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ЯКІСТЬ ВОДИ ТА ТРОФІЧНИЙ СТАТУС ОЗЕРА ТОБА, ПІВНІЧНА СУМАТРА, ІНДОНЕЗІЯ

Озеро Тоба, розташоване у провінції Північна Суматра (Індонезія), широко використовується в різних напрямках, включаючи туризм, транспорт, гідроелектроенергетику, питне водопостачання та рибне господарство. Індустріальна та антропогенна діяльність впливають на якість води озерної екосистеми. Основна проблема полягає у накопиченні біогенних речовин у формі азоту та фосфору. Метою роботи було визначення трофічного статусу озера Тоба на основі дослідження вмісту біогенних речовин. Дослідження проводили з квітня по липень 2018 р. на трьох станціях: А (станція, де знаходяться плавучі сітяні клітки, що використовуються для аквакультури), В (станція, що знаходиться під впливом побутового забруднення та водного транспорту) та станція С (розташована у центральній частині озера, що може слугувати контролем). Отримані дані показали, що обстежені станції відрізнялися за якістю води, що підтверджується багатофакторним аналізом та аналізом основних компонентів. На основі індексу трофічного стану, що базується на визначенні вмісту хлорофілу а, прозорості води за диском Секкі, а також на визначенні загального вмісту азоту та фосфору, озеро Тоба може бути віднесено до мезо-оліго-евтрофних водойм. У порівнянні з попередніми дослідженнями, проведеними у 2009, трофічний стан озера Тоба змістився з оліготрофного на мезотрофний, що вимагає особливої уваги з метою попередження евтрофікації, викликаної надмірно високим вмістом фосфору, у майбутньому.

Ключові слова: *фосфор, індекс трофічного стану, мезотрофний, евтрофікація.*

Lakes are important freshwater ecosystems representing suitable habitats for various aquatic organisms. In addition, they can be utilized as water source and aquaculture site by the local community to gain economical benefits for the well-being [3]. Indonesia has more than 500 lakes varying from tectonic or volcanic basins to floodplain lakes [7]. Lake Toba is one of the most substantial volcano-tectonic lakes in Indonesia located in the North Sumatra [10]. The water body is stratified thermally or oligomictic with a well-marked epilimnion and a drop of temperature from 26.4 to 23.9°C in the deep water [21]. Human utilization around the waters of Lake Toba has been documented in the form of residential area settlement, tourism, floating net cages for aquaculture, agricultural activities, and water transportation. Phosphorus load of 570.33 tons/year entering the waters of Lake Toba currently threatens the trophic state of the lake [9].

In 1929, when human activities were still limited in utilizing the water region of Lake Toba, the lake was still categorized as oligotrophic (nutrient-poor) with a light penetration reaching 22 m [21]. The floating net cages were established in Lake Toba in 1988 and managed by the local community and private sectors [5]. Since then, fishery activities increased in the waters of Lake Toba. These activities may alter the trophic state and ecological sustainability of Lake Toba in the form of eutrophication [14]. Eutrophication is a biological phenomenon commonly occurring in the inland waters such as lakes, reservoirs, and other freshwater habitats [20]. The phenomenon occurs due to the bulk or continuous discharge of nutrients into water bodies, especially nitrogen and phosphorus as the consequences of the agricultural activities and aquacultures. Eutrophication is primarily linked to phytoplankton productivity with some notable species capable of producing toxin compounds during the period of their mass development. Eutrophication is accompanied by the increase in water turbidity replacing macrophytes by phytoplankton community [17]. Therefore, the determination of the trophic state of fresh waters is important to obtain the current water quality for the sustainable utilization of the ecosystem. Trophic state has become a useful indicator to assess the environmental quality of various lakes in Indonesia such as Lake Kerinci, the South Sumatra [23], Lake Maninjau, the West Sumatra [25], Lake Rawa Pening, the Central Java [24], etc. In 2009, the trophic state of Lake Toba was classified as oligotrophic based on total phosphorus and chlorophyll *a* content and secchi disk depth. Certainly, the degradation of water quality may still continue until now [16]. Thus, it is necessary to study the current trophic status of Lake Toba as the basis for developing the concept of future sustainable management.

Material and Methods

Description of study sites.

The study was conducted in Lake Toba, the North Sumatra, Indonesia from April 2018 until July 2018. Three sampling sites were chosen purposively and given a code as A — Haranggaol utilized for fisheries and floating net cages, B — Ajibata-Parapat utilized as residential area and water transportation, and C — the central part of the lake as an undisturbed (control) site. The study area and sampling sites can be seen from Figure 1. Monthly sampling of lake water was conducted at 0 m and 5 m depths with three replications randomly selected near the sites. All water samples were collected in the morning (9—11 am) and in the afternoon (3—5 pm) in dark bottles of 1.5 L volume and transferred to the laboratory under preserved conditions. Water temperature

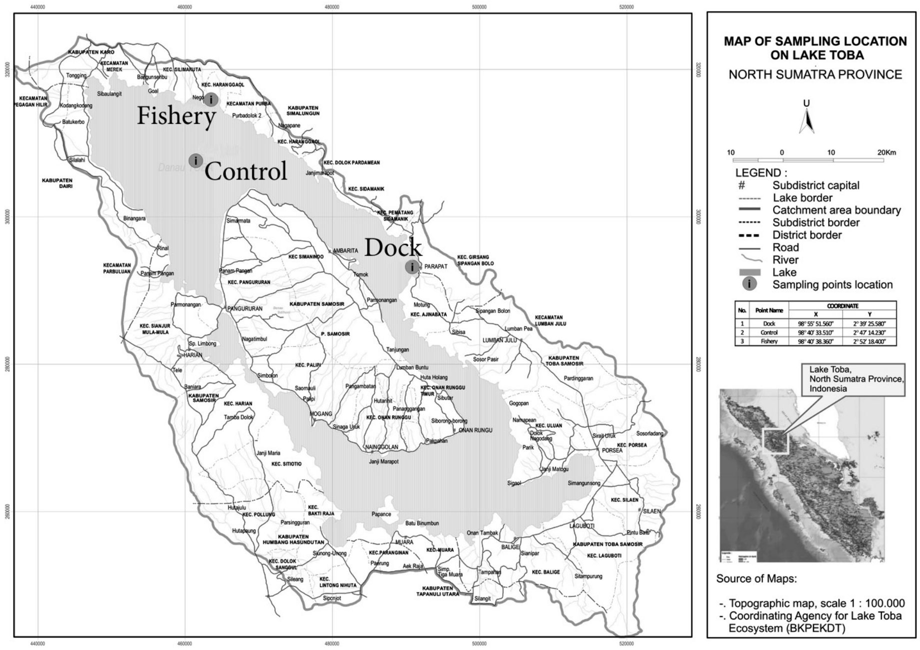

Fig. 1. Geographical map of study area

(T, °C), transparency or secchi disk depth (SDD, m), pH, dissolved oxygen (DO, mg/L), electrical conductivity (EC, μS/cm), total dissolved solids (TDS, mg/L), and turbidity (NTU or Nephelometric Turbidity Unit) were measured *in situ*, whereas total nitrogen (N) content (mg/m^3), total phosphorus (P) content (mg/m^3), and total chlorophyll *a* content (Chl *a*, mg/m^3) were determined under laboratory conditions.

Chlorophyll a extraction.

Liquid phase extraction of freshwater samples containing chlorophyll *a* (Chl *a*) were facilitated by using 90% acetone (v/v). Solutions were centrifuged at 3000 rpm for 15 min. The supernatant of each sample was then used to measure the UV absorbance in a spectrophotometer using the wavelength of 664, 647, and 630 nm [1]. The content of Chl *a* was quantified using the following equation:

$$\text{Chl } a = \frac{C_a \times V_a}{V \times d}$$

where:

Chl *a* = chlorophyll *a* content (mg/m^3);

C_a = $(11.85 \times E_{664})$ — $(1.54 \times E_{647})$ — $(0.08 \times E_{630})$;

V_a = acetone volume (mL);

V = filtered sample volume (mL);

d = diameter of a cuvette (cm);
E = UV absorbance.

Trophic State Index (TSI).

The index is used to indicate water quality in any aquatic ecosystem through indirect feature of algal biomass. The abundance of phytoplankton in the water was estimated through a serial measurement of total chlorophyll *a*, transparency, total N, and total P. Based on the Regulation of the Ministry of Environment, Republic of Indonesia No 28 of 2009, the trophic status of lake ecosystem is presented in Table 1 based on the modification of Carlson [4] and OECD [15].

Statistical analyses.

All numerical data were tested for statistical variability using a one-way ANOVA followed by a tukey's test to signify the individual mean differences among sampling sites and a two-sample *t*-test for different depths as spatial analysis. Relationship between the tested parameters was evaluated using Pearson's correlation test (P<0.05) and principal component analysis featured in Minitab® ver. 19.2020.1 software.

Results

The result of ANOVA between sampling sites and sampling depths is presented in Table 2. The results of mean comparison using tukey's test among the stations are presented in Table 3. Based on the obtained results, the more significant effect on water quality in Lake Toba was due to the spatial factor or sampling stations (Control, Dock, Fishery) than the depth of sampling (0 m, 5 m).

All physicochemical parameters were significant among sampling stations except the chlorophyll *a* and water transparency parameters. The pH value was significant and ranged from 6.79 (Control) to 8.23 (Fishery). In general, the pH values are still acceptable for aquatic organisms. Water conductivity or electrical conductivity (EC) is a measure of the total concentration of electrolytes in the water. The conductivity was significant and ranged between 167.15 (Control) and 171.55 (Fishery). The conductivity of freshwater is relatively low and ranges from 50 to 400 μS/cm. It has been found that the conductivity of the water in Lake Toba is low and limited in mineral composition. Other tested physicochemical parameters, including turbidity (0—0.39 NTU), total dissolved so-

Table 1

Classification of lake trophic status

Trophic Status	Total N (mg/m^3)	Total P (mg/m^3)	Chlorophyll *a* (mg/m^3)	Transparency (m)
Oligotrophic	≤650	<10	<2	≥10
Mesotrophic	≤750	<30	<5	≥4
Eutrophic	≤1,900	<100	<15	≥2.5
Hypereutrophic	>1,900	≥100	≥200	<2.5

lids (104.7—107.57 mg/L), dissolved oxygen (3.17—6.53 mg/L), total N (37.75—328.33 mg/m^3), and water transparency (3.2—4.32 m), were significant. The total P between control (20.83 mg/m^3) and fishery (24.17 mg/m^3) site was not significant. The control (26.43^{o}C) and dock (26.57^{o}C) sites similar in water temperature were grouped together. In addition, chlorophyll *a* content

Table 2

Statistical results of water quality parameters among sampling sites and depths

Parameters	Station^a		Depth^b	
	F-value	P	*T*-value	P
pH	359.13	0.000**	0.47	0.640^{ns}
Conductivity (μS/cm)	63.03	0.000**	1.16	0.116^{ns}
Turbidity (NTU)	28.57	0.000**	-0.76	0.453^{ns}
Total dissolved solids (mg/L)	671.00	0.000**	0.00	1.000^{ns}
Dissolved oxygen (mg/L)	358.51	0.000**	-0.74	0.462^{ns}
Chl *a* (mg/m^3)	2.89	0.070^{ns}	3.61	0.001**
Total P (mg/m^3)	7.39	0.002**	0.00	1.000^{ns}
Total N (mg/m^3)	390.93	0.000**	-0.28	0.780^{ns}
Transparency (m)	0.26	0.773^{ns}	—	—
Water temperature (^{o}C)	15.07	0.000**	3.54	0.001**

Note. a — one-way ANOVA; b — two-sample *t*-test; ns — non-significant; ** — significant difference at P<0.01

Table 3

Mean comparison (Tukey) **and standard deviation between the sampling sites**

Parameters	Station C (Control)	Station A (Fishery)	Station B (Dock)
pH	6.79±0.06^A	8.23±0.21^B	7.80±0.07^C
Conductivity (μS/cm)	167.15±1.51^A	171.55±0.49^B	169.22±0.48^C
Turbidity (NTU)	0±0.00^A	0.39±0.15^B	0.19±0.15^C
Total dissolved solids (mg/L)	104.7±0.00^A	107.57±0.33^B	106±0.00^C
Dissolved oxygen (mg/L)	6.53±0.24^A	3.17±0.21^B	5.34±0.43^C
Chl a (mg/m^3)	2.76±0.88^A	3.58±1.16^A	2.83±0.64^A
Total P (mg/m^3)	20.83±9.96^A	24.17±5.15^A	13.33±4.92^B
Total N (mg/m^3)	37.75±5.56^A	328.33±24.47^B	122.3±37.8^C
Transparency (m)	4.32±0.08^A	3.20±0.00^B	3.56±0.36^C
Water temperature (^{o}C)	26.43±0.32^A	26.95±0.15^B	26.57±0.22^A

Note. Similar letters denote non-significant differences of mean between the sampling sites.

Table 4

Pearson's correlation (*r*) among the tested parameters

Parameters	pH	EC	Turbidity	TDS	DO	Chl *a*	Total P	Total N	SDD	T
pH	1									
EC	0.868*	1								
Turbidity	0.727*	0.758*	1							
TDS	0.940*	0.895*	0.834*	1						
DO	-0.871*	-0.850*	-0.850*	-0.970*	1					
Chl *a*	0.363*	0.530*	0.246	0.363	-0.342	1				
Total P	0.026	0.298	0.215	0.207	-0.254	0.079	1			
Total N	0.857*	0.857*	0.790*	0.958*	-0.966*	0.370*	0.289	1		
SDD	-0.192	-0.413	-0.016	-0.119	-0.004	-0.551*	-0.060	-0.068	1	
T	0.594*	0.834*	0.514*	0.644*	-0.622*	0.502*	0.394*	0.646*	-0.663*	1

Note. EC — electrical conductivity; TDS — total dissolved solids; DO — dissolved oxygen; Chl *a* — chlorophyll *a*; SDD — secchi disk depth or transparency; T — water temperature. * — significant difference at $P<0.05$.

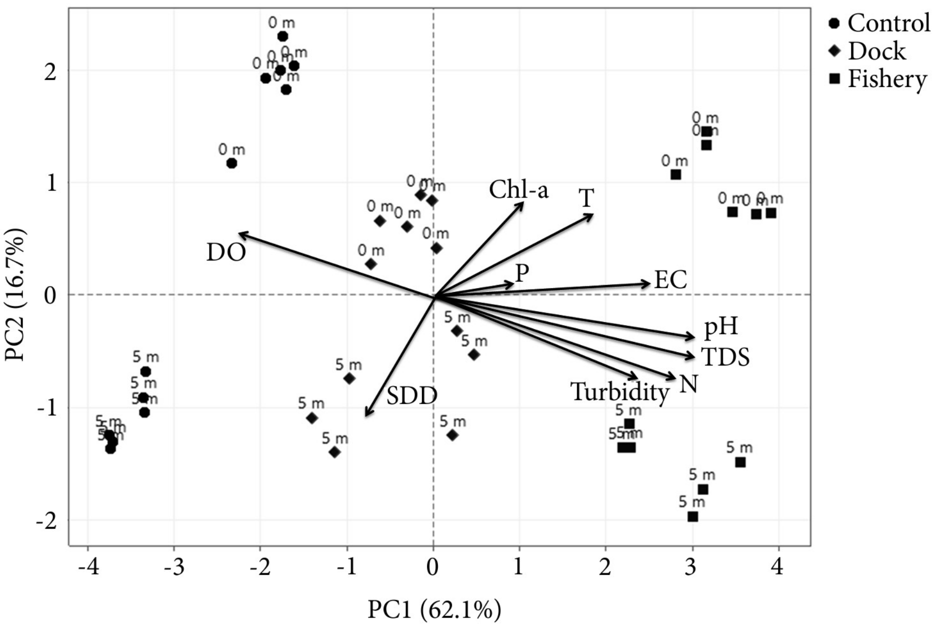

Fig. 2. Principal component analysis (PCA) biplot (loading plot and score plot) for water quality parameters and sampling sites at 0 and 5 m depths in Lake Toba: DO — dissolved oxygen; SDD — secchi disk depth or transparency; Chl *a* — chlorophyll *a*; N — total N; P — total P; T — water temperature; EC — electrical conductivity; TDS — total dissolved solids.

was not significant between sampling sites (2.76—3.58 mg/m^3). Large deviations were also documented from the lowest DO and the highest total N in the fishery site which may indicate the presence of organic nutrients and possibly a high pollution load near the water region.

Correlation between water quality parameters was determined based on Pearson's correlation test and principal component analysis (PCA) as presented in Table 4 and Figure 2. Strong and significant positive correlations were obtained between pH — EC, Turbidity — EC, TDS — pH, TDS — EC, TDS — Turbidity, Total N — pH, Total N — EC, Total N — Turbidity, Total N — DO, Total N — TDS, and Temperature — EC. Positive association between the parameters was supported by the homogeneity in their distribution pattern. Strong and significant negative correlations were noted between DO — pH, DO — EC, DO — Turbidity, DO — TDS, Total N — DO, Temperature — DO, and Temperature — Transparency. Negative correlation between the parameters is associated with dissimilar distribution pattern and their contradictive behavior in nature.

Multivariate analysis between sampling sites was performed using a principal component analysis to reveal the correlation pattern among parameters as plotted in the biplot (loading and score plot) in Figure 2. Based on the ordination of eigenvalues, the first two components (PC1, PC2) are sufficient to explain the variance of measured parameters with cumulative percentage of

78.8%. The result showed that each station was placed in its own ordinates revealing the contribution of spatial dynamics to water quality of Lake Toba. Moreover, the difference in depth also contributed to the distinct physicochemical characteristics of the waters although not statistically significant based on the previous result. The projection of each parameter to the sampling station showed the interconnected parameter to the sampling sites. Higher loadings were documented between chlorophyll *a*, water temperature, total P, and water conductivity in the fishery site at 0 m while other loadings such as pH, TDS, total N, and turbidity varied in the fishery site at 5 m. The obtained results showed that the chemical composition of Lake Toba was more likely influenced by the exogenous contribution such as soil erosion, influx of agricultural waste or fertilizers and surface runoffs in the lake watershed. The evaluation of trophic status based on water quality parameters as suggested by the Indonesian regulation revealed that the trophic state of Lake Toba waters is oligotrophic, mesotrophic, and eutrophic based on each indicator, including chlorophyll *a*, total N, total P, and secchi disk depth (SDD) or water transparency (Table 5).

Discussion

The determination of the trophic state of a lake is fundamental in assessing the environmental health and its current condition for any possible pollution in the area. The trophic condition of a lake may be influenced by nutrients, light penetration, TDS, phytoplankton community structure, and temporal hydrodynamic conditions [12]. The TSI based on secchi disk depth or water transparency is indicative of meso-eutrophic status of the lake. The determination of TSI-Transparency may be biased due to the presence of inorganic particles that may interfere with the algal particles and other suspended solids leading to a false indication [13]. A priority is then attributed to the biological parameters such as chlorophyll *a* content, total nitrogen, and total phosphorus as the major contributors to the algal biomass and eutrophication [4]. Excessive nutrient influx (phosphorus and nitrogen) to the water may result in the progressive proliferation of algae leading to algal blooms and eutrophication [27]. Based on the TSI-Total N, the lake is classified as oligotrophic. This state may be seasonal due to the limited human activity for a period of time especially regarding the agricultural activities [2]. Chlorophyll *a* is a biopigment produced by phytoplankton as a key feature in determining the trophic state of many tro-

Table 5

Trophic status of three sampling sites in Lake Toba

Parameters	Station C (Control)	Station A (Fishery)	Station B (Dock)
TSI-Total Nitrogen	Oligotrophic	Oligotrophic	Oligotrophic
TSI-Total P	Mesotrophic	Mesotrophic	Oligotrophic
TSI-Chlorophyll *a*	Mesotrophic	Mesotrophic	Mesotrophic
TSI-Transparency	Mesotrophic	Eutrophic	Eutrophic

Note. TSI — Trophic status index.

pical lakes. Existing phytoplankton community has been reported by former researchers in the waters of Lake Toba with a dynamic assemblage of dominant algal species but mainly from Chlorophyta, Chrysophyta and Cyanophyta groups [26, 19, 18]. It is also noteworthy that the structure of algal community may be distinct following the spatial and temporal dynamics that occur throughout the lake region. On the whole, the algal biomass as predicted from total chlorophyll *a* and the concentration of phosphorus or total P which has reciprocal correlation to the water transparency and a limiting factor to algal bloom may contribute to the trophic state of a lake [11]. According to the TSI from total P and chlorophyll *a*, the trophic state of Lake Toba is mesotrophic at all sampling stations with an exception to Station 3 (Dock) which is oligotrophic based on the TSI-Total P. A higher level of phosphorus in the water can be conditioned by the dissolution of rock phosphates and by the influx of agricultural fertilizers into the water [6]. Other studies suggest that significant phosphorus impact is the major limiting factor responsible for the increase in inland water productivity accompanied by the shift of its trophic state index, for example Lake Bhindawas, India [22], Lake Renuka, India [8], and Lake Grati, Indonesia [11]. Hence, the anthropogenic activities around the lake have contributed significantly to the alteration of the trophic state of Lake Toba due to the input of domestic fertilizers and industrial wastes into surface waters. Therefore, the input of phosphorus products into the water must be limited to prevent the eutrophication of Lake Toba.

Conclusion

The performed monitoring of current water quality in Lake Toba revealed clear spatial variations in its physicochemical parameters. Multivariate analysis confirmed that water quality significantly varied at the fishery and dock stations compared to the control site due to the human interferences. The trophic state index (TSI) was assessed through the level of chlorophyll *a*, total nitrogen, total phosphorus, and secchi disk depth or water transparency. The trophic state of Lake Toba was consistently mesotrophic, whereas in 2009 it was classified as oligotrophic. Considering potential threats to water quality, special attention must be given to the limit of phosphorus products entering lake water to prevent any potential eutrophication of Lake Toba.

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WATER QUALITY AND TROPHIC STATUS OF LAKE TOBA,
NORTH SUMATRA, INDONESIA

Lake Toba located in the North Sumatra Province, Indonesia is utilized locally for various interests, such as tourism, transportation, hydroelectric power, drinking water, and fisheries. The industrial and anthropogenic activities result in the degradation of water quality in lake ecosystem. The main problem is due to the accumulation of nutrients in the form of nitrogen and phosphorus in lake water. The purpose of this study was to determine the trophic status of Lake Toba based on nutrient content through survey. The study was carried out from April until July 2018 at three sampling sites, including the waters of Haranggaol (utilized for fisheries and floating net cages for aquaculture), Ajibata-Parapat (representing the sites impacted by household pollution and water transportation), and the central part of the lake as a reference or control site. The obtained results showed that various sampling sites of Lake Toba differed in their water quality as confirmed from the multivariate analysis using a principal component analysis (PCA). The trophic state index (TSI) based on chlorophyll *a* content, secchi disk depth or water transparency, and total nitrogen and phosphorus content categorized Lake Toba as meso-oligo-eutrophic lake with a consistent mesotrophic characteristics based on abundant nutrient availability at all sampling stations. Compared to the previous study carried out in 2009, the trophic state of Lake Toba has shifted from oligotrophic to mesotrophic which needs a special attention to prevent eutrophication by excessive phosphorus enrichment in future.

Keywords: *phosphorus, Trophic State Index, mesotrophic, eutrophication.*