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Physico-chemical and biological water quality of Warna and Pengilon Lakes, Dieng, Central Java

Tri Retnaningsih Soeprobowati[1), 2)], Nurul Layalil Addadiyah[1)], Riche Hariyati[1)], Jumari Jumari[1)]

[1)] Diponegoro University, Faculty of Science and Mathematics, Department of Biology, Jl. Prof. Soedarto, SH. Street, Tembalang, Semarang, 50275, Indonesia

[2)] Universitas Diponegoro, School of Postgraduate Studies, Imam Bardjo Street Number 3-5, Semarang, 50241, Indonesia

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Abstract: Warna and Pengilon Lakes are very close to each other and connected with the sill, a famous tourist destination in the Dieng Plateau Java. Land-use changes are the main problem that affected the lakes. The conversion of forest into an agricultural area had induced erosion and increased the volume of nutrients discharged to the lake due to high use of fertilisers in potatoes farms. In the dry seasons, water from those lakes was pumped to irrigate agricultural land. This study aimed to determine the water quality of Warna and Pengilon Lakes based on physical, chemical parameters, and phytoplankton communities. Water samples were collected from 4 sites at each lake to analyse biological oxygen demand (*BOD*), chemical oxygen demand (*COD*), ammonia, nitrate, nitrite, and total nitrogen (*TN*). Temperature, pH, dissolved oxygen (*DO*), turbidity, and conductivity (*EC*) were measured in-situ. During this research, turbidity and *BOD* in Warna and Pengilon Lakes exceeded the Indonesian water quality standard. Based on the STORET method, the water quality of Lake Warna was assessed as highly polluted for all classes. However, based on the pollution index (*PI*), Lake Warna was slightly to moderately polluted, as well as the saprobic index was in the β-mesosaprobic phase. Based on the species diversity index of phytoplankton, both Warna and Pengilon Lakes were moderately polluted. The long-term monitoring studies are necessary as an early warning sign of water quality degradation. Therefore, they provide insight into the overall ecological condition of the lake and can be used as a basis for developing suitable lake management.

Keywords: Dieng, Lake Warna, Lake Pengilon, phytoplankton, pollution index, saprobic index, STORET method, water quality

INTRODUCTION

Monitoring of water quality started in the 1960s, mostly based on chemical and physical parameters. Physical and chemical monitoring represent only at the time of measurement and unable to detect the source of pollution [Forio *et al.* 2020]. Biomonitoring of water quality uses aquatic organisms or their responses to monitor water quality [Oertel, Salanki 2003]. The organism used in the monitoring of water quality is called a biomonitor, whereas the organism or group of organisms that indicate the state of water quality is called a bioindicator. Biomonitoring is cheap and requires fewer instruments, and it reflects integrationed pollution. It is also rapid, easy to interpret, and environmentally friendly [Oertel, Salanki 2003; Piranti, Wibowo 2020; Singh *et al.* 2013; Soeprobowati *et al.* 1999; 2017].

A potential bioindicator needs to have a cosmopolitan distribution, low mobility, well known ecological characteristics, and high population. It also needs to be suitable for laboratory tests, sensitive to the stressor, quantifiable, and easily identifiable by non-specialists. Organisms that have proved to be good bioindicators of water quality include phytoplankton [Meng *et al.* 2017; Nguyen, Nhien 2020; Oterler 2017; Zeng *et al.* 2017], benthic macronvertebrate [Custodio *et al.* 2020; Kuntke *et al.* 2020; Lobo *et al.* 2017], diatoms [Battarbee *et al.* 1997; Bellinger *et al.* 2006; Soeprobowati *et al.* 2016; Tibby *et al.* 2019; Xue *et al.*

2019], macrophytes [Bytyqi *et al.* 2020; Ding *et al.* 2020], and fish [Lee *et al.* 2018].

Phytoplankton is a primary producer and plays important roles for ecosystem functioning and services. Phytoplankton provides an insight into interaction between abiotic and biotic factors. Phytoplankton is a tool for environmental assessment of water quality [Akhter, Brraich 2020; Li *et al.* 2019; Parmar *et al.* 2016; Pawar 2018] popular in Europe and America, and China. Phytoplankton has been used in a preliminary study on pearl oyster potential culture development in the North Gorontalo, Indonesia [Sahami *et al.* 2017]. Being a bioindicator of water quality, phytoplankton has been applied in the Wadaslintang Reservoir, Indonesia [Piranti, Wibowo 2020].

The common approach to water quality assessment involves a variety of indices, biotic indices, or a multivariate approach. Water quality degradation influences ecosystem structure, which in turn reduces the diversity of phytoplankton. A polluted lake usually has a low diversity index comparing to natural lakes [Piranti, Wibowo 2020]. A high diversity stabilises the ecosystem function [Bartkowski 2017], as biodiversity involves a variety of life forms, from genetic variations, species, populations, communities, and ecosystems [Soeprobowati *et al.* 2020].

The quality of water in lakes reflects the quality in the catchment area. Catchment areas of Lake Warna are mostly used for potato plantations, where fertilisers are applied to boost production. Some nutrients and pesticides enter the lake with the rainfall and threatens the lake ecosystem [Soeprobowati *et al.* 2017; 2018a, b; Sudarmadji *et.al.* 2015]. Local communities use the lake water to irrigate their potato farms [Soeprobowati *et al.* 2019]. In the Dieng Plateau, most agricultural production is based on monoculture, with potato as its main crop. Local farmers have been developing terracing methods on their farms as Dieng has an inclination of 45%. In 2007, 63.22% of the Dieng area is non-forest land. The percentage increased to 66.1% in 2010 [Soeprobowati *et al.* 2018b]. The non-forest area in Dieng has been rapidly growing, which increase the possibility of toxic pollutants to enter the lake. This research aims to determine water quality in Lakes Warna and Pengilon based on physical, chemical, and biological indicators.

MATERIAL AND METHOD

DESCRIPTION OF THE STUDY AREA

Warna is a small volcanic lake located at the Dieng Plateau, Java. Warna means colour, so the name of Lake Warna reflects its characteristics. Lake Warna has various colours, such as red, white, blue, and yellow, depending on the location, timing, and season. Red and yellow correspond to sulphur sedimentation, while white comes from limestone rocks and quartz at the bottom of the lake [Soeprobowati *et. al.* 2017]. Different colours appear due to the sunlight which enters the water and is reflected by minerals [Sudarmadji *et al.* 2015]. However, Lake Warna is mostly blue, which indicates mud deposited at the bottom. Another characteristic feature is gas bubbles and sulphurous odours from the lake.

Lake Pengilon is located next to Lake Warna and connected with it by a channel. Therefore, Warna and Pengilon form a complex of small lakes. Both lakes are conservation areas based on the Decree of the Minister of Agriculture No. 740/Um/11/1978 [Keputusan Menteri Pertanian Nomor 740 Tahun 1978]. Geographically, Lake Pengilon is located between 109°54’47” S and 109°55’10” E. As regards the administrative division, the lake is located in theJojogan Village, Kejajar, Wonosobo, Central Java. The lakes occupy an area of 39.6 ha and are located at 2,100 m a.s.l. The area has a rain intensity of 1.713 with a daily temperature of 14.3–26.5°C, and a minimum temperature of 1–5°C [BPS 2020].

This research was performed in April 2019 in Warna and Pengilon Lake, Dieng. Purposive random sampling was used to determine research sites, and each lake had four sites based on its environmental characteristics (Fig. 1). In every site, water quality was measured based on temperature, pH, turbidity, salinity, total dissolved solid (*TDS*), and dissolved oxygen (*DO*). Water samples were collected to analyse nitrite, ammonia, total nitrogen (TN), chemical oxygen demand (*COD*), and biological oxygen demand (*BOD*). Phytoplankton was collected using a plankton net with the mesh size of 25 μm, preserved in the 4% formalin. Identification of phytoplankton used the Sedgwick Rafter Counting under the microscope with the magnification of 1,000.

DATA ANALYSIS

STORET water quality index. To determine the water quality status of Warna and Pengilon lakes based on physical and chemical parameters, the study used the STORET (Storage and Retrieval) method based on the value system from US-EPA [Rahim, Soeprobowati 2019]. The STORET method calculation was done using the following steps:

1. Periodical water quality data collection to form time-series data from research in 2014–2015 [Soeprobowati *et al.* 2017] which was combined with data from this research.

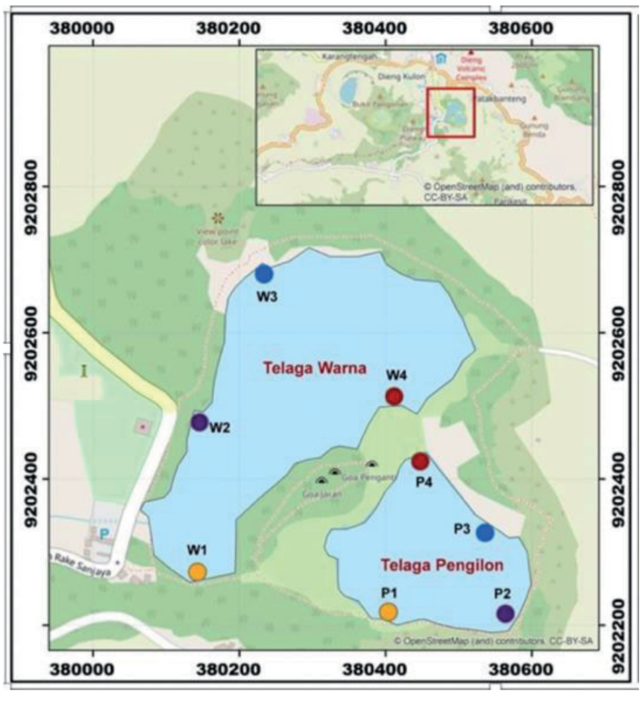

Fig. 1. Research sites in Warna and Pengilon Lakes, Dieng, Java; W = Lake Warna, P = Lake Pengilon; source: own elaboration

2. Comparison of measurement data for each water parameter with water quality standard values according to the water class. If the measurement results met water quality standards (measurement results < quality standards) then a score of 0 was given.
   If the measurement result was not fulfilling the standard, the score given to the parameter was as stated in Table 1.
3. If the results of the measurement did not meet the water quality standard (measurement results > quality standard), then a score was as in Table 2.
4. The negative sum of all the parameters was calculated and the quality status of the total score was obtained using the defined score system.

Pollution index (*PI*). *PI* was based on four predetermined water quality parameters, namely *DO*, pH, *COD,* and *BOD*. The first step in determining water quality used the pollution index (*PI*) method to calculate the value as in Equation (1), then the evaluation of the *PI* value was included in Table 3.

Table 1. The water quality scoring system

Amount	Value	Parameter		
		physical	chemical	biological
<10	maximum	−1	−2	−3
	minimum	−1	−2	−3
	average	−3	−6	−9
≥10	maximum	−2	−4	−6
	minimum	−2	−4	−6
	average	−6	−12	−18

Source: Keputusan Menteri Lingkungan Hidup Nomor 115 [2003].

Table 2. Water quality classification from US-EPA value system

Score	Class	Characteristic of water quality
0	A	meet the quality standard
From −1 to −10	B	lightly polluted
From −11 to −30	C	moderately polluted
≥−31	D	highly polluted

Source: Keputusan Menteri Lingkungan Hidup Nomor 115 [2003].

Table 3. Class of water contamination method pollution index (*PI*)

Value range	Water quality status
0 ≤ *PIj* ≤ 1.0	meet quality standards
1.0 < *PIj* ≤ 5.0	lightly polluted
5.0 < *PIj* ≤ 10	moderately polluted
PIj > 10	heavily polluted

Source: Keputusan Menteri Lingkungan Hidup Nomor 115 [2003].

$$PI_j = \sqrt{\frac{(C_i \,/\, L_{ij})_M^2 \ + (C_i \,/\, L_{ij})_R^2}{2}} \tag{1}$$

where: PI = pollution index, C_i/L_{ij} = pollution caused by water quality parameter, M = maximum, R = average

Abundance of phytoplankton. Phytoplankton abundance was calculated using the APHA formula [2012]:

$$N = \frac{T}{L}\frac{p_1}{p_2}\frac{V_1}{V_2}\frac{1}{V_w} \tag{2}$$

where: N = plankton abundance (ind.·dm^{-3}), T = number of boxes in (Sedgwick Rafter Counting SRC) SRC (1,000), L = number of boxes in one observation point of view, p_1 = number of observed plankton, p_2 = number of observed SRC, V_1 = volume of water in a sample bottle, V_2 = volume of water in SRC boxes, V_w = volume of filtered water.

Diversity index. To analyse the number of individuals in each growth step, a habitat community was approached by determining the Shannon–Wiener diversity index (H') [Magguran 2004].

$$H' = \sum_{i=1}^{s} P_i \ln P_i \tag{3}$$

$$P_i = n_i/N \tag{4}$$

where: P_i = proportion number of individual of species i to the total individual of all species, s = the total number of species in the sample; n_i = number of individual of a species, N = total individuals of all species.

The diversity index criteria are as follows:

$H' \leq 1$ = low diversity,

$1 < H' < 3$ = moderate diversity,

$H' < 3$ = high diversity.

Evenness index. The evenness index (E) is the number of individuals between species in a phytoplankton community. The formula is below:

$$E = H/H_{max} \tag{5}$$

$$H_{max} = lns \tag{6}$$

where: E = evenness index, H' = the Shannon–Wiener index of diversity, s = number of species found.

The criteria are as follows:

$0 < E \leq 0.5$ = depressed community,

$0.5 < E < 0.75$ = unstable community,

$0.75 \leq E \leq 1$ = stable community.

Dominance index (*D*)

$$D = \sum_{i=1}^{s} P_i^2 \tag{7}$$

Index values range from 0 to 1 by the following categories:

$0 < D < 0.5$ = low dominance,

$0.5 < D \leq 0.75$ = moderate dominance,

$0.75 < D \leq 1.0$ = high dominance.

Saprobic index. The saprobic index was calculated using the following formula [Dresscher, van der Mark 1979]:

$$X = \frac{C + 3D - B - 3A}{A + B + C + D} \tag{8}$$

where: X = saprobic coefficient (from –3 to +3), A = amount of cyanophytes species (polysaprobic), B = amount of euglenophytes species (α-mesosaprobic), C = amount of chlorophytes species (β-mesosaprobic), D = amount of cryophytes species (oligosaprobic).

The overall methodology can be illustrated in the framework a physico-chemical analysis which followed the Government Regulation of Republic Indonesia [Peraturan Pemerintah Nomor: 82 2001], Keputusan Menteri Lingkungan Hidup Nomor 115 [2003] for the pollution index, and Kementerian Lingkungan Hidup [2008] for the trophic state. Biologically, the water quality of Warna and Pengilon lakes was determined based on the composition and species dominance, diversity, evenness, dominance, and saprobic indices as shown in Figure 2.

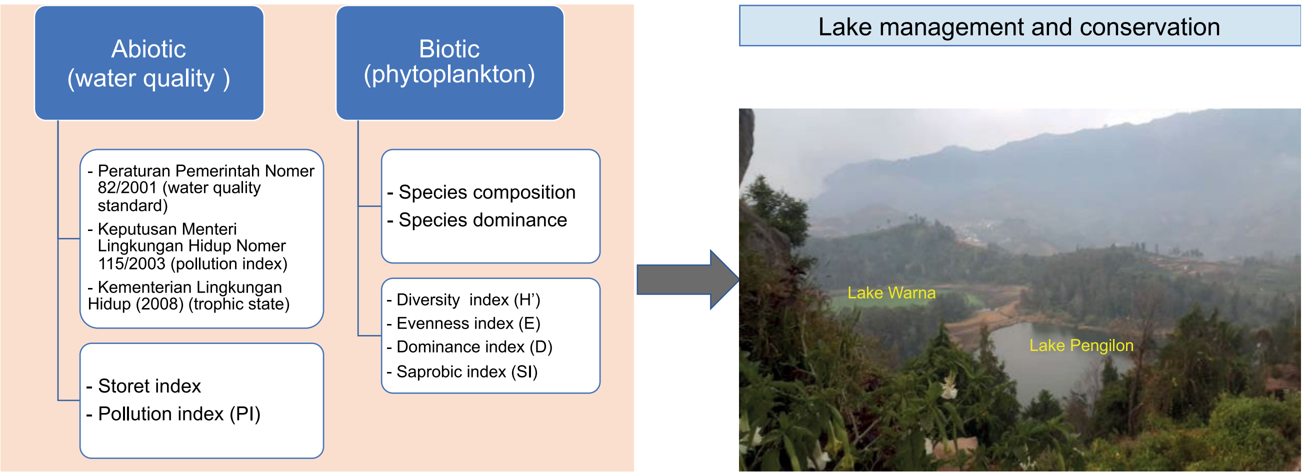

Fig. 2. Framework for analysis physico-chemical and biological water quality of Warna and Pengilon Lakes, Dieng Java; source: own elaboration

RESULTS AND DISCUSSION

While referring to the Indonesian water quality standard, the research determined water quality of Warna and Pengilon lakes as relatively good as a source for drinking water (class I), recreation, livestock and fish farming (class II), livestock, fish farming, and agriculture (class III), and agriculture (class IV), as stated in the Government Regulation [Peraturan Pemerintah Nomor: 82 2001]. The measured parameters that fulfil the water quality standard were temperature, dissolved oxygen, nitrite, and nitrate.

Temperature. The temperature at Warna and Pengilon lakes (Fig. 3) meets the criteria for water quality standards based on Indonesian Government Regulation Number 82 of 2001 [Peraturan Pemerintah Nomor: 82 2001] for classes I, II, III, and IV, which states that the water temperature is at a 3°C deviation from the natural conditions of the surrounding environment. Changes in the air body temperature are closely related to changes in atmospheric temperature [Dhungana 2019]. The average value indicates that the temperature difference between the sampling station and the ambient temperature is not at a level that can adversely affect life [Mutlu, Kurnaz 2018]. Specific species responses of diatom to temperature are affected by interspecific interactions [Zhang *et al.* 2018].

Dissolved oxygen (*DO*). Dissolved oxygen (*DO*) measured at all stations in Warna and Pengilon lakes was above 7, where the limit of national *DO* for class I is >6, class II >4, and class III >3 (Fig. 4). *DO* is very important for aquatic life and is required for biochemical oxidation. In freshwater, *DO* must be at least 5 mg·mg^{-3} for healthy aquatic life [Mutlu, Kurnaz 2018].

Indicators of organic substance content. Biological oxygen demand (*BOD*) in Warna and Pengilon lakes has exceeded the national water quality standard for all classes except P4 for class IV.

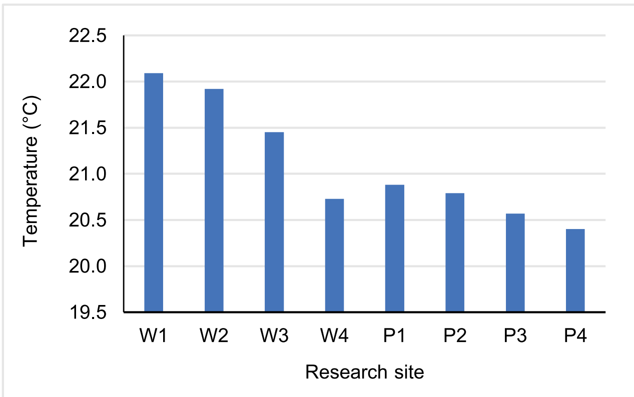

Fig. 3. Temperature of water in Warna and Pengilon lakes, April 2019; W = Lake Warna, P = Lake Pengilon; source: own study

COD and *BOD* indicate the amount of organic matter present in water [Koda *et al.* 2017]. Based on *COD* and *BOD*, the Warna and Pengilon lakes were not suitable as a source of drinking water (class I) and recreation, livestock, and fish farming (class II), but suitable for agriculture. Local communities pumped water from the lakes to irrigate their potato farmland. As a result, the water volume in the lake dropped during the dry season. In the wet season, water from Lake Pengilon flows to Lake Warna with one outlet at Lake Warna. However, during the dry season, water flows from Lake Warna to Lake Pengilon due to 80 pumps operated on Lake Pengilon for irrigation at different elevations. Lake Warna dried and the lowest level reduced to 3 m during the dry season in April 2019 [Soeprobowati *et al.* 2019]. On average, the abstraction rate of 200 dm^3·min^{-1} significantly reduced water volume [Soeprobowati *et al.* 2019; 2020].

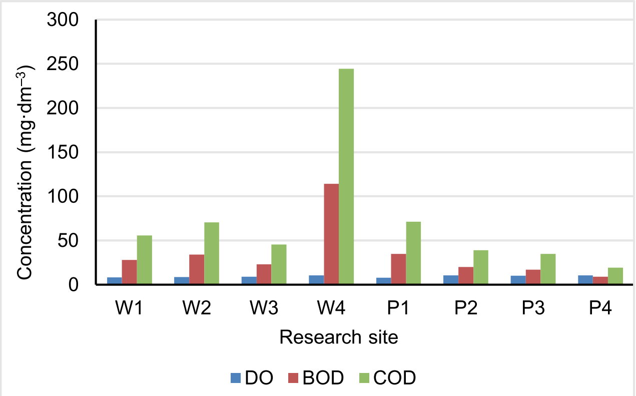

Fig. 4. Dissolved oxygen (*DO*), biological oxygen demand (*BOD*), and chemical oxygen demand (*COD*) in water of Warna and Pengilon lakes, April 2019; W = Lake Warna, P = Lake Pengilon; source: own study

pH. The measurement of the physical parameter on April 9, 2019, showed that the pH of Lake Warna was slightly acidic (but tends to be neutral) in the range of 6.02–7.28 (Fig. 5). The pH of water in Lake Warna was fluctuating. In August 2014, its pH was in the range of 2.2–2.4 and in February 2015, in the range of 4.91–5.35 [Soeprobowati *et al.* 2017]. Based on the pH data from 2014, 2015, and 2019, we may conclude that the acidity of these lakes increased. This increase might be related to changes in particular seasons and the day and night cycle from year to year. The acidification of waters can be influenced by water temperature through the distribution of cycles in seasons and between day and night [Romanescu *et al.* 2016] or an imbalance in the carbonate and bicarbonate equilibrium [Nakhate, Kale 2018]. Water pH in Lake Warna tends to increase (towards more neutral). The average pH of water in Lake Pengilon is 5.99, in the range of 5.4–6.89 (Fig. 4). Therefore, water from Lake Pengilon was only suitable for agriculture (class IV) as specified in the Government Regulation [Peraturan Pemerintah Nomor: 82 2001].

Turbidity. The turbidity in Lake Warna was in the range of 2.59–58.4 NTU (Fig. 6). Samples from W1, W2, and W3 exceeded the threshold for water quality standard criteria based on the Government Regulation [Peraturan Pemerintah Nomor: 82 2001] for classes I, II, III, and IV, which determine the turbidity of –10 NTU. The turbidity in Lake Pengilon ranged from 0.05 to 18.02 NTU. High turbidity is usually caused by high turbulence and water mixing, which leads to an increase in the suspended particulate matter [Natkahe, Kale 2018], and the obstruction of light entering water [Li *et al.* 2013]. Water turbidity is associated with clay, silt, very fine organic and inorganic matter, algae, soluble coloured organic compounds, plankton, and other microscopic organisms. But most likely the high turbidity value is due to the coliform load in water and precipitation [Loucif *et al.* 2020].

Total dissolved solids (*TDS*). The *TDS* in Warna and Pengilon lakes were relatively low (Fig. 7), below the threshold of the water quality standard criteria based on the Government Regulation [Peraturan Pemerintah Nomor: 82 2001] for classes I, II, III, and IV. Solids found in water consist of three forms, namely suspended, volatile, and dissolved matter. Suspended solids include silt, stirred bottom sediment, decomposed plant matter, and sewage treatment effluent [Bhateria, Jain 2016]. The *TDS* can be used as an indicator of nitrogen concentration [Zhang *et al.* 2017].

Nitrogen. Ammonia, nitrite, and nitrate concentration in Warna and Pengilon lakes (Fig. 8) were below the maximum concentration according to water quality standard criteria based on the Government Regulation [Peraturan Pemerintah Nomer 82 2001] for classes I, II, III, and IV. The ammonia content in water was caused by the release of NH_4^+ from sediment so that it could affect the concentration of NH_4^+ in water.

Ammonia has the potential for high toxic effects in the waters, especially in fish, molluscs, and crustaceans that are sensitive to the presence of ammonia. Due to the high emission of ammonia and its high toxic effect on aquatic organisms, the ecological risks caused by ammonia are increasingly present worldwide [Wang *et al.* 2020].

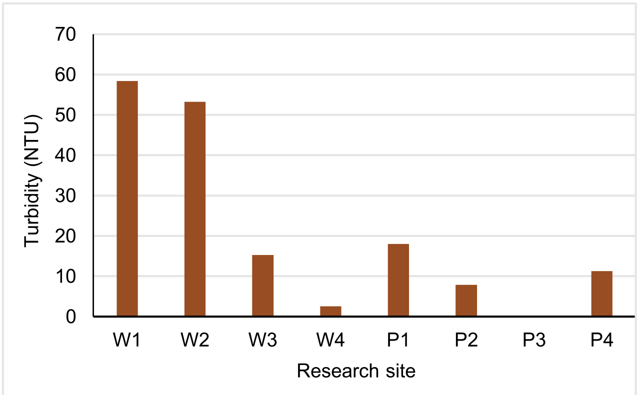

Fig. 6. Turbidity in Warna and Pengilon Lakes, April 2019; W = Warna Lake, P = Pengilon Lake; source: own study

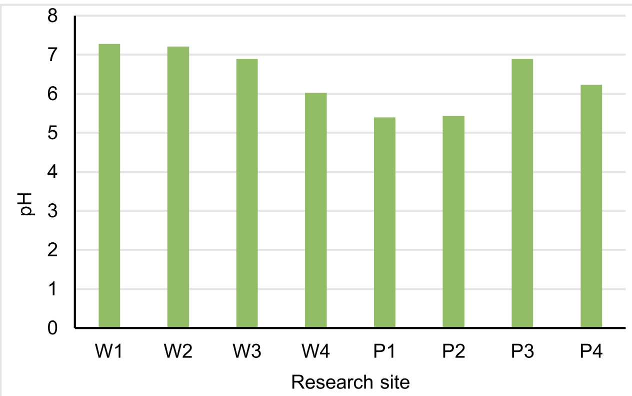

Fig. 5. pH of water in Warna and Pengilon Lakes, April 2019; W = Lake Warna, P = Lake Pengilon; source: own study

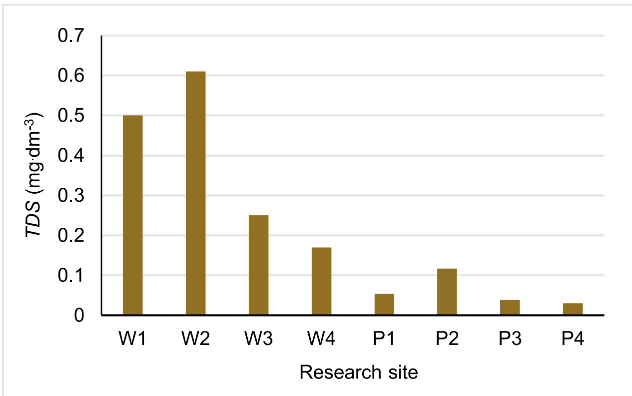

Fig. 7. Total dissolved solids (*TDS*) in Warna and Pengilon Lakes, April 2019; W = Warna Lake, P = Pengilon Lake; source: own study

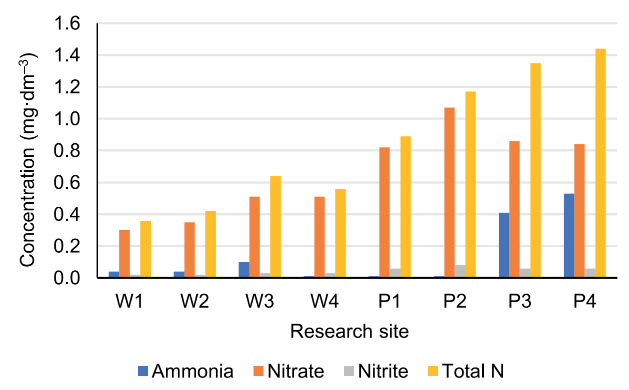

Fig. 8. Nitrogen compounds in water of Warna and Pengilon lakes, April 2019; W = Lake Warna, P = Lake Pengilon, total N = total nitrogen; source: own study

The concentration of nitrate in Warna and Pengilon lakes was below the threshold of the water quality standard for classes I, II, III, and IV based on the Government Regulation [Peraturan Pemerintah Nomer 82 2001]. The increase in the nitrate content is caused by the increase in water runoff during the rainy season which transports ammonium and ammonia cations from fertilisers, as well as the nitrite and nitrate due to the nitrification process [Wang *et al.* 2020].

The amount of nitrate is usually larger than the amount of nitrite because nitrite is unstable in the presence of oxygen whereas nitrite is also a transitional form between ammonia and nitrate [Ewaid, Abed 2017]. In natural uncontaminated waters, variations in nitrate depend on different factors, including season and origin of water, ranging from 1 to 15 mg·dm^{-3}, and concentrations of 2 or 3 mg·dm^{-3} are still considered normal. Nitrates are harmless but can be toxic when turned into nitrites [Loucif *et al.* 2020].

In 2019, nitrite levels in samples from all sampling sites on Lake Warna ranged from 0.02 to 0.03 mg·dm^{-3} with an average of 0.025 mg·dm^{-3} (Fig. 8), whereas in Lake Pengilon from 0.06 to 0.08 mg·dm^{-3} with an average of 0.07 mg·dm^{-3}. In 2019, the average value was still below the threshold of the water quality standard for classes I, II, III, and IV based on the Government Regulation [Peraturan Pemerintah Nomer 82 2001]. The source of nitrite in the waters was organic matter, nitrogen fertilisers, and some minerals. Nitrite concentrations higher than 1.00 mg·dm^{-3} in waters indicated pollution [Multu, Kurnaz 2018].

Total nitrogen (TN) was relatively low. In Lake Warna, the concentration of TN was 0.36–0.64 mg·dm^{-3} (Fig. 8), which was in the category of an oligotrophic lake, whereas in Lake Pengilon were 0.89–1.44 mg·dm^{-3}, which was in the category of a meso-eutrophic lake. This might be correlated with the pumping of lake water for irrigation [Soeprobowati *et al.* 2019].

Aquatic nitrogen is necessary for an organism's growth and is naturally produced by the action of light, decay of proteins, and the effect of nitrogen-fixing bacteria on ammonia. TN is an important parameter of eutrophic waters, particularly for those polluted by fertiliser run-off, animal wastes, and domestic sewage [Soeprobowati *et al.* 2012; Zeiny, El-Kafrawy 2017]. TN in the decomposition of aquatic plants, particulates, and dissolved nitrogen in domestic wastewater are the main substrate for NH_4^+ mineralization and TN is the dominant form of N in sediments [Zhu *et al.* 2019].

Total phosphorus (TP). Based on the previous studies of 2014–2015 [Soeprobowati *et al.* 2017], TP concentration in Lake Warna (in the range of 0.16–0.28 mg·dm^{-3}) indicated a hypereutrophic state (Fig. 9). The lakes are in a hypereutrophic state when the concentration of TP is >0.1 mg·dm^{-3} [Kementerian Lingkungan Hidup 2008]. The main sources which increase the phosphorus load in river water include fertilisers, use of detergents, and domestic sewage [Sharma, Walia 2017]. The growing phosphorus concentration promoted algae and reduced oxygen levels. In nature and wastewater, phosphorus is bound to oxygen to form phosphate (PO_4). Phosphorus in aquatic systems occurs as organic and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, nucleic acids, phospholipids, inositol phosphates, sugar phosphates, condensed P, etc. Inorganic phosphorus is composed of exchangeable phosphorus, Fe, Al, Mn oxides-bound phosphorus, and Ca-bound phosphorus. There were significant correlations between organic phosphorous forms and total phosphorus (TP) and inorganic phosphorus. Non-labile organic phosphorus had the strongest correlation with TP. In each region, the distribution of organic phosphorous forms was different due to the impact of human activities, industrial and agricultural production, and the land types; the heaver polluted sediments with high organic phosphorus fractions [Wan *et al.* 2020].

Pumping water in Lake Pengilon for irrigation (Photo 1) reduced the water volume in the lake. There were more than

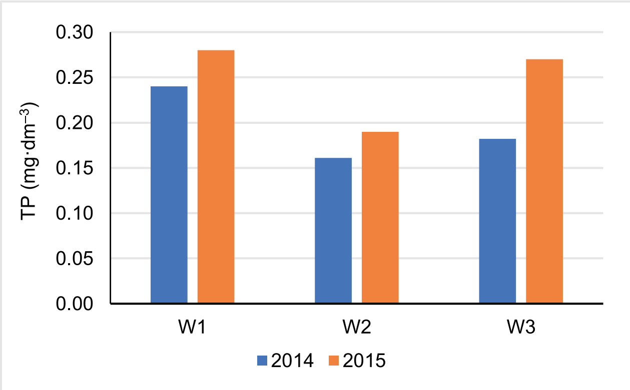

Fig. 9. Total phosphorus (TP) in water of Lake Warna, Dieng, 2014–2015; W1, W2, W3 = research sites; source: own elaboration based on Soeprobowati *et al.* [2017]

Photo 1. Pumping water for irrigation of agricultural farming in Lake Pengilon (phot.: *T.R. Soeprobowati*)

80 water pumps in Lake Pengilon, with an average pumping capacity of 266.67 $dm^3 \cdot s^{-1}$. As a result, water from Lake Warna flew to Lake Pengilon due to the different slopes. In the wet season, in Lake Warna, water pH turned to neutral whereas in Lake Pengilon its was acidic, which in the dry season in the opposite condition. This situation was impacted on the TN and TP concentrations which were higher at Lake Pengilon compare to Lake Warna. Lake Warna dried and the lowest tide reduced up to 3 m in April 2019 [Soeprobowati *et al.* 2019]. This condition is supported by water quality data discussed above.

Water pollution index. The predictive index assessment is based on criteria and attributes and its target is to protect the watershed and waterbodies under several land-use policies. The STORET index that needs a large number of water quality parameters, should be further considered regarding probable constraints, such as different and specific characteristics of certain waterbodies based on local conditions [Tallar, Suen 2015]. The STORET method is used to compare water quality with standards for water environment types.

Physiochemical parameters used in the calculation are observed temporally. Time series data of temperature, *DO*, pH, turbidity, *TDS*, ammonia, nitrite, nitrate, TN, *BOD*, and *COD* for Lake Warna in 2014 and 2015 [Soeprobowati *et al.* 2017] combined with the data from this research showed that the status of water in Lake Warna for all classes (class I as a source of raw drinking water, class II for recreation, livestock, and aquaculture in the fisheries, class III for animal husbandry, aquaculture in the fishery sector, and agricultural activities, and class IV for agricultural activities) fall into class D (highly polluted) (Tab. 4).

The determination of the overall water quality status can be performed using the STORET method which can describe parameters that meet or exceed quality standards. The scoring is based on the US-EPA system. Based on calculations using the STORET method, the status of Lake Pengilon water quality is shown in Table 4. Based on the US-EPA system, the information on the status of water quality from each class is class I as a source of raw drinking water, class II as a means of recreation, livestock, and aquaculture in the fisheries sector, class III as a means of

Table 4. Water quality status of Lake Warna based on the STORET method

Parameter	Measurement unit	Min.	Max.	Average	Score class I	Score class II	Score class III	Score class IV
Lake Warna								
pH	–	2.2	7.28	4.98	0	0	0	0
Temperature	°C	15.35	26.60	20.96	0	0	0	0
Dissolved oxygen	$mg \cdot dm^{-3}$	3.34	10.61	7.77	–16	–16	–20	–20
Lead (Pb)	$mg \cdot dm^{-3}$	0.01	0.06	0.03	–8	–8	–8	0
Cadmium (Cd)	$mg \cdot dm^{-3}$	0.01	0.14	0.03	–16	–16	–16	–16
Chromium (Cr)	$mg \cdot dm^{-3}$	0.01	0.03	0.02	0	0	0	–16
Copper (Cu)	$mg \cdot dm^{-3}$	0.01	0.06	0.03	–16	–16	–16	0
Total phosphorus	$mg \cdot dm^{-3}$	0.16	0.28	0.22	–20	–20	0	0
Total dissolved solid	$mg \cdot dm^{-3}$	0.17	0.61	0.38	0	0	0	0
Biological oxygen demand	$mg \cdot dm^{-3}$	23	114	49.75	–20	–20	–20	–20
Chemical oxygen demand	$mg \cdot dm^{-3}$	45.31	244.25	103.90	–8	–8	–4	–16
Ammonia	$mg \cdot dm^{-3}$	0.01	0.1	0.048	0	0	0	0
Nitrate	$mg \cdot dm^{-3}$	0.3	0.51	0.42	0	0	0	0
Nitrite	$mg \cdot dm^{-3}$	0.02	0.03	0.025	–20	0	0	0
Pollution index					**–124**	**–104**	**–84**	**–88**
Lake Pengilon								
pH	–	5.4	6.89	5.99	0	0	0	0
Temperature	°C	20.4	20.88	20.66	0	0	0	0
Dissolved oxygen	$mg \cdot dm^{-3}$	7.91	10.53	9.80	–20	–20	–20	–20
Total dissolved solid	$mg \cdot dm^{-3}$	0.03	0.117	0.06	0	0	0	0
Biological oxygen demand	$mg \cdot dm^{-3}$	9	35	20.25	–20	–20	–20	–20
Chemical oxygen demand	$mg \cdot dm^{-3}$	19.1	71.1	41.05	–20	–16	–4	0
Ammonia	$mg \cdot dm^{-3}$	0.01	0.53	0.24	–16	0	0	0
Nitrate	$mg \cdot dm^{-3}$	0.82	1.07	0.90	0	0	0	0
Nitrite	$mg \cdot dm^{-3}$	0.06	0.08	0.07	–16	–16	–16	0
Pollution index					**–92**	**–72**	**–60**	**–40**

Source: own study.

animal husbandry, aquaculture in the fishery sector and agricultural activities, and class IV which is used for agricultural activities included in class D with the highly polluted category. Based on the pollution index (*PI*), Warna and Pengilon lakes are lightly and moderately polluted. Only site P4 met the water criteria for class IV (used for agriculture, Fig. 10).

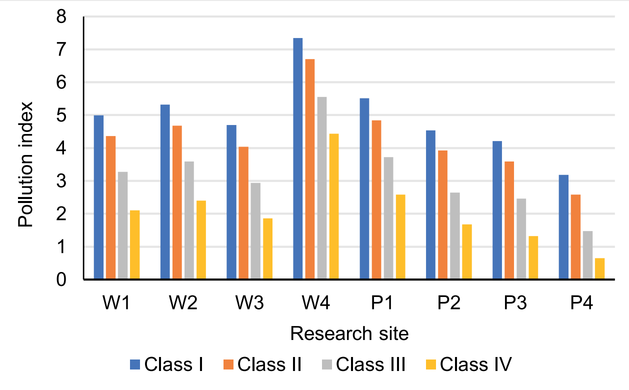

Fig. 10. Pollution index for water in Warna and Pengilon lakes, Dieng; W = Lake Warna, P = Lake Pengilon, class I = a source for drinking water, class II = for recreation, livestock and fish farming, class III = for livestock, fish farming, and agriculture, class IV = for agriculture; source: own study

Phytoplankton. Based on this research, Bacillariophyta, known as diatoms dominated in Lake Pengilon, but in Lake Warna only dominated at W4, because Chlorophyta dominated at W3, W1, and W2. Charophyta and Rhodophyta were found in P4 only, and Cyanobacteria and Euglenophyta were found in Lake Pengilon only (Fig. 11). Bacillariophyta are potential bioindicators of water quality, in particular eutrophication and pollution of organic matter, due to fast growth, high biodiversity, and high sensitivity to physico-chemical water factors [Khudher, Al-Jasimee 2019; Soeprobowati *et al.* 2020]. Bacillariophyta contribute to lake's oxygen that can chemically change the environment of surrounding waters [Letáková *et al.* 2018].

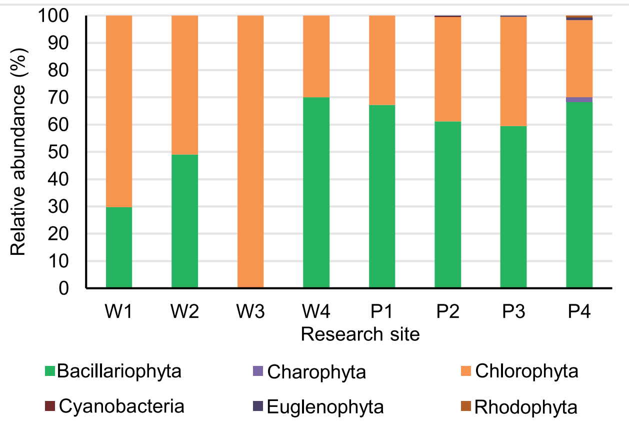

Fig. 11. Composition (%) of phytoplankton in Warna and Pengilon lakes; W = Lake Warna, P = Lake Pengilon; source: own study

Chlorophyta are mostly distributed in freshwaters and are generally abundant in lakes with sufficient light intensity [Dembowska *et al.* 2018]. Some Chlorophyta species are adaptable, fast-breeding, and highly tolerant to temperature fluctuations [Siagian, Simarmata 2018].

The diversity index for both Warna and Pengilon lakes indicated moderate diversity (1.7–2.14), as shown in Figure 12. An increase in the number of species was followed by an increase in the diversity index. The more species in the community, the more uniform the distribution of various individuals, and the higher the index. This indicated a good diversity of the community. The diversity index was more useful to describe the lake ecosystem, and it indicated a variety of phytoplankton species. The species diversity indices of phytoplankton in Warna and Pengilon lakes indicated that Lake Pengilon had rich variety of phytoplankton species when compared to Lake Warna. The role of phytoplankton species and their assemblage as bioindicators reflected pollution and corresponded to the water pollution index. Water quality assessment can be based on phytoplankton that polluted waters and induced stressed communities. This is characterised by a change in the abundance of species.

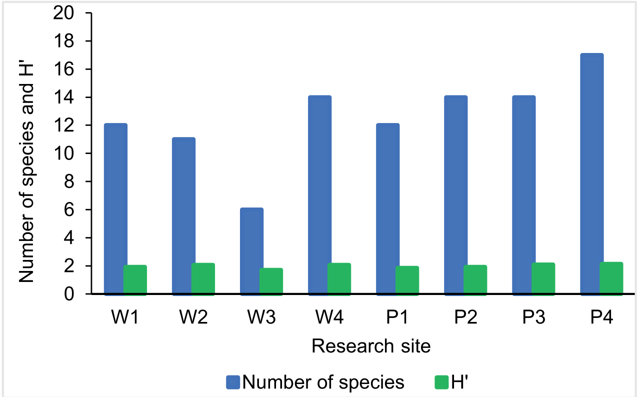

Fig. 12. The number of species and Shannon–Wiener diversity index (*H'*) in Pengilon and Warna lakes; W = Lake Warna, P = Lake Pengilon; source: own study

The lakes with the Shannon–Wiener diversity index <1 are classified as heavily polluted, 1–3 moderately polluted, and >3 clean [Yusuf 2020]. In the present study, the Shannon–Wiener diversity index ranges between 1.7 and 2.14, which indicates that Pengilon and Warna lakes are moderately polluted. This is reflected in an even distribution of the index. However, in Lake Warna the index was higher than in Lake Pengilon (Fig. 13), which meant that phytoplankton in Lake Warna was more stable than in Lake Pengilon. With the uniformity of its value, the index describes the number of biota in each species.

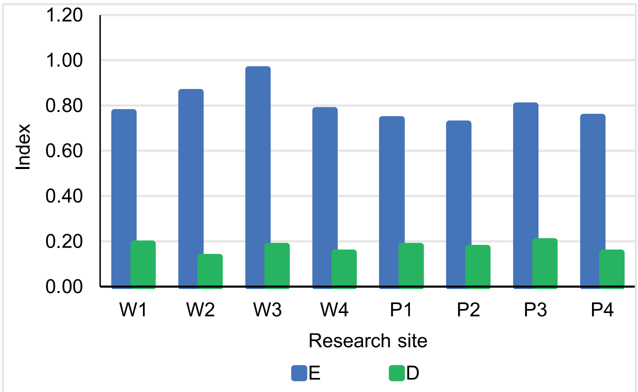

Fig. 13. The evenness index (*E*) and dominance index (*D*) in Pengilon and Warna Lakes, Dieng; W = Lake Warna, P = Lake Pengilon; source: own study

A relatively low index indicates low dominance of species against other species or no species dominated against the other. The dominance index is inversely proportional to the diversity index. The higher the dominance index, the diversity index decreases, or vice versa.

The phytoplankton species found in a water sample can be used to determine its level of pollution. Based on Table 5, the saprobic index in water of Warna and Pengilon lakes is 1.0 and 1.4 respectively. This result shows that the water in Warna and Pengilon lakes is lightly polluted by organic or inorganic pollutants with β-mesosaprobic phase. This category shows that the pollutant is most likely originating from agricultural activities. In both lakes, the pollutant intake is determined by natural decomposition in the surrounding area.

Table 5. The saprobic index in water of Warna and Pengilon lakes

Lake	Saprobic index	Saprobic phase	Level of pollution	Pollutant
Warna	1.0	β-mesosapro-bic	lightly polluted	organic and inorganic substances
Pengilon	1.4	β-mesosapro-bic	lightly polluted	organic and inorganic substances

Source: own study.

The water quality and level of pollution can be determined using the saprobic index. Some phytoplankton has different responce and tolerance towards environmental changes. The saprobic index is used to comprehend the dependency of any organism on a certain substance, specifically organic pollution. Usually the sites with a higher saprobic index are characterised by highly tolerant diatom species [Wan Maznah, Makhlough 2015]. The dominance of *Nitzschia* in Pengilon and Warna lakes (Fig. 14) indicate that the lakes show high organic content [Aprisanti *et al.* 2013], whereas the occurrence of *Closterium* indicates eutrophic conditions of the lake [Sulastri, Nomosatryo 2019].

Plankton abundance in Warna and Pengilon lakes varies due to the unequal distribution of aquatic organisms. Water quality parameters that influence phytoplankton abundance are nutrients, water flow, light, water currents, and internal factors, such as the life cycle of phytoplankton [Rahayu *et al.* 2020]. The abundance of phytoplankton is affected by the increase in nutrients in water, particularly nitrogen and phosphate. These nutrients generally originate from residential, agricultural, livestock, and fisheries waste [Makhlough *et al.* 2016].

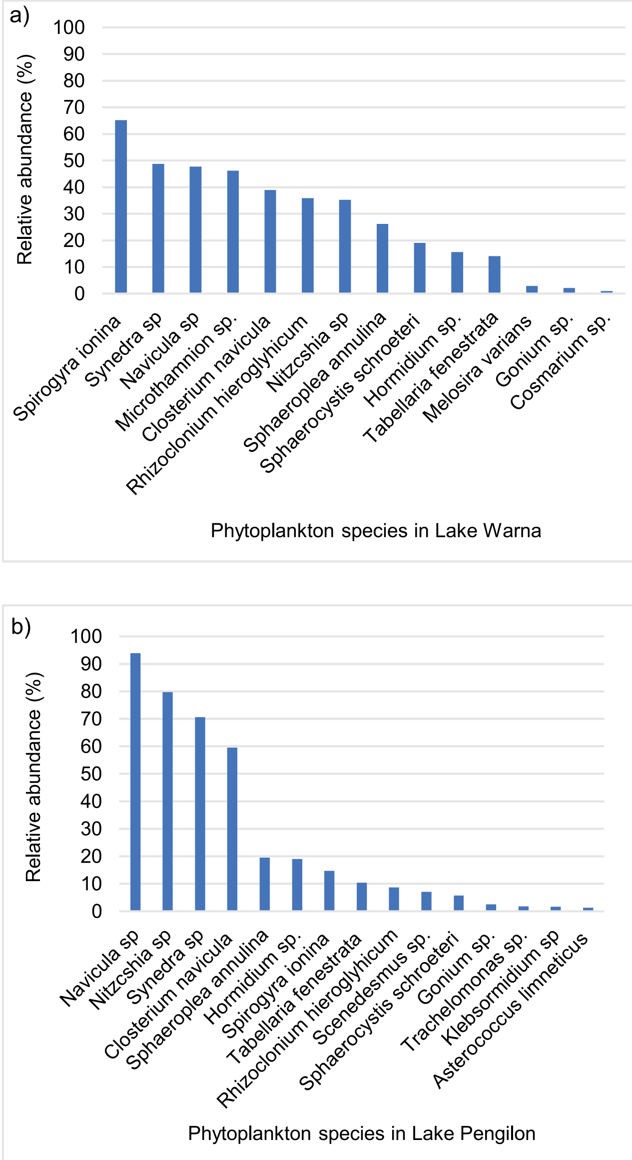

Fig. 14. The phytoplankton species with relative abundance >1% in investigated lakes: a) Lake Warna, b) Lake Pengilon; source: own study

CONCLUSIONS

Based on the physical and chemical parameters, some of water quality parameters pertaining to Warna and Pengilon lakes fulfil water quality standards as regards temperature, DO, nitrite, and nitrate. Based on the STORET method, the water is highly polluted, while based on the PI method, the water of Warna and Pengilon lakes is lightly and moderately polluted. This condition is similar to the saprobic index, which indicates that the Warna and Pengilon lakes are lightly polluted. The dominance of *Closterium* indicates that the lakes were in the eutrophic condition, which is supported by the concentration of TP which was >0.1 mg·dm^{-3}. Phytoplankton was a reliable tool to assess water quality. Long-term water quality monitoring in Warna and Pengilon lakes is necessary for effective prediction and efficient lake management.

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