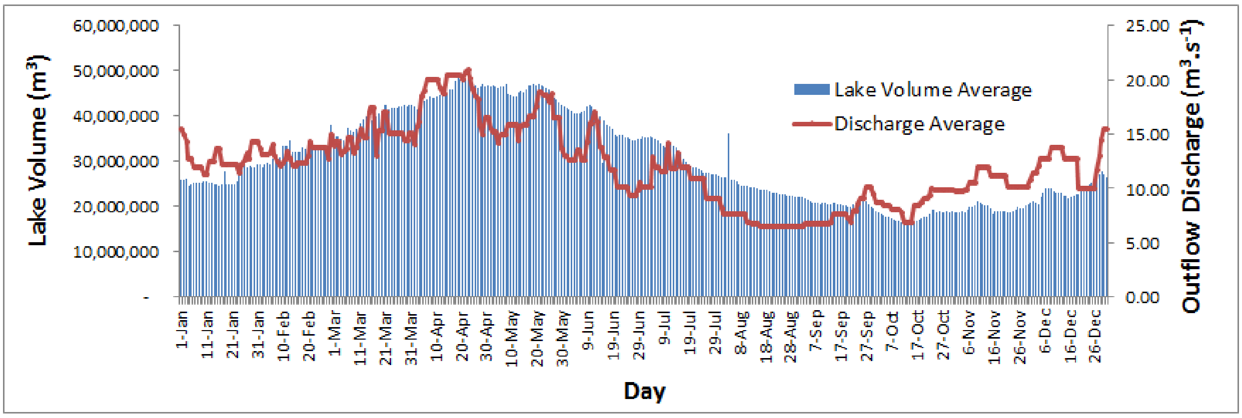

Figure 3. Daily average of water volume and water discharge of Lake Rawa Pening from 2010 to 2013 (Source: Database of Department of Public Works in Tuntang, unpublished).

Gambar 3. Volume air rata-rata dan debit air keluar Danau Rawa Pening dari tahun 2010 sampai 2013 (Sumber: Database Dinas Pekerjaan Umum di Tuntang, tidak diterbitkan).

Sediment Loads and Water Quality

The total sediment loads that enters the lake is about 10.42 million kg·year^{-1}, while the sediment loads that exit the lake is approximately 3.16 million kg·year^{-1} (Table 3). This indicates that the lake acts as a sediment sink.

Lower turbidity and TSS values in the lake water and outflow supports that the lake acts a sink of sediment. A similar pattern was observed for nutrient concentrations. In the tributaries, nutrient concentrations were higher than those in the lake water and in the lake outflow, indicating that the lake also acts as a sink for nutrients that originated from the tributaries, which eventually causes the eutrophication of the lake. The highest total nitrogen and nitrate concentrations were found in Sraten Tributary, while the highest total phosphorus and orthophosphate levels were observed in Teragon Tributary (Table 3). It seems that Sraten and Teragon tributaries contribute high nutrient load into Lake Rawa Pening.

Concentration of chlorophyll-*a* in the lake water ranged from 9.98 to 25.42 µg·L^{-1} (Table 3). This chlorophyll-*a* concentration is commonly found in eutrophic lakes. The average DO concentrations were above the standard DO concentration for fisheries (>3 mg·L^{-1}) as regulated by the Government of Republic of Indonesia under Peraturan Pemerintah No. 82 Tahun 2001 (Table 3). In lake inflow, the lowest DO concentration was found in Torong Tributary. It seems that Torong Tributary contributes high sediment loads and discharges water with poor quality into Lake Rawa Pening. DO concentration in the outflow was lower than DO concentration in the lake, indicating that the high rate of outflow could not improve the water quality of the lake water exiting the lake, especially for the DO parameter.

Temperatures in the lake inflows were lower than the temperatures within the lake. Based on their pH values, the lake inflows, the lake water, and the lake outflow were slightly alkaline. Conductivity values within the lake were similar to the inflows.

Lake Rawa Pening showed normal conductivity values ranging from 170 to 261 µS·cm^{-1} (Table 3). Many equatorial lakes in the forest regions have a conductivity of less than 600 µS·cm^{-1} (Payne, 1986).

Research Locations in the Lake

Based on the Principal Component Analysis (PCA) scaling plot of 4 sites and 9 water quality parameters, there are two groups of research locations having similar environmental characteristics (Figure 4). The first group is station 1 (St 1) and station 4 (St 4) characterized by high concentrations of chlorophyll-*a*, DO, pH, N-NO_3, and P-PO_4. The second group is St 2 located near the outlet and St 3 located in the center of the lake, which are characterized by low concentrations of chlorophyll-*a*, DO, pH, N-NO_3, and P-PO_4.

Spatial and Temporal Distribution of Water Quality in the Lake

Spatially and temporally, DO concentration varied during the observation period (Table 4). In St 1 and St 2, low DO concentrations (<3 mg·L^{-1}) were found in August. In St 4, DO concentration was high (5.74–9.2 mg·L^{-1}). From May to July

2013 at the surface and the bottom layer the DO concentrations ranged from 7.22 to 7.52 $mg \cdot L^{-1}$ and 1.39 to 2.36 $mg \cdot L^{-1}$ respectively. Low DO concentrations were found in St 3 in May. There were no data for DO in July and August at this station because of the changes in water hyacinth coverage. A strong wind during the dry season in this area causes changes in the position of water hyacinth coverage. Therefore, there was no access to take samples and water quality measurements during those months.

Temperature and pH values in Lake Rawa Pening are commonly observed in other tropical lakes. Temperature and pH showed variability over time. High temperatures were found in July, while alkaline conditions (pH > 7) were found in July and August (Figure 5). Spatially and temporally, TSS and chlorophyll-*a* showed variability (Figure 6). The lowest total suspended material (TSS) was found in St 3 in May and June, while the highest TSS was observed in August (Figure 6). St 3 is located in the center of the lake and generally TSS has been filtered in the littoral area. High TSS in St 1 and St 4 may be contributed to by the input of TSS from the water inflow tributaries entering the lake.

The highest concentrations of chlorophyll-*a* were found in St 1 and St 4 while the lowest were found in St 2 and St 3. High chlorophyll-*a* in St 1 and St 4 was accompanied by high concentrations of nutrients in those stations (Figure 4). Temporally, lower concentrations of chlorophyll-*a* were found in August, which did not follow the pattern of nutrients concentrations (TP, N-NO_3, and P-PO_4), despite the high nutrient concentration. This condition was merely due to massive water hyacinth coverage on the water surface that inhibited light penetration into the lake.

Total nitrogen concentration varied spatially and temporally, ranging from 0.4 to 1.8 $mg \cdot L^{-1}$ indicating that lake was nutrient rich (SEPA, 1991) (Figure 4). The higher concentrations of TN were found in St 1 and St 4 (1.800 and 1.528 $mg \cdot L^{-1}$) while temporally the highest TN was found in May at St 1 (1.8 $mg \cdot L^{-1}$), in June at St 4 (1.425 $mg \cdot L^{-1}$), and in July at St 4 (1.528 $mg \cdot L^{-1}$). The lower nitrogen concentration was found at St 2 in May and in June (0.436 and 0.400 $mg \cdot L^{-1}$) and this may be related to the position of St 2 being close to the outlet, which causes a high nitrogen concentration in this station that has been assimilated by the aquatic macrophytes. The months of May and June are considered to represent the transition from rainy to dry season, and the rainfall in the months of October to February increases the runoff entering the lake (Figure 2).

Total phosphorus (TP) also varied spatially and temporally, ranging from 0.0218 to 0.2190 $mg \cdot L^{-1}$ at the water surface and from 0.0146 to 0.2541 $mg \cdot L^{-1}$ in the secchi depth, indicating that the lake was nutrient rich (SEPA, 1991). During this observation, high concentrations of TP were found in August at almost all stations (Figure 6). During this observation, TP and SS levels indicated no significant correlation (Table 6). However, TP had a strong correlation with phosphate (PO_4), which showed a strong correlation with TSS (Table 6). In addition, PO_4 concentration was also high in August (Figure 6)

Nitrate concentration in Lake Rawa Pening also varied spatially and temporally, ranging from. 0.027 to 1.078 $mg \cdot L^{-1}$ (Figure 6). In this study, high concentrations of nitrate (N-NO_3) were observed in May and August, especially in St 1 and St 4. Nitrates also showed a strong correlation with TSS (Table 6).

Trophic Status Index (TSI)

Using the Trophic Status Index (TSI) calculation by Carlson and Simpson (1996), Lake Rawa Pening was classified as eutrophic (Table 7 and Figure 7). The relationship between TSI variables shows that (TSI (CHL) < TSI SD), TSI (CHL) < TSI (TP) and low TN:TP (Figure 7). This condition indicates that non-algae particulate matter dominates light attenuation, surplus of phosphorus and nitrogen as limiting factor for phytoplankton growth. The results suggest that phosphorus could be a major cause of eutrophication and may stimulate massive macrophyte growth.

Table 3. The values of water quality parameters in the lake (St 1, St 2, St 3, St 4), as well as the inflow and outflow of Lake Rawa Pening (inlet 1: Panjang, inlet 2: Torong, inlet 3: Muncul, inlet 4: Sraten, inlet 5: Kedungringis, inlet 6: Gajahbarong, inlet 7: Teragon, outlet: Tuntang**)**.
Tabel 3. Nilai parameter kualitas air di perairan danau (St 1, St 2, St 3, St 4), dan di aliran air masuk dan keluar Danau Rawa Pening (inlet 1: Panjang, inlet 2: Torong, inlet 3: Muncul, inlet 4: Sraten, inlet 5: Kedungringis, inlet 6: Gajahbarong, inlet 7: Teragon, outlet: Tuntang).

Parameter	**St 1, St 2, St 3, St 4**	**Inlet 1**	**Inlet 2**	**Inlet 3**	**Inlet 4**	**Inlet 5**	**Inlet 6**	**Inlet 7**	**Outlet**
Discharge ($m \cdot s^{-1}$)		3.12	2.68	2.12	0.99	0.64	0.24	0.1	40.1
Sediment load (million $kg \cdot year^{-1}$)		3.73	5.36	0.53	0.12	0.34	0.25	0.05	3.16
Secchi depth (m)	0.63–0.95								
Chlorophyll ($\mu g \cdot L^{-1}$)	9.982–25.42								
Turbidity (NTU)	9.0–38.7	117	52.9	13.4	20.65	71.5	104	49.7	19.45
TSS ($mg \cdot L^{-1}$)	4.2–17.1	38	63.5	8	4	17	34	17	2.5
Conductivity ($mS \cdot cm^{-1}$)	0.170–0.261	0.181	0.138	0.206	0.24	0.233	0.287	0.177	0.163
Temperature (°C)	26.4–27.1	23.55	25.48	24.6	24.14	25.2	23.43	23.81	26.44
DO ($mg \cdot L^{-1}$)	4.15–6.23	7.65	3.75	7.58	7.41	7.85	7.3	7.54	3.24
pH	7.09–7.70	7.6	7.49	7.35	7.45	7.95	7.73	7.61	7.5
TN ($mg \cdot L^{-1}$)	0.084–1.467	1.642	1.14	1.905	3.509	3.246	2.068	1.003	0.456
$N\text{-}NO_3$ ($mg \cdot L^{-1}$)	0.053–1.004	1.372	0.976	1.652	3.177	2.646	1.805	0.755	0.375
TP ($mg \cdot L^{-1}$)	0.036–0.178	0.22	0.136	0.177	0.179	0.169	0.179	0.215	0.082
$P\text{-}PO_4$ ($mg \cdot L^{-1}$)	0.009–0.073	0.067	0.05	0.091	0.074	0.077	0.098	0.101	0.011

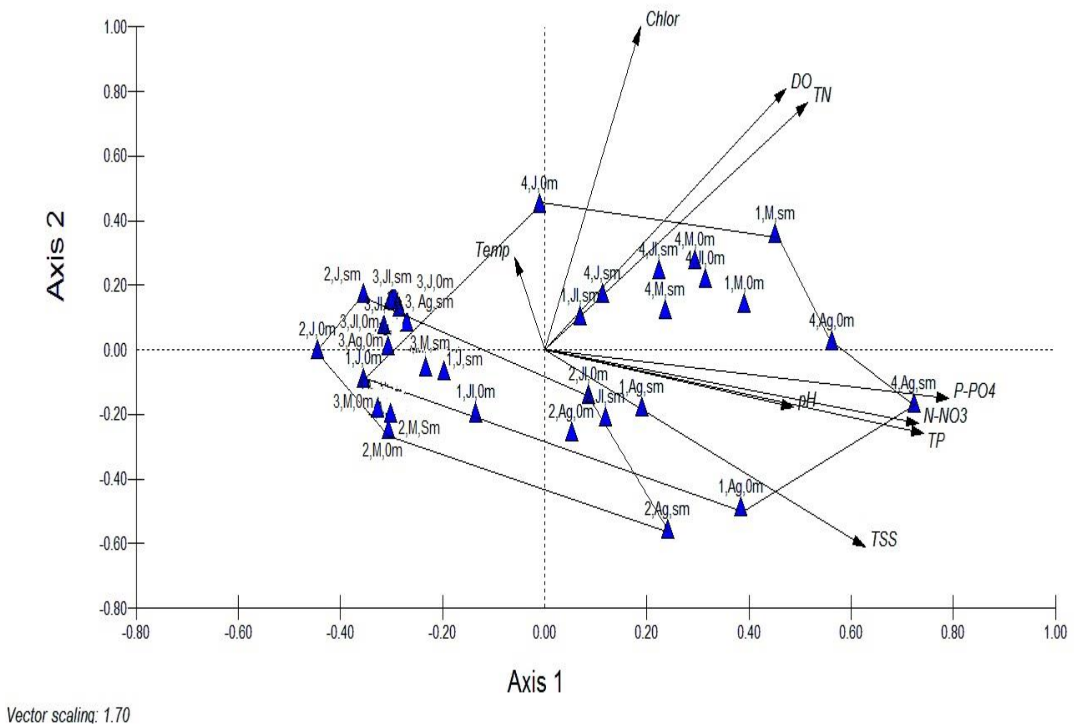

Figure 4. PCA scaling plot of 4 sampling sites by 9 water quality parameters (TSS, Temperature, DO, pH, TN, TP, N-NO_3, P-PO_4, Chlorophyll-*a*). Symbol: Station (1, 2, 3, 4); sampling point (0m = water surface, sm = secchi depth); observation time: May, June, July, and August (M,J,Jl,Ag).

Gamabar 4. Ordinasi analisis komponen utama dari 4 stasiun penelitian dan 9 parameter kualitas air (TSS, Temperature, DO, pH, TN, TP, N-NO_3, P-PO_4, klorofil-a). Simbol: Stasiun (1, 2, 3, 4); titik sampling (0m = permukaan air, sm = kedalaman secchi), waktu pengamatan: Mei, Juni, Juli, dan Agustus (M, J,Jl,Ag).

Table 4. The dissolved oxygen (DO) concentration in Lake Rawa Pening, 2013.
Tabel 4. Konsentrasi oksigen terlarut (DO) Danau Rawa Pening, 2013.

Name of station	Sampling point	Observation			
		May	June	July	August
St 1	0 m	11.52	3.34	3.02	2.02
	Secchi depth	8.38	2.42		1.48
St 2	0 m	4.49	5.52	5.12	3.15
	Secchi depth	4.41	5.5	4.65	2.4
St 3	0 m	2.73	5.61		
	Secchi depth	2.74	3.41		
St 4	0 m	7.78	8.74	7.72	9.2
	Secchi depth		5.95	5.74	6.67

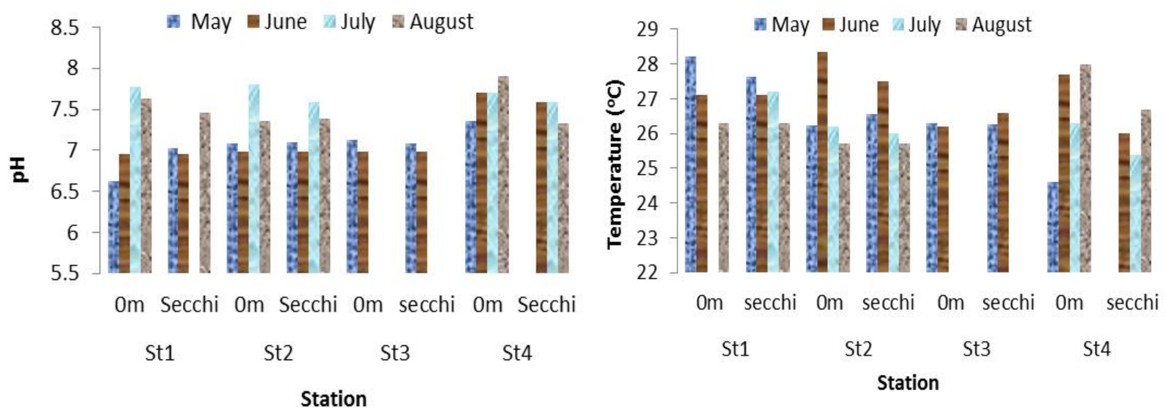

Figure 5. Distribution of pH and temperature in Lake Rawa Pening.
Gambar 5. Sebaran pH dan suhu di Danau Rawa Pening.

Table 5. Temperature and pH in Lake Rawa Pening in 2007, 2008, 2012, and 2013.
Tabel 5. Temperatur dan pH di Danau Rawa Pening pada tahum 2007, 2008, 2012, dan 2013.

Parameter	Observation			
	May to June 2007	**October 2008**	**May to July 2012**	**December 2012 to January 2013**
Temperature (°C)	27.65–28.55	31.0–32.0	27.81–28.84	26.0–27.0
pH	7.1–7.3	11.1–11.3	7.0–8.5	5.3–5.43
Reference	Zulfia & Aisyah, 2013	Suprobowati, 2011	Rovita et al., 2012	Purnomo et al., 2013

Table 6 Matrix of correlation of water quality in Lake Rawa Pening.
Table 6. Matriks korelasi kualitas air di Danau Rawa Pening.

	DO	**Temperature**	**pH**	**TSS**	**Chl-*a***	**TN**	**TP**	**N-NO_3**	**P-PO_4**
DO	1								
Temperature	0.355	1							
pH	0.089	-0.25	1						
TSS	0.177	0	0.291	1					
Chl-*a*	0.362	-0.195	0.247	-0.24	1				
TN	0.442	-0.01	0.056	0.09	0.41	1			
TP	0.161	-0.228	**0.524**	0.437	0.023	0.385	1		
N-NO_3	0.314	-0.036	0.274	**0.52**	0.001	0.245	0.424	1	
P-PO_4	0.314	0.079	0.196	**0.54**	0.029	0.36	**0.608**	**0.677**	1

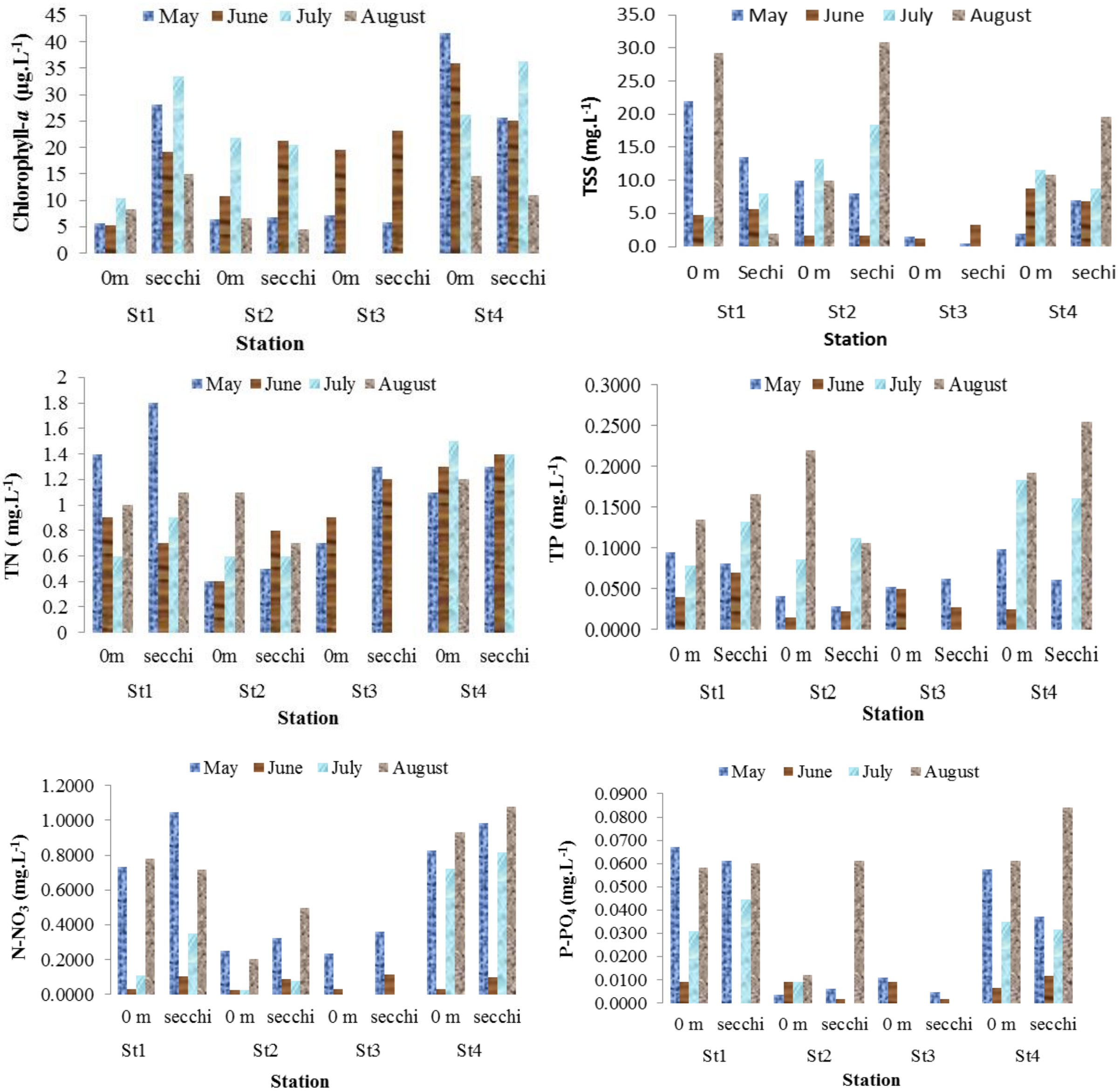

Figure 6. Distribution of TSS, Chlorophyll-*a*, TN, TP, $N\text{-}NO_3$, and $P\text{-}PO_4$ in Lake Rawa Pening.
Gambar 6. Sebaran TSS, klorofil-a, TN, TP, $N\text{-}NO_3$, dan $P\text{-}PO_4$ di Danau Rawa Pening.

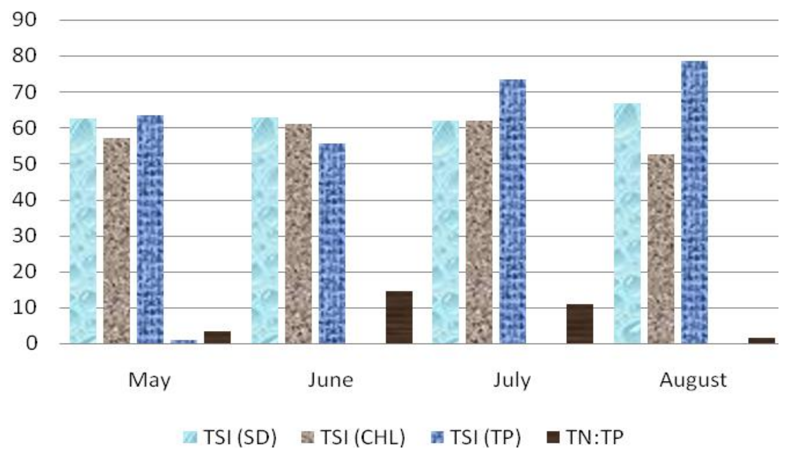

Figure 7. Trophic Status Index (TSI) and TN:TP ratio of Lake Rawa Pening.
Gambar 7. Indeks Status Trofik (TSI) dan rasio TN:TP di Danau Rawa Pening.

Table 7. Trophic state based on TSI score according to Carlson and Simpson (1996).
Tabel 7. Status trofik berdasarkan skor TSI, menurut Carlson dan Simpson (1996).

TSI	Chlorophyll-*a* (μg·L^{-1})	T-P (μg·L^{-1})	Secchi depth (m)	Trophic status and characteristics of lake
< 30	<0.95	< 6	>8	Ultraoligotrophic
30–40	0.95–2.6	6–12	8–4	Oligotrophic
40–50	2.6–7.3	12–24	4–2	Mesotrophic
50–60	7.3–20	24–48	2–1	Eutrophic (Anoxic hypolimnia, possible macprophyte problems)
60–70	20–56	48–96	1–0.5	Eutrophic (Blue-green algae dominate, algal scums, and macrophyte problems.)
70–80	56–155	96–192	0.5–0.25	Hypereutrophic

Discussion

The fluctuating pattern of water volume and water discharge in Lake Rawa Pening follows the fluctuations of rainfall, indicating that seasonally the variations in rainfall affect more on water volume and discharge of Lake Rawa Pening. Shallow lakes in tropical regions such as Lake Rawa Pening with monsoonal climate as reported by Osborne (2005) that rainfall strongly affects the water level of the lake.

High sediment loads in Lake Rawa Pening could be derived from Torong and Panjang tributaries due to their high turbidity and TSS. Land use in the watershed of these tributaries is dominated by paddy fields and non-irrigated agriculture for vegetable cultivation, which could be the source of erosion (Wuryanta & Paimin, 2012). The high nutrient concentration (TN and TP) from the tributaries might be due to varied land use in the watershed of Lake Rawa Pening such as agriculture, human settlement, and plantations (Wuryanta & Paimin, 2012). Fertilizer made its way into the ground water and finally to the surface water triggering nutrient contamination (Anonymous, 2004).

The inflow tributaries have lower temperatures than Lake Rawa Pening and this is a common phenomenon because the tributaries generally are located at higher altitudes than the lake basin. Starmühlner (1986) reported that temperature was influenced by altitude and geographical latitude. The conductivity in Lake Rawa Pening was close to the conductivity in the inflow tributaries. Payne (1986) reported that the lake received dissolved substances in large amounts from rivers and rain, and there is a rapid turnover time, so it is likely that the total ionic concentration and composition of lake water and inflow will be the same.

Eutrophication in Lake Rawa Pening can not only be seen by the massive coverage of water hyacinth, but also by the high concentration of chlorophyll-*a*. For eutrophic lakes chlorophyll-*a* concentration ranges from 9.5 to 275 μg·L^{-1} (Wetzel, 2001). In Lake Limboto, a shallow eutrophic lake in Sulawesi with similar problems of massive water hyacinth coverage, the concentration of chlorophyll-*a* ranged from 16.9 to 24.304 μg·L^{-1} (Krismono, 2010).

Spatially, water quality and nutrient concentrations in the lake were also found in various locations. Previous studies reported that the water quality of Lake Rawa Pening was quite variable. The highest temperature and pH were found in October 2008, while the lowest temperature and pH were found between December 2012 and January 2013 or during the rainy season (Suprobowati, 2011; Purnomo et al., 2013). During this observation, the pH ranged from 7.09 to 7.70 and these slightly alkaline conditions were found in July and August (Table 5). According to Goldman and Horne (1983) most lakes have a pH ranging from 6 to 9, and pH increases when vigorous photosynthesis occurs in productive lakes.

Variation of DO concentration in the lake was also reported (Rovita et al., 2012; Purnomo et al., 2013) with DO concentrations in December 2012 and January 2013 at the surface water and at the bottom layer (1.80 to 1.84 m in depth) ranging from 5.3 to 5.43 mg·L^{-1} and 0.58 to 0.71 mg·L^{-1} respectively. During this observation, high values for DO in St 4 may have been due to the influence of water quality from the inflow tributaries that also have high DO values. Low DO and nutrient concentrations at St 1 and St 2 in August may be due to the influence of the metabolic process in the lake such as mineralization and nutrient uptake by microbes, algae, aquatic macrophytes such as *Hydrilla* sp. and *Eichornia crassipes* (water hyacinth) and the decomposition of organic materials in the sediment. St 1 is an area used for fish culture in cages that releases large amounts of organic materials into the lake and St 2 is located near the lake outlet and surrounded by dense water hyacinth. Therefore, it is suspected that this station also contains rich organic material deposits in the sediment. In a productive lake, respiration by decomposers may remove the oxygen from the water overlying the sediment (Osborne, 2005). Windy conditions, which often occur in August, might cause mixing, and subsequently, the low DO water in the bottom layer may ascend to the upper water column.

The highest value for total suspended solids (TSS) was found in August. However, chlorophyll-*a* concentration was low in this month. As reported by Zhu et al., 2007, for a shallow lake such as Lake Rawa Pening, when the wind increases, as it does in the dry season (August), the water sediment interface frequently is disturbed causing intensive sediment resuspension. The strong wind in August might cause the water mixing and sediment resuspension which limits photosynthesis and the biomass of phytoplankton. It was observed that the growth of phytoplankton occurred persistently in the upper illuminated layer or the euphotic zone (Reynolds, 1984). For shallow lakes, light limitation by resuspension of matter is the limiting factor for phytoplankton growth (Mac-Intyre & Cullen, 1996). High concentrations of chlorophyll-*a* in St 4 may be related to the photosynthesis activity, indicated by high DO concentrations at this station (Table 4).

The variation of total nitrogen concentration in the lake may be caused by the variation of nitrogen input from the inflow tributaries and monsoon season. The higher concentration of TN in St 1 and St 4 in May and June is thought to be caused by the higher input of nitrogen from the inflow tributaries. St 1 receives water inflow from Panjang tributary with TN concentration of 1.64 mg·L^{-1} and St 4 receives water inflow from Muncul and Sraten tributaries with high TN concentrations of 1.140 and 3.509 mg·L^{-1} respectively (Table 3). The months of May and June are considered to be transition from the rainy to the dry season and rainfall in these months from October to February has increased runoff entering the lake (Figure 2).

The high TP found in August may be related to the TP releases from the sediment. The source of phosphorus can be divided into point source and non-point source such as rainfall, runoff, or industrial and municipal influent. Moreover, one of the crucial sources of phosphorus in the lake is the internal lake system itself such as aquatic plants, algae, and sediment (Zan et al., 2011). In shallow lakes, the role of sediment as a nutrient source is potentially greater than in a deep lake. Gaudet & Muthuri (1981) emphasized the importance of water level fluctuations in the regeneration of nutrients from sediments. The water quality in shallow tropical lakes is affected more by variation in rainfall, wind speed and direction, and cloud conditions than by seasonal variations in day length and temperature. P-exchange between sediments and the water column depends on diffusion-related processes and sediment resuspension during wind events in shallow lakes (Schindler et al., 1977). It was reported that a wind speed of over 12 m·s^{-1} increased TP concentration in Lake Taihu (Tammeorg et al., 2013). Similar phenomenon may also occur in shallow lakes such as Lake Rawa Pening. Consequently, when wind events occur in the dry season (August), nutrients such as TP concentration could also increase. According to Gerhardt and Schink (2005), at higher turbulence the sediment surface becomes oxygenated and P is immobilized by iron. However, de Vicente et al. (2010) stated that an increase in turbulence slightly enhances the diffusion of P from the sediment until a critical turbulence is exceeded and the top layer of the sediment is resuspended. Furthermore, the effect of resuspension events on PO_4 availability depends on the particular properties of the lake water (i.e. PO_4 concentration) and sediment (Søndergaard et al., 1992)

Higher nitrate levels were found in May and August. Higher concentrations of nitrate in May might be due to high nitrate input from inflow tributaries. As reported by Goldman & Horne (1983), the main inputs of nitrate into the lake are rainfall and runoff. The higher nitrate levels in August may be due to the input of nitrate from the water sediment interface. Nitrate also exhibits a strong correlation with TSS (Table 6). Nitrate may diffuse to the water as a result of the nitrification process in the well oxygenated surface of the littoral zone or during water circulation and/or sediment disturbance (Landner & Larson, 1973). Although the condition must be aerobic for the nitrification to occur, the process of nitrification may continue until the concentration of dissolved oxygen (DO) declines to about 0.3 $mg \cdot L^{-1}$ (Wetzel, 2001).

The observation showed that the high nutrient (TP, PO_4, and NO_3) contents were found in the transition season (May) and the dry season (August). This may be due to nutrient transport from tributary inflows or input of nutrients from the lake itself, which could further stimulate eutrophication in Lake Rawa Pening.

Conclusion

The water volume and water discharge from the outflow of Lake Rawa Pening follows the pattern of rainfall fluctuation, indicating that the monsoon affects water levels in the lake. Lake Rawa Pening acts as a sink of sediment and nutrients and that could stimulate eutrophication and sedimentation in the lake. Water quality of Lake Rawa Pening shows high variability and richness of nutrients. It seems that the nutrients in Lake Rawa Pening is not only from external sources but also from the internal input of the lake system. Lake Rawa Pening is a eutrophic lake and phosphorus is clearly a major factor causing eutrophication and massive macrophyte coverage. Sedimentation and eutrophication will reduce the water column, carrying capacity, habitat for aquatic organisms, and ecosystem services in the lake. Reductions in the external loads of both nitrogen and phosphorus can be achieved through the introduction of pollution control practices within the lake catchment area such as creating wetlands. Internal loading of nutrients in the lake can be reduced through the biological control of macrophytes, enforcing resource allocation programs, and improving fish culture methods.

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