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Original Research

Water Quality and Trophic Status to Estimate Fish Production Potential for Sustainable Fisheries in Lake Poso, Central Sulawesi

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Abstract

Lake Poso is a tectonic lake and the third largest of the lake in Indonesia, and is a potential area for endemic fish resources and tropical eels, disturbance to ecosystem balance in the form of habitat destruction and unfriendly fishing techniques will affect the existence of these resources. This study aimed to determine and evaluate the current condition of water quality, trophic status, and potential for fish production in Lake Poso. Observations were conducted in 2021 in five stations with random purposive methods sampling. The observed main parameters were water quality such as depth, transparency, temperature, conductivity, pH, dissolved oxygen, alkalinity, hardness, phosphate, nitrate, ammonia, and chlorophyll-a. The results showed that the characteristics of the water quality parameters and trophic status index, classified as waters were good for the life of fish and other organisms. The productivity rate of the lake waters seen from the value of the trophic status index was 46.18 which classified the waters at a mesotrophic level. The potential for fish production was low with numbers ranging from 2445-2605 tons/year and an average of 2545 tons/year. Finally, to maintain aquatic biological resources and sustainable fisheries in Lake Poso are needed (a) maintaining the value trophic state index in condition oligotrophic and mesotrophic, (b) protecting the habitat around the lake by maintaining the optimal vegetation limits, (c) maintaining the aquaculture activities so it no growth up and water condition keep stable and (d) maintaining the capture endemic fish species with traditional fishing gear methods.

Keywords: water quality, trophic status index, fish production, sustainable fisheries, Lake Poso

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Introduction

The main lakes on the island of Sulawesi such as Lake Poso, Lake Matano, Lake Towuti, and Lake Mahalona are famous for having many endemic fish species [1-5]. However, the increase in time and ecological pressure will cause some changes in the biological and non-biological resources in the lake waters. These changes can include changes in water quality, water fertility rates, stocks, composition, and fish production potential. In the world of research and management of aquatic resources, it needs to be conserved, while if there are negative changes, it is necessary to increase efforts in the context of sustainable use.

The biodiversity of fish in the inland waters of Sulawesi in 2004 showed that the composition of fish was dominated by the fish species introduced [6, 7]. [8, 9] describes Indonesia as the number three mega-biodiversity country in the world with 1,193 species of fish with 120 endemic fish species. Indonesian freshwater fish inhabit three geographic distribution areas (Sundanese, Wallace, and Sahul) bounded by two virtual lines: the Wallace Line and the Weber Line which have their species characteristics [8, 10]. In addition to endemic fish species, Lake Poso has several typical fish that grow fast and have important economic value for the surrounding community. This is one of the threats to the existence of endemic fish that have a high biodiversity value [11]. Lake Poso is a tectonic lake [12] and the third largest after Lake Toba in North Sumatra and Lake Towuti in South Sulawesi [13, 14]. Lake Poso has a depth of up to 510 meters, an area of 368.9 km^2 or 39,890 hectares, and is located at an altitude of 657 meters above the level sea [15].

The water of Lake Poso is very clear and not cloudy despite flooding in the rivers flowing into the lake. The activities of the people living around Lake Poso include agriculture, tourism, fisheries, transportation, and settlements. The community's fishing activities are raising various types of fish (carp, tilapia, eel) in floating and fishing activities. The natural condition that is complemented by the life of the surrounding community provides added value to Lake Poso as a natural tourist attraction in Poso Regency and Central Sulawesi Province. The waters of Lake Poso and the surrounding terrestrial habitat are one of the lake ecosystems on Sulawesi Island that have a high wealth of organisms [16]. Therefore, many types of flora and fauna are unique and endemic and attract the attention of many biological researchers. Water quality is one of the problems that need to be maintained, currently, the trophic status of the Poso watershed based on nutrient values and chlorophyll-a is oligotrophic to eutrophic [17]. The trophic status of Lake Poso waters based on the Carlson trophic status Index has a value between 42.94-53.05, this condition is mesotrophic to mid-eutrophic and the status in recent years has been disturbed in the balance of the ecosystem with indicators of a high erosion sedimentation rate [14]. The assessment of surface water quality in lakes, rivers, and reservoirs is a major issue for environmental monitoring and management and fish sustainability [18-21]. In fact, nutrients (nitrogen and phosphorus) have major problems in fresh water and can be explored and used as a basis for managing water [22-24]. Eutrophication has multidimensional consequences related to ecosystem water quality, human health, and economic and social impacts [25], as happened in Lake Maninjau, West Sumatera, Indonesia [26]. Therefore, understanding, efficient assessment, and eutrophication control are essential [25].

Capture fisheries activities carried out by fishing communities are generally still on a small scale using equipment methods and traditional simple fishing [27]. The dominant types of fishing gear used are gill nets, cast nets, long lines, fishing rods, and spears. With the establishment of Lake Poso as one of the nine lakes prioritized as a pilot for lake management, it is necessary to study various aspects of fisheries and other factors such as environmental changes in the waters and pollution factors both industrial and household which pose a serious threat to fish resources and water quality of Lake Poso. This study aims to assess and evaluate the current state of water quality, trophic status, and fish production potential in the waters of Lake Poso.

Material and Methods

Study Site and Sampling

The study was conducted in 2021 in Lake Poso, Poso Regency, Central Sulawesi (Fig. 1). The research is a field survey and analysis in the laboratory. In this study, 5 research stations were determined and selected purposively. The names, coordinates, and descriptions of the 5 predetermined research stations are listed in Table 1.

Parameters and Data Analysis

The physicochemical and biological parameters of the measured waters, as well as the materials, tools, and methods used are listed in Table 2. The parameters consist of depth, transparency, temperature, conductivity, pH, dissolved oxygen, alkalinity, hardness, phosphate, nitrate, ammonia, and chlorophyll-a. Methods and equipment for measuring water quality refer to the book "Standard Methods for Water and Wastewater Examination" [28]. Data analysis was performed by using XLSTAT 2023 software. Principal Component Analysis (PCA) is an important step to avoid the multi-linearity of independent variables. The dependent variable was chlorophyll, phosphate, and transparency.

The trophic state of the waters is analyzed by calculating the value of the trophic state index (TSI index) formulated by [29] with the following series formula:

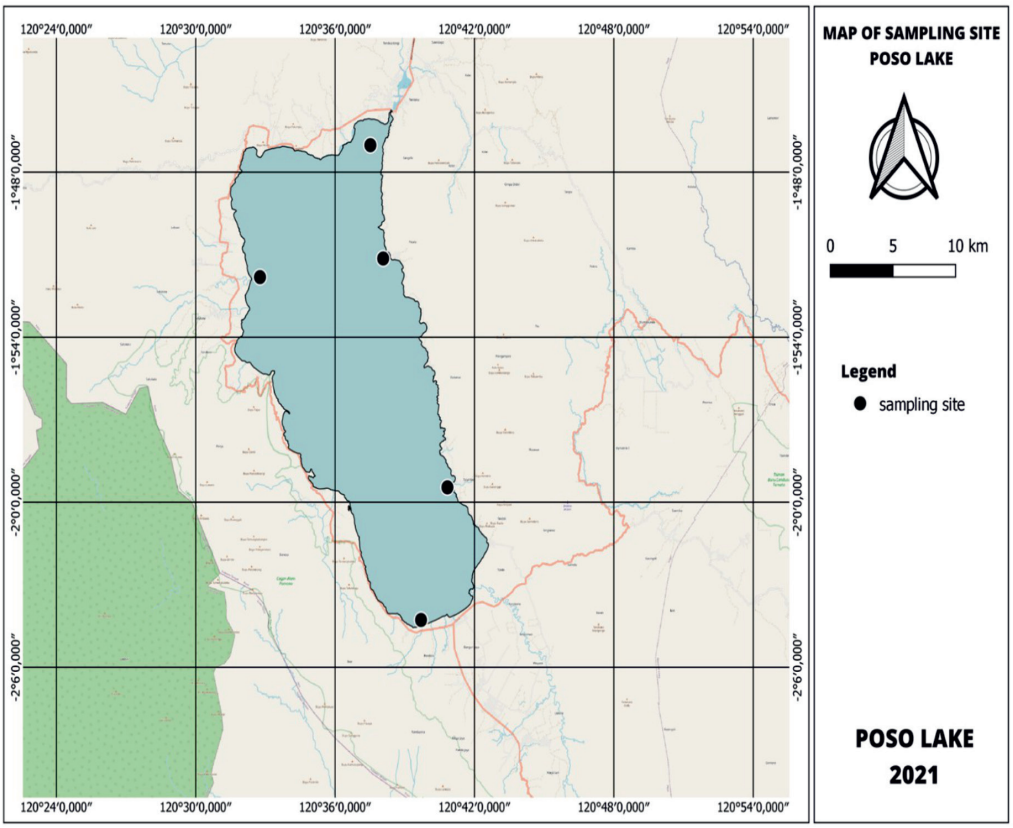

Fig. 1. Sampling sites in Lake Poso.

$$TSI = (TSI\text{-}SD + TSI\text{-}TP + TSI\text{-}Chl)/3 \quad (1)$$

TSI = Carlson Trophic State Index, TSI-SD = 60 – 14.41 * Ln [SD], where SD = transparency of water in meters; TSI-TP = 4.15 + 14.42 * Ln [TP], where TP = total phosphorus in µg/liter;
TSI-Chl = 30.6 + 9.81 * Ln [Chl], where Chl = chlorophyll-a concentration in µg/liter.

Based on TSI values, lakes are classified as oligotrophic (low-productive), mesotrophic (moderately productive), and eutrophic (highly productive). The Carlson's water state criteria are classified in productivity levels i.e. very low, low, medium, and high (Table 3).

Fish production potential is estimated using the formula proposed by [30], namely:

Table 1. Name, Coordinates, and Description of sampling sites in Lake Poso.

No	Name of Station	Coordinates	Sampling sites details
1	Koburo	S 01^0 49.418^1 E 120^0 31,774^1 Altitude: 505 m	Hilly area with a rocky bottom, steep coast, no water plants, well away from settlements, and the forest is still quite good.
2	Bo'e	S 02^0 04.446^1 E 120^0 39,740^1 Altitude: 517 m	Sloping rocky sandy beach area, lots of shrubs and rice fields, near settlements, ndi s a fishing area.
3	Tolambo	S 01^0 56.920^1 E 120^0 40.498^1 Altitude: 510 m	Steep beaches, hilly terrain, forests, and candlenut orchards, far from settlements, and high-speed line towers.
4	Peura	S 01^0 50.953^1 E 120^0 38,319^1 Altitude: 521 m	Slightly gently rising beach with a stony sandy bottom, heavily logged plantation, and forest areas.
5	Tentena	S 01^0 46.284^1 E 120^0 38.380^1 Altitude: 519 m	The outlet of Lake Poso with flowing into the Poso River.

$$Y = 14.314 * MEI^{0.4681} \quad (2)$$

Where: Y= value of fish production potential (kg/ha/year) and MEI = Morphodhaphic Index (μmhos/cm.meter^{-1}) = conductivity value in μmhos/cm units divided by the average depth of each station in meters.

Results and Discussion

The results of laboratory measurements and analysis of water quality parameters of the Lake Poso research in 2021 are listed in Table 4. The characteristics of the waters of Lake Poso, judged by the results of measurements and analysis of several water quality parameters, give the following description: The fluctuated water of Lake Poso between the rainy and dry seasons averages 60 cm (0.6 meters). The fluctuation in water level of 60 cm between the rainy and dry seasons in Lake Poso is relatively small. There is one habitat that is classified as productive in lake waters, namely coastal habitats. The coastal habitats are often called coastal zones that have high diversity and good growth of organisms and reflect the ratio of the maximum depth of photosynthesis to the maximum depth of the lake [31]. This habitat will be maintained naturally if the fluctuations or water levels between the rainy and dry seasons are not high so that the damage to the coastal habitat of the lake waters is relatively small [32, 33]. Water transparency ranges from 22-27 meters, classified as oligotrophic to mesotrophic [34]. It is explained that the status of the waters is oligotrophic which tends to clear water and up to the mesotrophic status which indicates the waters have not been indicated to be polluted [35-37]. A possible correlation is between total suspended solids, conductivity, and transparency values. In effect, minerals dissolved in sediments

Table 2. The methods and techniques for physical-chemical and biological parameters measurements.

No	Parameters	Methods	Process
1.	Depth	Sounder Depth	*In-situ*
2.	Transparency	Secchi Disk	*In-situ*
3.	Temperature	Digital Temperature	*In-situ*
4.	Conductivity	SCT Gauge	*In-situ*
5.	pH	Digital pH Indicator	*In-situ*
6.	Dissolved Oxygen	DO Meter	*In-situ*
7.	Alkalinity	Titrimetric	*In-situ*
8.	Hardness	Titrimetric	*In-situ*
9.	Phosphate (PO_4-P)	Spectrophotometric	Vanadate Molybdate
10.	Nitrate (NO_3-N)	Spectrophotometric	Nesler's
11.	Ammonia (NH_3-N)	Spectrophotometric	Phenate
12.	Chlorophyll-a	Spectrophotometric	Colourimetry

Table 3. Trophic State Categories based on Carlson's Trophic State Index.

Score	Trophic State	Explanation
<30	Ultraoligotrophic	Water is clear, the dissolved oxygen content is high throughout the year, and reaches the hypolimnetic zone.
30-40	Oligotrophic	Clear water, to allow anoxic restriction in the periodic hypolimnetic zone (DO = 0).
40-50	Mesotrophic	The transparency of water is moderate, the nature of the change of anoxic increase in the hypolimnetic zone.
50-60	Mild eutrophic	Reducing the transparency of water, the hypolimnetic zone isoxic, there are problems of aquatic plants, fish can only live in warm water.
60-70	Moderate eutrophic	The waters are dominated by blue-green algae, clumping occurs, the problem of aquatic plants has been widespread.
70-80	Heavy eutrophic	Heavy algae blooming occurs, aquatic plants form a layer of beds like hypereutrophic conditions.
>80	Hypereutrophic	Thickets of algae, dead fish, aquatic plants are slightly dominated by algae.

Table 4. Water quality parameters in Lake Poso.

No.	Parameters	Unit	Station					Average
			S-1	S-2	S-3	S-4	S-5	
1.	Depth	Meter	3,0	4,0	3,5	3,0	3,0	3,3
2.	Transparency	Meter	25	22	26	26,5	27	25,3
3.	Temperature	^{0}C	28,5	28,5	29,2	28,4	28,3	28,6
4.	Conductivity	µS/cm	107,3	93,3	103,3	101,1	102,3	101,5
5.	pH	Unit	7,0	7,0	7,0	7,0	7.2	7,0
6.	Dissolve Oxygen	mg/L	7,25	7,15	7,12	7,2	7,05	7,15
7.	Alkalinity	mg/L	64	64	64	56	72	64
8.	Hardness	mg/L	72,07	64,06	68,07	76,08	68,07	69,67
9.	Phosphate (PO_4-P)	mg/L	0,010	0,007	0,006	0,009	0,007	0,008
10.	Nítrate (NO_3-N)	mg/L	1,600	0,708	0,253	1,200	0,037	0,759
11.	Ammonia (NH_3-N)	mg/L	0,023	0,006	0,007	0,02	0,013	0,014
12.	Chlorophyll-a	mg/m^3	7,35	7,65	6,80	10.45	10,20	8,49

are suspended in water flows, erosion of rocks on natural and anthropogenic factors [38]. In the event of flooding, transparency is strongly influenced by suspended and dissolved organic/inorganic matter, as well as the abundance of plankton and other microorganisms [39].

Water temperature ranges from 28.3-29.2ºC with an average value of 28.6ºC which is in a good range for fish life. The average water temperature for aquatic life is 26-32ºC, which ensures metabolism, oxygen production, and degradation of toxic matter goes well and fish species still survive [40]. This almost homogeneous temperature will have a good effect on the life of aquatic organisms including fish. [41] said that a small change in water temperature (less than 28ºC) does not endanger fish life. Temperature can affect the metabolism and respiration of fish, an increase in temperature will affect oxygen consumption for fish and survive within a temperature range of 20ºC-30ºC [42]. If the surface temperature is lower than the bottom of the water, the mass of water on the surface will be heavier, which can cause the water to circulate from top to bottom and from bottom to top (upwelling). An upwelling event can occur when there is a long heavy rain so that the surface water layer drops to the bottom. In fact, the water temperature of Lake Poso from this study is still good for fisheries and ideal as a fish habitat.

The conductivity value ranges from 93.3-107.3 µS/cm with an average of 101.5 µS/cm indicating a relatively good value for fish to survive [43]. For certain cases, such as the waters of Lake Batur, the conductivity value is very high, which is above 2500 µS/cm [44]. The high value of conductivity in waters is due to the high content of dissolved mineral salts in the waters of the lake. [45] said that the limit of fish tolerance to conductivity values is influenced by the hardness of the waters. In soft waters, fish can tolerate conductivity in the range of 150-500 µS/cm [46]. When this parameter is above 500 µS/cm the fish will be stressed and cannot tolerate it if the concentration is more than 1000 µS/cm.

The pH ranges from 7.0 to 7.2 with an average value of 7.0 (Table 4) indicating alkaline water, which means that the water contains many mineral materials that can increase the pH value so that the pH value of the lake water is stable. To support the life of fish in a natural way, a concentration value range from 5.0-9.0 is required [43]. [40] states that the ideal waters to support fish life and aquatic organisms as fish food are water pH between 6.5-8.5. Based on these criteria, the water quality of Lake Poso is ideal to support fish life. pH concentrations in waters can also be caused by the loading of internal phosphorus when algae actively grow and remove carbon dioxide so that the pH increases [47, 48].

The presence of dissolved oxygen in inland waters with a minimum concentration of 3 mg/L means that fish can grow, but if the oxygen content is less than 3 mg/L fish can still survive but have no growth normally. When the concentration less than 2 mg/L could be fish death [41]. The source of oxygen in the waters comes from the process of photosynthesis of aquatic plants, mainly by phytoplankton, and from the process of diffusion of oxygen from the atmosphere [49]. Excessively saturated nitrogen concentrations do not contribute to optimal levels of chlorophyll concentrations [50]. In fact, Chlorophyll-a concentrations increase due to strong transparency values, which can promote plankton metabolism [51].

The oxygen content in Lake Poso is still quite high with a dissolved oxygen value of 7.05 mg/L-7.25 mg/L with an average of 7.15 mg/L. [39] said that for fish to live well, it is necessary to have a dissolved oxygen level of at least 4 mg/L. Based on [52], water quality criteria

with oxygen levels of 6 mg/L and above belonging to class I is classified as very good, and between 4-6 mg/L is classified as good (class II). Waters of Lake Poso with an average dissolved oxygen content of 7.15 mg/L are included in the criteria for group I, so the waters of Lake Poso are classified as excellent waters to support fish life.

The alkalinity value is between 56-72 mg/L $CaCO_3$ eq with an average of 64 mg/L $CaCO_3$ eq. classified as waters with low fertility rates because the alkalinity value is below the range of 100-250 mg/L $CaCO_3$ eq. The accumulation of limestone as the main source of alkalinity and hardness components in water will have a high hardness [53]. The hardness concentration range from 64.06-76.08 mg/L $CaCO_3$ eq. with an average value of 69.67 mg/L $CaCO_3$ eq. classified as soft water with a low level of hardness and indicate that the salt content derived from alkaline soil cations (Ca and Mg cations) is also low.

The phosphate levels (PO_4-P) ranged from 0.006-0.010 mg/L with an average value of 0.008 mg/L. Based on the proposed criteria by [54], the productivity of Lake Poso waters was classified as low to medium level. Phosphate levels in natural waters typically rarely exceed 0.100 mg/L, unless the water receives household waste, industrial waste, and runoff from agricultural/ plantation areas that receive phosphate fertilization [55]. Based on the concentration value of phosphate showed that the condition of Lake Poso is still fairly good because not much-received waste from outside.

The nitrate levels ranged from 0.037-1.600 mg/L with an average value of 0.759 mg/L (Table 4). Based on water fertility criteria, the waters of Lake Poso with an average nitrate content of 0.759 mg/L, were classified as waters with moderate fertility levels [56, 39]. The ammonia levels range from 0.006-0.023 mg/L with an average value of 0.014 mg/L. [47] said that in tropical waters, ammonia levels should not exceed 1.0 mg/L. Referring to [52], it is recommended that the concentration of free ammonia in the waters should not exceed 0.02 mg/L. Based on these criteria, the waters of Lake Poso include waters with low ammonia levels. The waters of Lake Poso have chlorophyll-a levels between 6.80-10.45 mg/m^3 with an average value of 8.49 mg/m^3. The chlorophyll content is related to water fertility and when viewed from the average chlorophyll value of 8,49 mg/m^3, Lake Poso is a lake that has moderate levels [57, 17].

Analysis with PCA can describe 70,99% of the correlation of water quality parameters. The trophic level of the lake ecosystem is correlated with a few key factors such as chlorophyll-a, phosphate, and transparency. In this relationship, Chlorophyll-a values had a close correlation with pH and transparency with hardness. However, correlatively negative with Ammonia dan and nitrate as nitrogen parameters. Nitrogen concentrations that are oversaturated do not contribute to optimal chlorophyll concentration levels [58]. The increasing chlorophyll-a concentration is closely related to the transparency value, which can drive plankton metabolism [59]. Phosphate is positively correlated with turbidity concentration as it impacts the accumulation of dissolved sediments. The potential fish production depends on the conductivity value of the water, the PCA result showed that the conductivity is correlated with turbidity and phosphate (Fig. 2).

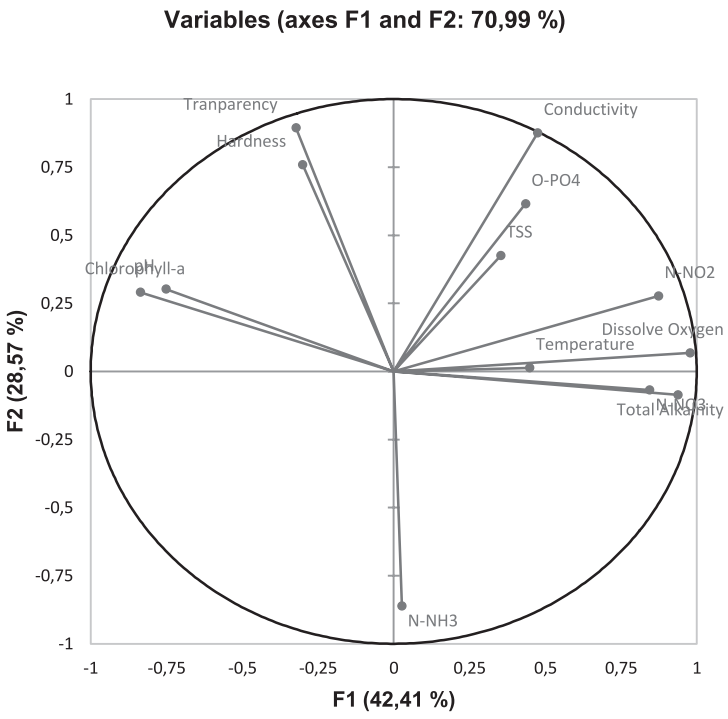

Fig. 2. PCA of Water Quality in Lake Poso.

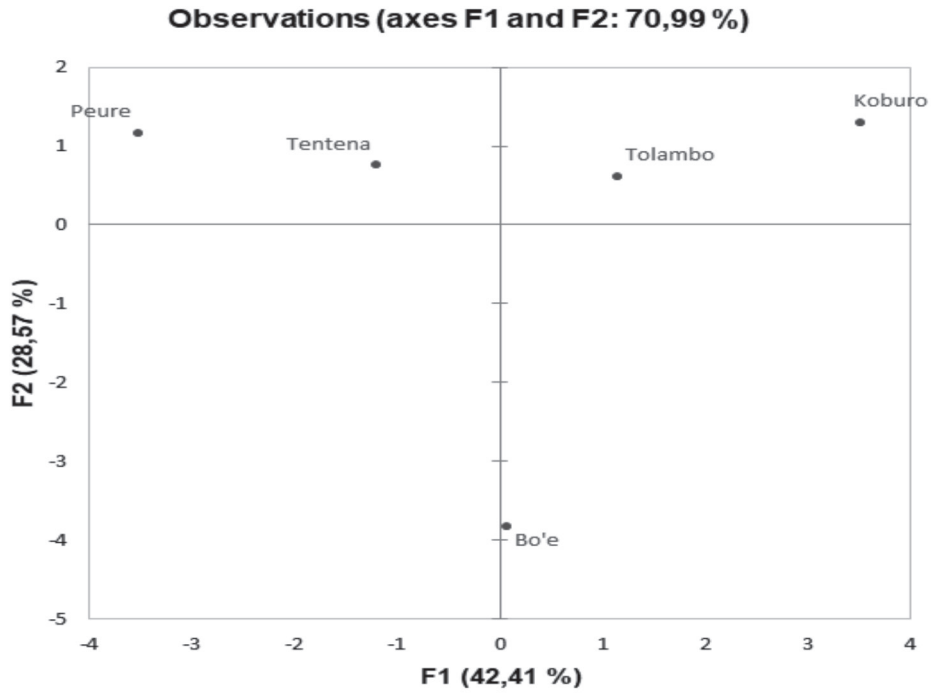

Fig. 3. Principal Component Analysis at five sampling sites in Lake Poso.

The PCA analysis divided the sampling stations into three groups based on similarities in basic parameters and close relationships. The first group is Peure and Tentena, with the highest chlorophyll. the second group is Tolambo and Koburo with the highest Conductivity values and the last is Bo'e station with the lowest transparency and highest ammonia value (Fig. 3).

The trophic status of water is characterized by high and low nutrient content, such as N and P as well as phytoplankton abundance or chlorophyll concentrations [60]. TSI can be determined and describe water productivity and limit values in ecological susceptibility using transparency, total phosphate, and chlorophyll parameters [49,61]. Based on the results of the study, the farther the distance from the sampling location in the cage shows a lower TSI trend even though the difference in TSI values is not too far. The difference in TSI values is due to the difference in the concentration and transparency of the total phosphorus and chlorophyll-a compared to these points farther from the fish cage [62]. Floating net cages can cause changes in the color of the lake from the residual feed that accumulates at the bottom of the lake affecting the color to dark green [63]. Measurements of trophic levels were carried out in two versions using data on the concentration of total phosphorus on the surface and bottom layers.

The index value of the trophic status of the waters of Lake Poso ranges from 44.55-48.55 with an average index value of 46.18 (Table 5). The results showed that the value of the trophic index of Lake Poso belongs to the mesotrophic level. The pace of conditions is thought to be due to the nutrient load derived from residential activities, plantation activities, and rice fields commonly found around the lake. Compared to other state trophic lakes in Indonesia, Lake Poso can still be deployed for fisheries activities, but it must need regulation and maintain its water quality. Some studies showed that some lakes have become eutrophic such as Batur, Tempe, Maninjau, and Kerinci lakes which can damage aquatic ecosystems and even cause fish to die (Table 6). For this reason, it is needed to monitor water quality and TSI level and provide management recommendations for the sustainability of aquatic organisms.

Lake Poso's fish production potential ranges from 61.3 to 65.3 kg/ha/year, with an average value of 63.8 kg/ha/year (Table 7). With a lake water area of 39890 hectares, the potential of lake water to produce fish ranges from 2445-2605 tons/year with an average figure of 2545 tons/year. The average fish production

Table 5. Trophic Status Index Value in Lake Poso.

Station	Station	Index value	Trophic State
1	Koburo	45,63	Mesotrophic
2	'o'e	47,62	Mesotrophic
3	Tolambo	44,66	Mesotrophic
4	Peura	44,55	Mesotrophic
5	Tentena/outlet	48,50	Mesotrophic
	Average	46,18	Mesotrophic

Table 6. Trophic Status Levels of Some Lakes in Indonesia.

No	Lake's Name	Province	Trophic Status Level	Year
1.	Towuti	South Sulawesi	Mesotrophic	2009 [56]
2.	Ranau	South Sumatra	Meso-eutrophic	2011 [60]
3.	Tempe	South Sulawesi	Eutrophic	2012 [50]
4.	Maninjau	West Sumatra	Eutrophic	2012 [62]
5.	Batur	Bali	Eutrophic	2014 [44]
6.	Lindu	Central Sulawesi	Oligo-mesotrophic	2014 [33]
7.	Kerinci	Jambi	Eutrophic	2015 [64]
8.	Rawa Pening	Central Java	Eutrophic	2016 [65]
9.	Danau Diatas	West Sumatra	Oligo-mesotrophic	2016 [66]
10.	Ayamaru	Papua	Mesotrophic	2022 [67]

Table 7. Fish production potential based on the Morphoedaphic Index in Lake Poso.

No	Station	Fish production potential (kg/ha/year)	Fish production potential (ton/year)
1	Koburo	65,0	2593
2	'o'e	64,3	2565
3	Tolambo	61,3	2445
4	Peura	65,3	2605
5	Tentena/outlet	63,1	2517
	Average	63,8	2545

potential figure is 63.8 kg/ha/year (2545 tons/year), which is relatively low [53]. By maintaining water quality conditions can be possible to evaluate production capacity limits [68]. Fish production potential figures analyzed using MEI values reflect mineral or nutrient content in the waters. These minerals or nutrients are elements needed by producers (phytoplankton and aquatic plants) which are the first level in the food chain system.

The trophic states index value of 44.5 to 48.5 (mesotrophic) has been able to preserve biological resources in Poso Waters, especially for fish resources. To maintain the potential for fish production to remain stable, the conductivity value of the waters must be managed by maintaining the trophic state value between oligo to mesotrophic. Protecting the habitat around the lake by maintaining optimal vegetation boundaries in Lake Poso as well as agricultural activities, industries, and domestic waste. Aquaculture activities such as floating net cages in Lake Poso have no growth that can be increased eutrophication and decline of endemic fish species in Lake Poso.

Conclusion

The characteristics of lake waters through the assessment of several water quality parameters such as temperature, transparency, electrical conductivity, pH, dissolved oxygen, alkalinity, hardness, phosphate, nitrate, ammonia, chlorophyll-a, and trophic status index, concluded that lake waters are classified as good waters for fish life and other organisms as fish food. The trophic level of lake waters seen from the value of the trophic states index is 46.18 which classifies waters at moderate/mesotrophic levels. Lake Poso fish production potential is low with quantities ranging from 2,445-2,605 tons/year and an average of 2,545 tons/year. Its shows that, the water quality conditions in Lake Poso are feasible for fish resources. With this value, the potential for fish production is low, but this condition must be maintained the feasibility of fish resources.

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Conflict of Interest

The author stated there is no conflict of interest.

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