Trophic state index and spatio-temporal analysis of trophic parameters of Laut Tawar Lake, Aceh, Indonesia

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Abstract. Laut Tawar Lake plays roles in the economy, ecology, health, energy, and aesthetics for the community around the lake. Anthropogenic activities in the catchment areas and the quality of the lake water impact the sustainability of the lake ecosystem. The lake covers an area of 5862 hectares and is used for capturing fisheries and aquaculture activities. The catchment area of 18878 hectares is used for plantations, rice fields, residential, forests, and shrubs. The anthropogenic activities potentially increase phosphorus input which can elevate the trophic state of the lake. This study aimed to determine the trophic state, to analyze trophic parameters spatially and temporally, and to analyze the influence and relationship between rainfall and trophic parameters. The result showed that Laut Tawar Lake has an eutrophic state. The trophic parameters did not differ spatially, which means no partial effect of the inlet on the lake water. The trophic parameters values were relatively identical in all parts of the lake water which was caused by the perfect mixture of water. Variations in trophic parameters were influenced by variability in rainfall temporally. The effect of rain on the trophic parameters forms a non-linear relationship. Rainfall below 200 mm month^{-1} can increase the phosphorus input into the lake water from the catchment area, increase the chlorophyll-*a* and decrease the Secchi disc visibility. Still, the rain above 200 mm month^{-1} causes an accumulation of the rainwater in the lake leading to a decrease in phosphorus and chlorophyll-*a* concentrations and an increase in Secchi disc visibility. This study concluded that low rainfall could increase phosphorus concentrations while high rainfall causes dilution of phosphorus concentrations in the water of the lake.
Key Words: anthropogenic, eutrophic, inlet, non-linear, rainfall.

Introduction. Laut Tawar Lake has economic significance for the community around the lake. The lake is a source of income for fishing communities through fisheries and aquaculture (Indra 2015; Marini & Hufiadi 2015; Muchlisin et al 2018; Adhar et al 2021a). In addition, it is also a tourist destination that provides economic benefits for the people around the lake. Ecologically, it is a source of biodiversity in aquatic biota, especially some endemic fish such as depik fish (*Rasbora tawarensis*), eyas fish (*Rasbora* sp.), and kawan fish (*Poropuntius tawarensis*) (Muchlisin et al 2010; Rahmandi et al 2015; Muchlisin et al 2018; Adhar 2020).

Most people in Takengon use water from the lake for drinking (Muchlisin et al 2018; Zamzami et al 2018). Besides, the lake outlet discharge that flows into Krueng Peusangan becomes a source of energy to drive the Peusangan Hydroelectric Power Plant turbine (Adhar 2020). The description above illustrates the significant roles of Laut Tawar Lake in economic, ecological, health, aesthetic, and energy terms. The sustainability of Laut Tawar Lake is crucial to be preserved as damage to the lake ecosystem will adversely impact those living around it.

Laut Tawar Lake ecosystem is increasingly threatened due to environmental pressures from anthropogenic activities resulting from the use of resources in the catchment area and water (Husnah & Fahmi 2015; Rahmandi et al 2015). The environmental pressures are caused by an increase in the human population leading to an increase in demand for food, housing, and energy, which eventually creates a high demand for water resources (Giri & Qiu 2016). Fishery management in Laut Tawar Lake has experienced overcapacity (Marini & Hufiadi 2015) and overfishing (Indra 2015; Muchlisin et al 2018). Floating net cage activities hurt the water quality of Laut Tawar Lake (Iriadi et al 2015a), producing phosphorus (P) waste due to excess feed (Adhar et al 2021a). These affect nutrient enrichment in Laut Tawar Lake.

Anthropogenic activities have highly increased the input of nitrogen (N) and P into the lake leading to eutrophication (Smith et al 2016). Nutrient loading into the lake is driven by human activities in the catchment area (Gorman et al 2014). Types of land use in the catchment area indicate water pollution (Sobolewski 2016), which varies in terms of location, time, weather, and source of pollution (Giri & Qiu 2016). The lake inlet draining several materials from the catchment area affects the lake's water quality. The water quality of the lake inlet depends on the land use in the catchment area. Its area of 18878 hectares has five types of uses: plantations, rice fields, settlements, shrubs, and forests (Muchlisin, et al 2018; Adhar 2020).

Agricultural activities in the catchment area of Laut Tawar Lake in the form of plantations covering an area of 4576 hectares (24.24%) and rice fields covering an area of 1061 hectares (5.62%) (Adhar 2020) are sources of pollutants that affect the quality of lake water. Water degradation is strongly associated with agricultural activities (Ribeiro et al 2014; Withers et al 2014; Sobolewski 2016; Giri & Qiu 2016; Hossain 2017; Camara et al 2019). Agricultural fertilizers and cultivation practices lead to nutrient enrichment downstream (Tanaka et al 2021). The main pollutants from agricultural land are nutrients and pesticides (O'Bannon et al 2013). Nutrients produced from agricultural land are N and P compounds (Ribeiro et al 2014; Matysik et al 2015; Crooks et al 2021). Agricultural land run-off has a major effect on lake eutrophication (Rahmani et al 2013). The pollutant load in the run-off flow is quite low in the dry season and very high in the rainy season (Ribeiro et al 2014; Hossain 2017), which is also affected by tillage (Ribeiro et al 2014).

Land use for residential in Laut Tawar Lake catchment area is 646 hectares (3.42%) (Adhar 2020). The urban area affects the quality of the lake water (Giri & Qiu 2016) because the population's activities pollute the lake (Sieńska et al 2016). It was indicated by the high concentration of biogenic compounds in urban drainage (Matysik et al 2015). Land use for settlement is the main source of water pollution (Camara et al 2019), so urbanization is the cause of eutrophication (Tanaka et al 2021). The human population is one of the attributes that have a primary influence on pollution control of Laut Tawar Lake (Iriadi et al 2015b).

The forest area also indicates water pollution (Camara et al 2019). There are 8034 hectares of forest (42.56%) and 4561 hectares of shrubs (24.16%) (Adhar 2020). The land use of forest and bushland has the potential to cause nutrient inputs to lake water. In addition to land-use activities, tourism activities in Laut Tawar Lake also contribute to increasing pollutant inputs (Iriadi 2015). Tourist has several negative effects leading to the degradation of the aquatic environment (Sieńska et al 2016).

Based on several flow inputs from the catchment area and activities in the water, Laut Tawar Lake has the potential to experience eutrophication, in the form of an increase in trophic state. This might be caused by an increase in nutrient inputs, especially N and P elements (Schindler 2012; Hollister et al 2016). N and P are key elements for the growth of phytoplankton in water bodies (Mamun & An 2017). The increased load of N and P discharged into the aquatic environment is responsible for the degradation of water from an oligotrophic state to a eutrophic or hypertrophic state (Smith et al 2016).

Furthermore, the water quality of Laut Tawar Lake is also affected by the resuspension of organic matter from the lake bottom. It is due to the characteristics of Laut Tawar Lake as a shallow lake (KLH 2008) with an average depth of 25.19 m (Husnah & Fahmi 2015), which has a constant water-sediment interaction (Gorman et al 2014). The growth of phytoplankton in the water of Laut Tawar Lake is also affected by the resuspension of organic matter containing P from the bottom of the lake. The abundance of phytoplankton in shallow lakes is potentially influenced by ambient P concentrations (Gorman et al 2014). The increase in the availability of P nutrients will increase the number of phytoplankton, which in turn will reduce the brightness of the water. These conditions encourage an increase in the trophic state of Laut Tawar Lake.

Trophic state assessment is needed to support strategic planning of water conservation and management (Opiyo et al 2019) as efforts to control algae blooms (Nojavan et al 2019). A trophic state needs to regulate the utilization and management of aquatic and fish resources (Husnah 2012). Capture fisheries or aquaculture activities must be based on a trophic state as a guide for environmental feasibility (Samuel & Adiansyah 2016). The lake trophic level describes the productivity of the lake system (Ayoade et al 2019) and the biological characteristics that integrate the hydro-ecology of lake water bodies (Adamovich et al 2019). The trophic state index provides insight into how nutrient and light availability controls phytoplankton development (Cunha et al 2013).

Several previous studies have shown that the trophic level of the water of Laut Tawar Lake is no longer in the category of nutrient-poor water (oligotrophic), but is increasingly moving towards a category above it. Data from August 1994, November 1994, and February 1995 indicate that the lake's trophic state is mesotrophic (Kartamihardja et al 1995). The sample taken in March-April 2010 categorized the water as eutrophic (Nurfadillah 2010). Likewise, data from March 2012 showed that the trophic state of Laut Tawar Lake was eutrophic (Husnah 2012). Moreover, data from May-October 2012 categorized it as mesotrophic leading to eutrophic (Hasri & Juandela 2012).

All of the studies only observed trophic parameters in a particular month or several months. Measurements were not taken for a year which could representatively describe the condition of Laut Tawar Lake according to the weather throughout the year. Therefore, this study aims to determine the trophic state of Laut Tawar Lake by observing data representing weather conditions throughout the year. In the study, the spatial analysis of trophic parameters was observed to decide the effect of input from the catchment area. Meanwhile, temporal analysis was used to observe the influence and relationship between weather, especially rainfall, and the trophic parameters of Laut Tawar Lake.

Material and Method

Description of the study sites. Laut Tawar Lake is a tectonic-type lake (Lehmusluoto & Machbub 1997) located in Aceh Tengah Regency, Aceh Province, Indonesia. The geographical location of the Laut Tawar Lake catchment area is 4^{o}31'50" - 4^{o}40'22" North latitude and 96^{o}48'15" - 97^{o}02'43" East longitude. The Laut Tawar Lake geographically is located between 4^{o}34'46"-4^{o}38'34" North latitude and 96^{o}51'25"-96^{o}59'48" East longitude (Adhar et al 2021a). The lake has a surface area of 5.862 hectares (Adhar 2020) as the largest lake in Aceh Province (Muchlisin et al 2018). The lake is at 1230 meters above sea level with an average depth of 25.19 meters and a maximum depth of 84.23 meters (Husnah & Fahmi 2015). Laut Tawar Lake catchment area of 18878 hectares has five types of land uses, namely plantations, rice fields, settlements, shrubs, and forests (Muchlisin et al 2018; Adhar 2020).

This study was conducted from October 2016 to September 2017 in Laut Tawar Lake area. Parameters observed included total phosphorus concentration (TP), chlorophyll-*a* concentration (Chl), and Secchi disc visibility (SD). Monthly samples of Laut Tawar Lake water were taken over one year at seven observation stations (see Figure 1). The observation stations were determined by purposive sampling based on land use in the sub-catchment area where the inlet flows into the lake and activities in the lake water. Table 1 describes the characteristics of each observation station.

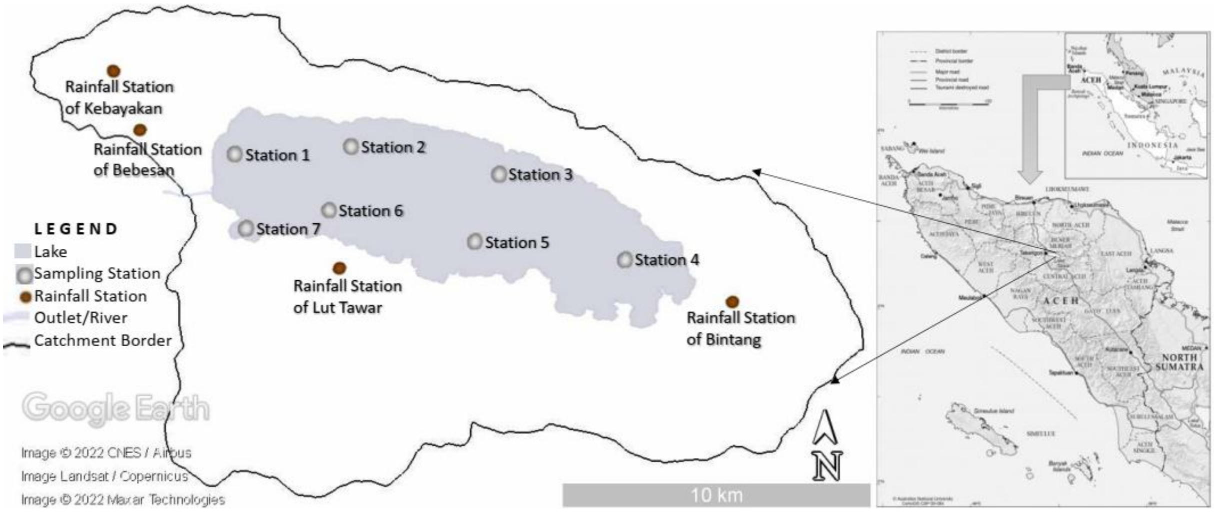

Figure 1. The map of the study location.

Table 1

The characteristics of each observation station

Station	*Characteristics: closest point to*
Station 1	The sub-catchment area dominated by residential and plantation land use
Station 2	The land use dominated by shrubs
Station 3	The water source from spring
Station 4	The sub-catchment area dominated by rice fields and plantations
Station 5	The sub-catchment area dominated by forest and shrubs
Station 6	The sub-catchment area dominated by forest and plantation land use
Station 7	The floating net cage area

Measurement and analysis. SD was observed at each station in situ. The black-and-white disk was lowered into the water column until it is no longer visible. This point was recorded as the first value. Then the second value was done by raising the Secchi disk from an invisible position until the visible point. The average of the two values was considered SD. The measurement was carried out several times to get the appropriate average value. During observations, water samples were also collected for analysis of TP and Chl.

TP and Chl were analyzed according to the standard method of APHA, AWWA, and WEF (2012). The Chl was determined by extracting chlorophyll-*a* in water samples using acetone. The absorption was measured at four wavelengths, namely 630, 647, 664, and 750 nm. TP analysis was carried out by oxidizing the sample with potassium persulfate under alkaline conditions and heated in an autoclave for 55 minutes at a temperature of 120^{o}C. It was then reacted with ammonium molybdate and potassium antimonial tartrate, and reduced by ascorbic acid, resulting in a blue molybdenum compound whose absorption was measured at a wavelength of 880 nm (APHA, AWWA, WEF 2012).

Rainfall data were collected from four rainfall monitoring stations in the catchment area of Laut Tawar Lake (Figure 1). The stations are Kebayakan, Lut Tawar, Bebesan, and Bintang Station. The average rainfall in Laut Tawar Lake area was calculated by the Thiessen Polygon method. It accounts for the weight of rainfall in each station representing the rainfall of the area around it (Kurniawan et al 2018). The Thiessen method assumes that measured amounts at any station could be applied halfway to the next station in any direction. It means that any point of rainfall was equal to the observed rainfall at the closest gauge. The center area of each polygon was weighed to find out the amount of rainfall in each station (Schumann 1998; Kang et al 2019).

Rainfall groups were classified based on the amount of rainfall according to the Oldeman classification. The criteria of the Oldeman classification are wet months if the average rainfall is more than 200 mm month^{-1}, dry months below 100 mm month^{-1}, and humid months between 100 and 200 mm month^{-1} (Ahmada et al 2020).

Data analysis Data were analyzed descriptively by tabulating tables and graphs. Rainfall data were tabulated based on the Oldeman classification criteria to classify the groups of dry months, humid months, and wet months. The TP, Chl, and SD graphics describe the highest and lowest values on the group of observation stations and observation time. The mean difference in each group of trophic parameters was compared in terms of its observation stations and observation time. In addition, normality and homogeneity were also tested to determine the use of the type of test, parametric or non-parametric. The mean difference in the observation station group showed a spatial difference while the mean difference in the observation time group showed a temporal difference. The closeness and linearity of the relationship between trophic parameters (TP, Chl, and SD) and rainfall were tested by correlation and linearity tests. A regression test was applied to obtain the effect of rainfall on trophic parameters.

The lake trophic state was determined using the trophic state variable and the Carlson model (Carlson 1977; Tibebe et al 2019; Lizotte et al 2021). The trophic state index proposed by Carlson (1977) is a method widely and often used in several lake studies over the last two decades (Liu et al 2012; Cunha et al 2013; Thomatou et al 2013; Hu et al 2014; Havens & Ji 2017; Lizotte et al 2021). Values of the trophic state index are computed based on the content of TP, Chl, and SD, which is valuable because calculation requires relatively few commonly measured lake water quality variables (Liu et al 2012; Sieńska et al 2016; Lizotte et al 2021).

Results. The total rainfall in the catchment area and Laut Tawar Lake during the study period was 2372 mm. It was the rainfall value for 12 months, and an average of 197.63 mm month^{-1} or 6.51 mm day^{-1}. Rainfall data for each month and Oldeman classification are presented in Table 2.

Table 2

Rainfall in Laut Tawar Lake area

Observation time	*Rainfall*		*Oldeman classification*
	mm month^{-1}	*mm day^{-1}*	
Oct 2016	70	2.25	Dry
Nov 2016	379	12.64	Wet
Dec 2016	164	5.29	Humid
Jan 2017	248	8.01	Wet
Feb 2017	107	3.83	Humid
Mar 2017	328	10.58	Wet
Apr 2017	237	7.91	Wet
May 2017	158	5.09	Humid
Jun 2017	114	3.81	Humid
Jul 2017	42	1.36	Dry
Agt 2017	105	3.38	Humid
Sep 2017	419	13.95	Wet
Average	197.63	6.51	

Source: Agriculture Office of Aceh Tengah Regency (2018) and Analysis (2020).

Table 2 presents the rainfall that occurred in Laut Tawar Lake Area from October 2016 to September 2017. The lowest rainfall occurred in July 2017 at 42 mm month^{-1} or 1.36 mm day^{-1}. The highest rainfall was in September 2017 at 419 mm month^{-1} or 13.95 mm day^{-1}. The grouping of rainfall values according to the Oldeman method showed two dry months, five humid months, and five wet months.

TP in the water of Laut Tawar Lake during the study ranged from 22 to 47 µg L^{-1} with an average of 36.04±7.56 µg L^{-1}. The average Chl obtained was 10.73±3.94 µg L^{-1} with a range between 5 and 19 µg L^{-1}. SD ranged from 2 to 5 meters with an average of

3.15±0.75 meters. The minimum, maximum, and average values of TP, Chl, and SD at each observation station are presented in Figure 2.

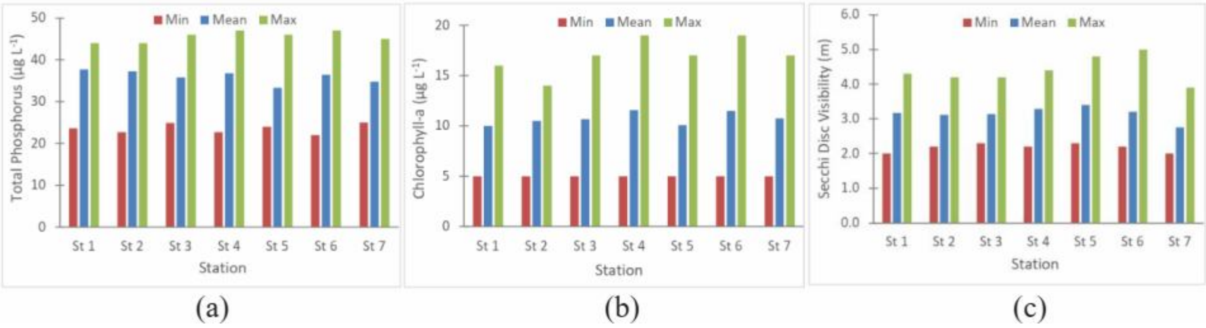

Figure 2 Total phosphorus (a), chlorophyll-*a* (b), Secchi disk visibility (c) in observation stations of Laut Tawar Lake.

Figure 2 presents the minimum, maximum, and average values of trophic parameters at each observation station. These describe the TP, Chl, and SD values at each station spatially. Station 1 showed the highest average TP of 37.75±6.62 µg L^{-1}, which ranges between 24 and 44 µg L^{-1}. The lowest average TP was 33.33±7.83 µg L^{-1} found at station 5 with a range of 24-46 µg L^{-1}. The highest average value of Chl was at station 4, which was 11.58±4.58 µg L^{-1} with values ranging between 5 and 19 µg L^{-1}. The lowest average Chl was obtained at station 1 with a value of 10.00±3.30 µg L^{-1}, and the values range between 5 and 16 µg L^{-1}. The lowest average SD was found at station 7 with a value of 2.76±0.63 meters, and the range was between 2 and 3.9 meters. The highest average SD was at station 5 with a value of 3.40±0.84 meters, ranging between 2.3 and 4.8 meters.

Quantitatively high TP content at station 1 was driven by the source of the inlet flow originating from residential and plantation land uses. The inlet of the urban area is the source of water pollution (Camara et al 2019) which contains high biogenic compounds (Matysik et al 2015). In addition, plantation land run-off contains many phosphorus nutrients (O'Bannon et al 2013; Ribeiro et al 2014; Matysik et al 2015; Crooks et al 2021), which come from agricultural fertilizers (Tanaka et al 2021).

Although station 1 had the highest TP value, the highest number of phytoplankton was found at station 4. The Chl represented the abundance of phytoplankton (Brezonik et al 2019). TP content in the water influences the number of phytoplankton (Gorman et al 2014; Mamun & An 2017; Brezonik et al 2019). TP input at station 4 comes from agricultural areas (rice fields and plantations) (O'Bannon et al 2013; Ribeiro et al 2014; Matysik et al 2015; Crooks et al 2021; Tanaka et al 2021), and the mixing of lake water from other inlet sources. The mixing lake water effect was suspected to be due to the high content of TP at station 1, but not followed by a high amount of Chl at the station. Instead, Chl was the highest at station 4.

In addition, the lowest SD was at station 7, not at station 4 or station 1, where the highest Chl and TP are, thus, strengthening the assumption that the lake water experienced homogeneous mixing. SD is a representation of water brightness (Brezonik et al 2019; Adhar et al 2021b) which is affected by the abundance of phytoplankton and the content of total suspended solids in the water of Laut Tawar Lake (Adhar et al 2021b). The low SD value at station 7 was caused by the location of floating net cage cultivation which produces phosphorus waste (Adhar et al 2021a), and there are many other suspended solids.

Observations of the trophic parameters of Laut Tawar Lake based on the times showed the highest TP in June 2017, the highest Chl in May 2017, and the lowest SD in April 2017. The average, minimum, and maximum values of TP, Chl, and SD, at each observation time, are presented in Figure 3.

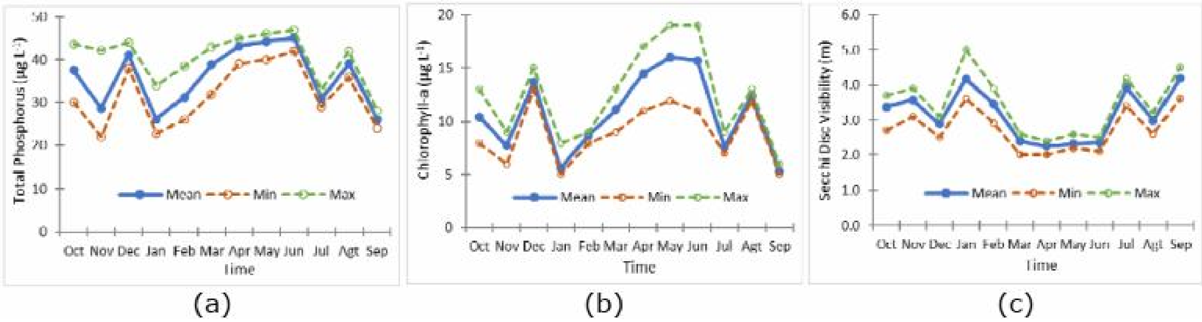

Figure 3. Total phosphorus (a), chlorophyll-*a* (b), and Secchi disk visibility (c) in observation time of Laut Tawar Lake.

Figure 3 graphics the minimum, maximum, and average values of the trophic parameters at each observation time. These describe the temporal fluctuation of TP, Chl, and SD values following the observation time. The highest average TP was in June 2017 at 45.14±1.95 µg L^{-1} with a range between 42 and 47 µg L^{-1}. The lowest average TP was in September 2016 at 26.00±1.29 µg L^{-1}, which ranges from 24 to 28 µg L^{-1}. Chl showed the highest average value in May 2017 of 16.00±2.71 µg L^{-1} ranging from 12 and 19 µg L^{-1}. The lowest average Chl was in September 2017, which was 5.29±0.49 µg L^{-1} ranging between 5 and 6 µg L^{-1}. The lowest average SD was in April 2017 at 2.26±0.14 meters, which ranges between 2.0 and 2.4 meters. The highest average SD was in September 2017 at 4.20±0.29 meters, which was from 3.6 to 4.5 meters.

Spatial and temporal analysis. The comparison test of TP between observation stations used the Kruskal-Wallis test. The test results showed no significant difference in the mean TP between observation stations. The mean TP between stations ranged from 33.33±7.83 to 37.75±6.62 µg L^{-1}. One-Way ANOVA Test was used to compare the mean of Chl. The test results showed no significant difference between the observation stations. The mean Chl value between stations ranged from 10.00±3.30 to 11.58±4.58 µg L^{-1}. To compare the SD, one-Way ANOVA test was also used. The test results showed no significant difference in the mean SD among the observation stations. The SD showed relatively identical values at all observation stations, where the mean SD ranges from 2.76±0.63 to 3.40±0.84 meters. Likewise, Chl and TP concentration at each station and at the same time of observation had relatively similar values.

The absence of differences in trophic parameter values among stations indicates no significant effect of inlets that drain several materials from catchment areas with different land uses. This phenomenon describes the state of Laut Tawar Lake, which has relatively identical water characteristics in all observation stations at the time. It was affected by the perfect mixing of lake water (Adhar et al 2021b). The assimilation was affected by water disturbance caused by wind (Andersen et al 2020). The lake morphometry, where the average depth of the lake is 25.19 meters (Husnah & Fahmi 2015), is in the shallow category (KLH 2008), so it is easy for water to be agitated by the wind. The depth of Laut Tawar Lake facilitates the perfect mixing of the water by the wind (Adhar et al 2021b) so that it has a constant water-sediment interaction (Gorman et al 2014). The agitating and mixing make the characteristics of the lake water relatively identical in all parts of Laut Tawar Lake.

Comparative analysis of mean TP in the observation time group used the Kruskal-Wallis test. The test results showed significant differences in mean TP among the observation times. Kruskal-Wallis test for mean Chl showed a significant difference among observation times. The comparative test for the mean SD in the observation time group used the Kruskal-Wallis test also showed a significant difference in the mean of SD among the observation times.

The trophic parameters in the observation time group were significantly different due to the difference of the weather at each observation time. The weather difference is closely related to the rainfall at the research location. The higher rainfall in the catchment area, the more nutrients will flow into the lake (Ribeiro et al 2014; Hossain 2017). The difference in the nutrient input during the observation time causes the TP concentration in the Laut Tawar Lake water to be temporally different. It also caused the difference in the number of phytoplankton and the SD during the observation time. Therefore, it can be concluded that the trophic parameter values of Laut Tawar Lake were temporally different and were influenced by rainfall.

Influence of rainfall. According to the Oldeman method, there are three criteria for rainfall. The dry month has the amount of rainfall below 100 mm month^{-1}, the humid month has between 100 and 200 mm month^{-1}, and the wet month has more than 200 mm month^{-1} (Ahmada et al 2020). During this study, it was found that there were two dry months, five humid months, and five wet months (see Table 1). The trophic parameter values of Laut Tawar Lake in each rainfall group are shown in Table 3.

Table 3

Trophic parameter values of Laut Tawar Lake in dry months, humid months, and wet months

Trophic parameters	*Dry month*	*Humid month*	*Wet month*
TP range (µg L^{-1})	28-44	26-47	22-45
TP mean (µg L^{-1})	34.21±5.15	40.23±5.63	32.57±8.11
Chl range (µg L^{-1})	7-13	8-19	5-17
Chl mean (µg L^{-1})	9.0±1.96	13.31±3.21	8.83±3.78
SD range (meter)	2.7-4.2	2.1-3.9	2.0-5.0
SD mean (meter)	3.64±0.43	2.80±0.47	3.32±0.91

Table 3 shows the trophic parameter values of Laut Tawar Lake in each rainfall group. The highest mean TP value found in the humid month was 40.23±5.63 µg L^{-1}. The Kruskal-Wallis test showed a difference in the mean TP among the rainfall groups. Post Hoc test showed a significant difference between TP in dry months and TP in humid months, and between TP in humid months and TP in wet months. It showed that changes in the TP concentration in the Laut Tawar Lake water were related to the amount of rainfall. Rainfall in the catchment area causes an increase in the input of TP into the lake water, resulting in an increase in the TP concentration. The linearity test on rainfall and TP concentration resulted in a non-linear relationship. It showed that an increase in rainfall was not always followed by an increase in the TP concentration. It indicated that the mean TP in the dry month was not significantly different from the mean TP in the wet month. The wet month group experienced high rainfall (> 200 mm month^{-1}) but the TP concentration showed no significant difference in dry months, which has lower rainfall (< 100 mm month^{-1}).

The highest value of mean Chl was in the humid month, 13.31±3.21 µg L^{-1}. The Kruskal-Wallis test showed a significant difference in the mean Chl between the rainfall groups. Post Hoc test showed the Chl in the dry month was significantly different from the Chl in the humid month, and the Chl in the humid month was significantly different from the Chl in the wet month. Changes in the Chl values were related to rainfall although the relationship was indirect. The number of phytoplankton is affected by the availability of nutrient TP (Filstrup & Downing 2017; Atique & An 2019; Ma et al 2020; Adhar et al 2022), so the effect of rainfall on Chl was not different from TP parameter. The relationship between the rain and Chl formed was not linear, as evidenced by the linearity test. Also, there was no significant difference between Chl in the dry month and the wet month.

SD in the rainfall group was the lowest in the wet month with 2.80±0.47 m. The Kruskal-Wallis test showed that there were significant differences among the observation times. The Post Hoc Test showed that SD in the dry month was significantly different from the SD in the humid month, and the SD in humid month was significantly different from the SD in the wet month. The results were also not different from those obtained in the comparative analysis of TP and Chl parameters. It was because the effect of rainfall on SD did not occur directly. After all, SD is affected by Chl and suspended matter

(Fleming-Lehtinen & Laamanen 2012; Brezonik et al 2019; Harvey et al 2019; Adhar et al 2021b; Adhar et al 2022). The linearity test results showed a non-linear relationship between rainfall and SD. Likewise, according to the Kruskal-Wallis test, there was no significant difference in the mean SD in dry months and SD in wet months.

The effect of rainfall on the trophic parameters of Laut Tawar Lake was explained by non-linear regression analysis. There are several models of tests which can explain the relationship, however, in this study the second-order polynomial model was used as it is the most appropriate model and has the highest correlation coefficient values. The graph of the relationship between rainfall and trophic parameters of Laut Tawar Lake showed in Figure 4.

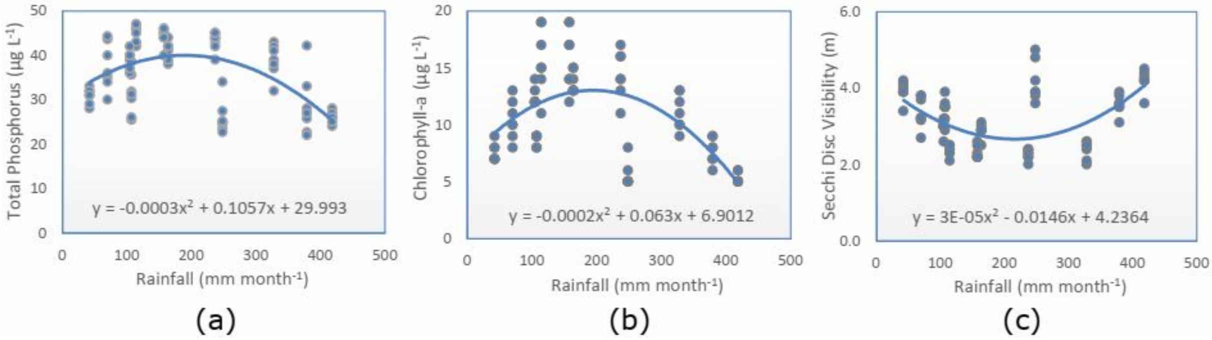

Figure 4. The relationship model rainfall and trophic parameters of Laut Tawar Lake.

Figure 4 displays a graph of the relationship between rainfall and trophic parameters of Laut Tawar Lake. Graph 4(a) for the TP parameter showed an increasing trend showing the increase of rainfall and its decrease after reaching a certain peak point. The decrease in TP was due to an increase in rainwater entering the lake. It causes the dilution of several dissolved materials, including TP. This decrease in TP does not mean a reduction in TP in the water but rather an increase, just an increase in the amount of water (solvent) causing a decrease in the concentration of TP (solute). The model showed an R-value (correlation coefficient) of 0.57, which means it has a moderate level of relationship and a coefficient of determination (R square) of 0.33.

Similar to TP, Chl in the Laut Tawar Lake water experienced the same thing as shown in Figure 4(b). It showed that TP nutrient availability influenced the presence of phytoplankton. Although Chl is affected by the availability of nutrient TP, Chl was related to rainfall indirectly. Figure 4(b) showed a trendline pattern in which an increase in rainfall causes an increase in Chl. After passing a certain point, there was a decrease in the Chl. It was a dilution of Chl due to rainwater input into Laut Tawar Lake. This condition does not describe the decrease in Chl because its amount follows the availability of TP nutrients in the water. The correlation coefficient value in the model was 0.60, which means it has a moderate level of relationship. The value of the determinant coefficient was 0.36.

The presence of Chl in the water affects the SD, but it was also indirectly related to rainfall. The rainfall effect on SD was non-linear regression as shown in Figure 4(c). The trendline in Figure 4(c) shows an increase in rainfall followed by a decrease in SD, and after reaching a certain point, there was an increase in the SD value with an increase in rainfall. It describes a certain amount of rain causing an increase in the input of materials that block the sunlight penetration into the water of Laut Tawar Lake. Materials that block the penetration of sunlight are Chl and suspended materials (Pal et al 2015; Brezonik et al 2019; Adhar et al 2021b).

An increase in TP nutrient input causes an increase in Chl (Adhar et al 2022) and an increase in suspended matter input due to an escalation in rainfall. In addition, an increase in the suspended matter and TP also occurred with an escalation in the water input at a high level of rain. It causes the dilution of the materials in the water. Reduced concentration of the suspended matter and Chl results in sunlight penetrating the water column easily. It causes an increase in SD when rainfall increases. The correlation coefficient value in the model was 0.56, which means it has a moderate level of relationship. The value of the determinant coefficient was 0.32.

Based on the description above, the rainfall below 200 month^{-1} caused an increase in TP and Chl and a decrease in SD in the water of Laut Tawar Lake. The rain above 200 mm month^{-1} caused a decrease in TP, Chl, and an increase in SD in the water of Laut Tawar Lake. These happened due to the material input and the dilution of the material caused by rainwater. Rainfall affects the amount of TP nutrient input from the catchment area into the lake on the one hand, but on the other hand, an increase in rainwater input into the lake causes a decrease in TP and Chl, thereby increasing the value of SD. The equation model obtained for each parameter relationship between trophic state and rainfall cannot be considered appropriate for predicting TP, Chl, and SD of Laut Tawar Lake. It was the determinant coefficient value of the equation, which was respectively 0.33, 0.36, and 0.32.

Trophic state. The trophic state describes the productivity of the lake system (Ayoade et al 2019), which can provide information to support the planning of conservation and management strategies (Opiyo et al 2019). The lake trophic state was determined using the trophic state variables of the Carlson model (Tibebe et al 2019; Lizotte et al 2021). The trophic state index values are valuable because calculation requires a few relatively commonly measured lake water quality variables such as TP, Chl, and SD (Liu et al 2012; Sieńska et al 2016; Lizotte et al 2021.

The trophic parameters values of Laut Tawar Lake obtained during the study were an average TP of 36.04±7.56 g L^{-1}, an average Chl of 10.73±3.94 g L^{-1}, and SD of 3.15±0.75 m. The values applied to the Carlson model equation obtained a trophic state index value of 51. It was categorized as eutrophic which attributes lower boundary of classical eutrophy: decreased transparency, warm-water fisheries only (Carlson 1977; Carlson 1984; Prasad & Siddaraju 2012). The value of the trophic state index was the average value of the trophic parameters of Laut Tawar Lake as a whole during the study, which was the average value for one year. When viewed temporally in that period, there was a variation in the value of the trophic state index. The monthly variation of the trophic state index and rainfall is described in Figure 5.

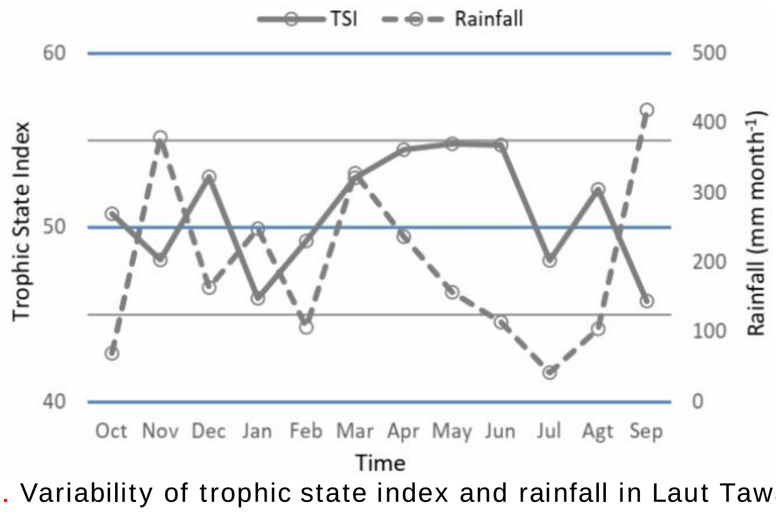

Figure 5. Variability of trophic state index and rainfall in Laut Tawar Lake.

Figure 5 shows the variation of the trophic state index and rainfall in Laut Tawar Lake. Based on the graph, the lowest trophic state index value in January 2017 and September 2017 was 46. The highest trophic state index value in May and June 2017 was 55. Most of the trophic state index values of Laut Tawar Lake appeared to be below 50, which means it was in the mesotrophic classification. The trophic state index of Laut Tawar Lake that was mesotrophic was in November, January, February, July, and September. Generally, the graph also showed an increase in rainfall followed by a decrease in the trophic state index value. It was due to an escalation in the amount of rainwater that caused a decrease in TP, Chl, and an increase in SD.

Conclusions. The trophic state of Laut Tawar Lake was eutrophic with the trophic state index value of 51. The trophic parameters of Laut Tawar Lake were not spatially different, which means that there was no partial effect of the inlet flowing into the lake water, and the value of trophic parameters was relatively identical in all parts of the Laut Tawar Lake water. These were due to the water of Laut Tawar Lake experiencing perfect agitating and mixing. Variations in trophic parameter values occurred temporally, which were influenced by variations in rainfall. The effect of rain on the trophic parameters of Laut Tawar Lake formed a non-linear relationship. Rainfall below 200 mm month^{-1} increased TP and Chl and reduced the value of SD in Laut Tawar Lake. These happened because there was an increase in nutrient phosphorus input from the catchment area through the lake inlet. TP and Chl decreased, and SD increased when rainfall was above 200 mm month^{-1}. There was an increase in the input of rainwater into the lake, which caused a dilution of dissolved materials in the water of Laut Tawar Lake.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Adamovich B. V., Medvinsky A. B., Nikitina L. V., Radchikova N. P., Mikheyeva T. M., Kovalevskaya R. Z., Veres Y. K., Chakraborty A., Rusakov A. V., Nurieva N. I., Zhukova T. V., 2019 Relations between variations in the lake bacterioplankton abundance and the lake trophic state: evidence from the 20-year monitoring. Ecological Indicators 97:120-129.

Adhar S., 2020 [Nitrogen and phosphorus dynamics model as an effort to control eutrophication of Laut Tawar Lake, central Aceh]. Sekolah Pasca Sarjana Universitas Sumatera Utara, 145 pp. [in Indonesian]

Adhar S., Rusydi R., Mainisa, Erlangga, Khalil M., Ayuzar E., 2021a [Phosphorus waste analysis of floating net cages in Laut Tawar Lake, central Aceh]. Serambi Engineering 6(3):2024-2032. [in Indonesian]

Adhar S., Barus T. A., Nababan E. S. N., Wahyuningsih H., 2021b The waters transparency model of Lake Laut Tawar, Aceh, Indonesia. IOP Conference Series: Earth and Environmental Science 869(1):012021.

Adhar S., Erlangga, Rusydi R., Mainisa, Khalil M., Muliani, Ayuzar E., Hatta M., 2022 [Modeling the trophic state of Laut Tawar Lake, central Aceh]. Serambi Engineering 7(2):2841-2851. [in Indonesian]

Ahmada B., Rahmah C. N., Larasati L. A., Muchlis L., Qonita M., Khoiruluswati N. M., Rohmah S., Rahayu T. D. K., Nurjani E., 2020 Climate-based crop pattern determination using Standard Precipitation Index (SPI) and the Oldeman classification in Sangiran Site. IOP Conference Series: Earth and Environmental Science 451:012019.

Andersen M. R., de Eyto E., Dillane M., Poole R., Jennings E., 2020 13 years of storms: an analysis of the effects of storms on lake physics on the Atlantic fringe of Europe. Water 12:318.

APHA, AWWA, WEF, 2012 Standard methods for examination of water and wastewater. 22nd edition. Washington: American Public Health Association, 724 pp.

Atique U., An K. G., 2019 Reservoir water quality assessment based on chemical parameters and the chlorophyll dynamics in relation to nutrient regime. Polish Journal of Environmental Studies 28(3):1043-1061.

Ayoade A. A., Osuala B. O., Adedapo T. A., 2019 Physico-chemical parameters, chlorophyll a and phytoplankton community as trophic state indices of two tropical lakes, southwestern Nigeria. EurAsian Journal of BioSciences 13(1):15-22.

Brezonik P. L., Bouchard Jr. R. W., Finlay J. C., Griffin C. G., Olmanson L. G., Anderson J. P., Arnold W. A., Hozalski R., 2019 Color, chlorophyll *a*, and suspended solids effects on Secchi depth in lakes: implications for trophic state assessment. Ecological Applications 29(3):e01871.

Camara M., Jamil N. R., Abdullah A. F. B., 2019 Impact of land uses on water quality in Malaysia: a review. Ecological Processes 8:10.
Carlson R. E., 1977 A trophic state index for lakes. Limnology and Oceanography 22(2):361-369.
Carlson R. E., 1984 The trophic state concept: a lake management perspective. Lake and Reservoir Management 1(1):427-430.
Crooks E. C., Harris I. M., Patil S. D., 2021 Influence of land use land cover on river water quality in rural North Wales, UK. Journal of the American Water Resources Association 57(3):357-373.
Cunha D. G. F., do Carmo Calijuri M., Lamparelli M. C., 2013 A trophic state index for tropical/subtropical reservoirs (TSI_{tsr}). Ecological Engineering 60:126-134.
Filstrup C. T., Downing J. A., 2017 Relationship of chlorophyll to phosphorus and nitrogen in nutrient-rich lakes. Inland Waters 7(4):385-400.
Fleming-Lehtinen V., Laamanen M., 2012 Long-term changes in Secchi depth and the role of phytoplankton in explaining light attenuation in the Baltic Sea. Estuarine, Coastal and Shelf Science 102-103:1-10.
Giri S., Qiu Z., 2016 Understanding the relationship of land uses and water quality in twenty first century: a review. Journal of Environmental Management 173:41-48.
Gorman M. W., Zimmer K. D., Herwig B. R., Hanson M. A., Wright R. G., Vaughn S. R., Younk J. A., 2014 Relative importance of phosphorus, fish biomass, and watershed land use as drivers of phytoplankton abundance in shallow lakes. Science of the Total Environment 466-467:849-855.
Harvey E. T., Walve J., Andersson A., Karlson B., Kratzer S., 2019 The effect of optical properties on Secchi depth and implications for eutrophication management. Frontier in Marine Science 5:496.
Hasri I., Juandela R., 2012 [Evaluation of bio-limnology and ecological niche of fish communities to determine types of fish to be stocked in Laut Tawar Lake]. Laporan Penelitian Hibah Bersaing Tahun 2012, Medan: Kopertis Wilayah I, 51 pp. [in Indonesian]
Havens K., Ji G., 2017 Inferences about seston composition and phytoplankton limiting factors during recovery of a large shallow lake from hurricane impacts. Inland Waters 7(2):236-247.
Hollister J. W., Milstead W. B., Kreakie B. J., 2016 Modeling lake trophic state: a random forest approach. Ecosphere 7(3):e01321.
Hossain M. S., 2017 Impact of land use change on stream water quality: a review of modeling approaches. Journal of Research in Engineering and Applied Sciences 2(1):1-6.
Husnah, 2012 [Determination of application index TRIX trophic status in Laut Tawar Lake, central District Aceh, Aceh Province]. Prosiding Seminar Nasional Limnologi VI Tahun 2012, Bogor, pp. 711-719. [in Indonesian]
Husnah, Fahmi Z., 2015 [Environmental characteristics and pollution status of Laut Tawar Lake]. In: Pengelolaan sumberdaya perikanan danau Laut Tawar Aceh Tengah. Wiadnyana N. N., Kamal M. M. (eds), Takengon: Amafrad Press, pp. 116-180. [in Indonesian]
Hu Z., Guo L., Liu T., Chuai X., Chen Q., Shi F., Jiang L., Yang L., 2014 Uniformisation of phytoplankton chlorophyll-*a* and macrophyte biomass to characterise the potential trophic state of shallow lakes. Ecological Indicators 37(A):1-9.
Indra, 2015 [Study of fisheries conditions in Laut Tawar Lake, Aceh Tengah]. Agrisep 16(2):62-69. [in Indonesian]
Iriadi R., 2015 [Model of pollution control in Laut Tawar Lake waters in Aceh Tengah Regency]. Bogor: Sekolah Pascasarjana Institut Pertanian Bogor, 166 pp. [in Indonesian]
Iriadi R., Riani E., Pramudya B., Fahrudin A., 2015a The effect of cage culture on water quality of Laut Tawar Lake in Aceh Tengah District, Indonesia. Environmental Science 4(5):261-263.
Iriadi R., Riani E., Pramudya B., Fahrudin A., 2015b [Evaluation of pollution control in Laut Tawar Lake waters in Aceh Tengah Regency]. Limnotek 22(1):64-75. [in Indonesian]

Kang B. S., Yang S. K., Kang M. S., 2019 A comparative analysis of the accuracy of areal precipitation according to the rainfall analysis method of mountainous streams. Journal of Environmental Science International 28(10):841-849.
Kartamihardja E. S., Satria H., Sarnita A. S., 1995 [Limnology and fish production potential of Laut Tawar Lake, Aceh Tengah]. Jurnal Penelitian Perikanan Indonesia 1(3):11-25. [in Indonesian]
KLH, 2008 [Lake ecosystem management guidelines]. Jakarta: Kementerian Negara Lingkungan Hidup, 55 pp. [in Indonesian]
Kurniawan B., Ruhiat Y., Septiyanto R. F., 2018 [Application of the Thiessen Polygon method to detect rainfall distribution in Tangerang Regency]. Untirta 2(1):122-130. [in Indonesian]
Lehmusluoto P., Machbub B., 1997 National inventory of the major lakes and reservoirs in Indonesia: general limnology. Research Institute for Water Resources Development, Ministry of Public Works, Agency for Research and Development, Helsinki, 69 pp.
Liu W., Zhang Q., Liu G., 2012 Influences of watershed landscape composition and configuration on lake-water quality in the Yangtze River basin of China. Hydrological Processes 26(4):570-578.
Lizotte Jr. R. E., Yasarer L. M. W., Bingner R. L., Locke M. A., Knight S. S., 2021 Long-term Oxbow Lake trophic state under agricultural best management practices. Water 13(8):1123.
Ma M., Jia J., Hu Y., Yang J., Lu Y., Shi K., Gao Y., 2020 Changes in chlorophyll *a* and its response to nitrogen and phosphorus characteristics over the past three decades in Poyang Lake, China. Ecohydrology 14(3):e2270.
Mamun M., An K. G., 2017 Major nutrients and chlorophyll dynamics in Korean agricultural reservoirs along with an analysis of trophic state index deviation. Journal of Asia-Pacific Biodiversity 10(2):183-191.
Marini M., Hufiadi, 2015 [Utilization of Laut Tawar Lake fishery resources]. In: Pengelolaan sumberdaya perikanan danau Laut Tawar Aceh Tengah. Wiadnyana N. N., Kamal M. M. (eds), Takengon: Amafrad Press, pp. 224-251. [in Indonesian]
Matysik M., Absalon D., Ruman M., 2015 Surface water quality in relation to land cover in agricultural catchments (Liswarta River basin case study). Polish Journal of Environmental Studies 24(1):175-184.
Muchlisin Z. A., Musman M., Azizah M. N. S., 2010 Length-weight relationships and condition factors of two threatened fishes, *Rasbora tawarensis* and *Poropuntius tawarensis*, endemic to Lake Laut Tawar, Aceh Province, Indonesia. Journal of Applied Ichthyology 26(6):949-953.
Muchlisin Z. A., Hasri I., Batubara A. S., 2018 A mini review on endemic and threatened fish *Rasbora tawarensis* in Lake Laut Tawar, Indonesia. IOP Conference Series: Earth and Environmental Science 216:012045.
Nojavan A. F., Kreakie B. J., Hollister J. W., Qian S. S., 2019 Rethinking the lake trophic state index. PeerJ 7:e7936.
Nurfadillah, 2010 [Dynamics of phytoplankton community structure and trophic status of Laut Tawar Lake waters, Aceh Tengah Regency]. Bogor: Sekolah Pascasarjana Institut Pertanian Bogor, 92 pp. [in Indonesian]
O'Bannon C., Carr J., Seekell D. A., D'Odorico P., 2013 Globalization of agricultural pollution due to international trade. Hydrology and Earth System Sciences Discussions 10(8):11221-11239.
Opiyo S., Getabu A. M., Sitoki L. M., Shitandi A., Ogendi G. M., 2019 Application of the Carlson's trophic state index for the assessment of trophic status of lake Simbi ecosystem, a deep alkaline-saline lake in Kenya. International Journal of Fisheries and Aquatic Studies 7(4):327-333.
Pal S., Das D., Chakraborty K., 2015 Colour optimization of the secchi disk and assessment of the water quality in consideration of light extinction co-efficient of some selected water bodies at Cooch Behar, West Bengal. International Journal of Multidisciplinary Research and Development 2(3):513-518.
Prasad A. G. D., Siddaraju, 2012 Carlson's trophic state index for the assessment of trophic status of two lakes in Mandya district. Advances in Applied Science Research 3(5):2992-2996.

Rahmandi, Koeshendrajana S., Muchlisin Z. A., 2015 [Overview and synthesis]. In: Pengelolaan sumberdaya perikanan danau Laut Tawar Aceh Tengah. Wiadnyana N. N., Kamal M. M. (eds), Takengon: Amafrad Press, pp. 1-13. [in Indonesian]
Rahmani T., Poorbagher H., Javanshir A., Kamangar B. B., 2013 Effects of agriculture, tourism and the dam on eutrophic status of the Zerebar Lake, Iran. International Journal of Advanced Biological and Biomedical Research 1(4):403-420.
Ribeiro K. H., Favaretto N., Dieckow J., Souza L. C. P., Minella J. P. G., de Almeida L., Ramos M. R., 2014 Quality of surface water related to land use: a case study in a catchment with small farms and intensive vegetable crop production in southern Brazil. Soil Use and Management 38(2):656-668.
Samuel, Adiansyah, 2016 [Water quality, trophic status and potential of fish production in the Lake Diatas, West Sumatera]. Jurnal Penelitian Perikanan Indonesia 22(2):83-94. [in Indonesian]
Schindler D. W., 2012 The dilemma of controlling cultural eutrophication of lakes. Proceedings: Biological Sciences 279(1746):4322-4333.
Schumann A. H., 1998 Thiessen polygon. In: Hydrology and Lakes. Encyclopedia of Earth Science. Springer, Dordrecht pp. 648-649.
Sieńska J., Dunalska J., Łopata M., Parszuto K., Tandyrak R., 2017 Trophic state and recreational value of Lake Mikołajskie. Limnological Review 16(3):147-154.
Smith V. H., Wood S. A., McBride C. G., Atalah J., Hamilton D. P., Abell J., 2016 Phosphorus and nitrogen loading restraints are essential for successful eutrophication control of Lake Rotorua, New Zealand. Inland Waters 6(2):273-283.
Sobolewski W., 2016 Effect of agricultural land use on the water quality of Polish lakes: a regional approach. Polish Journal of Environmental Studies 25(6):2705-2710.
Tanaka Y., Minggat E., Roseli W., 2021 The impact of tropical land-use change on downstream riverine and estuarine water properties and biogeochemical cycles: a review. Ecological Processes 10:40.
Thomatou A. A., Triantafyllidou M., Chalkia E., Kehayias G., Konstantinou I., Zacharias I., 2013 Land use changes do not rapidly change the trophic state of a deep lake. Amvrakia Lake, Greece. Journal of Environmental Protection 4(5):426-434.
Tibebe D., Kassa Y., Melaku A., Lakew S., 2019 Investigation of spatio-temporal variations of selected water quality parameters and trophic status of Lake Tana for sustainable management, Ethiopia. Microchemical Journal 148:374-384.
Withers P. J. A., Neal C., Jarvie H. P., Doody D. G., 2014 Agriculture and eutrophication: where do we go from here? Sustainability 6(9):5853-5875.
Zamzami, Azmeri A., Syamsidik S., 2018 [Clean water distribution network system of PDAM Tirta Tawar, Aceh Tengah Regency]. Jurnal Arsip Rekayasa Sipil dan Perencanaan 1(1):132-141. [in Indonesian]

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