Physical and Chemical Characterization of Lake Lanao (Mindanao, Philippines)

ABSTRACT

Lake Lanao is the second largest lake in the Philippines, wholly located within the province of Lanao del Sur. It is of great biological, ecological, economic and social importance. The first extensive limnological study of Lake Lanao was done by Frey in 1967-68, which was continued by Lewis with his more in-depth field work performed in 1970-71. Since these first studies, various changes have occurred such as that affecting the natural variation in the outflow of Lake Lanao. Some unusual phenomena, such as the occurrence of a fish kill, diagnosed as epizootic ulcerative syndrome, occurred in 1997 and an unusual greening occurred in September 2006. These unusual occurrences point out the need for a regular periodic monitoring of the lake. This study sought to measure the current status of various physical and chemical characteristics of Lake Lanao. An offshore station (alternating between Tugaya, Taraka, and Masiu) was chosen to represent the lake for doing the field measurements. The Secchi disk depth was taken while water samples were collected at different depths and/or integrated for the measurement of conductivity, dissolved oxygen, pH, and temperature. The same set of water samples were collected, kept in ice in a cooler, and brought to MSU-Naawan for laboratory analyses for nutrients (nitrate-N, ammonia-N, total phosphorus), alkalinity, and chlorophyll-a. Dissolved oxygen values showed no lack of oxygen for use of the lake organisms. The values for Secchi depth, nitrate- plus ammonia-nitrogen, total phosphorus, and chlorophyll-a indicated Lake Lanao to be oligotrophic-mesotrophic. In terms of its current physical and chemical parameters, Lake Lanao generally exhibits good water quality and insignificant organic pollution.

Keywords: Lake Lanao, physical limnology, chemical limnology, water quality, trophic state

INTRODUCTION

Lake Lanao is the second largest lake in the Philippines and is wholly located within the province of Lanao del Sur. It has great biological, ecological, economic and social importance – as the seat of evolution of an endemic species flock of cyprinids, as a sizable contributor to the local hydrologic cycle, as the source of water supply driving the Agus hydropower plants, and as the center of life and culture of its native inhabitants - the Maranaos who call themselves the “People of the Lake” (Garcia-Hansel and Metillo 2016).

The first extensive limnological study of Lake Lanao, which included determination of some of its physical and chemical characteristics, was done by Frey (1969). This was continued by Lewis with his more in-depth field work performed in 1970-71 (Lewis 1973). Frey summarized his morphometric data for Lake Lanao as follows: area – 357 km2; volume – 21.5 km3; maximum depth – 112 m; mean depth (volume/area) – 60.3 m; replacement time (volume/mean annual discharge) – 6.5 yrs. His other findings showed that during mid-February to mid-March, the lake was essentially isothermal at 24.40C, then rapidly warmed to 26.50. During May and June the surface water warmed to almost 280 which was probably the maximum for that year. Lewis (1973) made a more exhaustive study on the occurrence of thermal stratification of Lake Lanao, showing it to be a monomictic lake. Frey’s additional findings show that dissolved oxygen ranged from 7.3-8.5 ppm at the top 12 m (trophogenic zone) and was slightly supersaturated (106%) from mid-May through mid-June. pH within the top 10 m ranged from 8.2 to 8.9. Methyl-orange alkalinity averaged about 1.2 m.eq. and conductivity about 120 micromhos (1 micromho = 1 microSiemens/cm). The 1% light intensity level varied from 11 to 25 m. Transparency was low during overturn.

Since these first studies, various changes have occurred. One was affecting the natural variation in the outflow of Lake Lanao, namely the construction of a Marawi Lake Regulation Dam near the mouth of Agus River, the single outlet of Lake Lanao, in 1978, for effective control of the Agus River volume powering the Agus II hydropower plant in Saguiaran and a succession of hydropower plants (Agus IV, Agus V) downstream. A much greater influencer on the regulation of lake outflow resulted from the construction of Agus I hydropower plant on the shore of Lake Lanao near the mouth of Agus River, effectively making the lake itself its reservoir, which started operation in 1992 (Garcia-Hansel and Metillo 2016). The volume of lake outflow would influence the flushing rate, the rate at which water enters and leaves the lake relative to lake volume, usually expressed as time needed to replace the lake volume with inflowing water, or its replacement time. Lake outflow will also affect the lake water level, which although naturally occurring based on water inputs as affected by precipitation, may become markedly changed especially during a drought. Some unusual phenomena have also taken place. The occurrence of a fish kill, diagnosed as epizootic ulcerative syndrome by an MSU Team (Escudero et al. 1998) was observed by Lake Lanao fishermen and lakeshore dwellers at around the latter part of December 1997. An unusual greening occurred in September 2006, wherein subsequent to its peak, a hydrobiological investigation of the lake was performed (Lagmay et al. 2006). These unusual occurrences point out the need for a regular periodic monitoring of the lake. Prior to the Agus I hydropower plant operation, there was much protest claiming that Lake Lanao is dead (Garcia-Hansel and Metillo 2016).

What indeed is the true status of Lake Lanao? In terms of its physical and chemical parameters, what are their current values? This study sought to measure the current status of various physical and chemical characteristics of Lake Lanao. These include temperature, transparency measured as Secchi disk depth, pH, conductivity, dissolved oxygen, nutrients (nitrate-nitrogen, ammonia-nitrogen, total phosphorus), alkalinity, chlorophyll-a, and 5-day biochemical oxygen demand (5-day BOD). An updated measurement of these physical and chemical parameters will indicate the water quality and trophic status of Lake Lanao. Indication of the present water quality, trophic status and organic pollution of Lake Lanao will provide inputs for ordinances and laws, and policies and recommendations for the appropriate management of Lake Lanao and its surroundings. In view of the central role that Lake Lanao plays in the life and economy of the Maranao local community (e.g., for fisheries, transportation, religious ritual of ablution, water for household use) and Mindanao-wide (in relation to the lake's use for hydropower generation), its appropriate management will redound to socio-economic benefits overall. In the case of the scientific community, this study will advance the knowledge base of the science of tropical limnology in the Philippines.

MATERIALS AND METHODS

Entry protocol

A courtesy call to the Provincial Governor, Hon. Mamintal "Bombit" Adiong, Jr., was made on 27 October 2015, joining Project 6 of the Lake Lanao research program. We made our own courtesy calls to the LGUs of the municipalities adjoining the locations in the lake where we will do our lake water sampling and field measurements. This was done on 26 May 2016, where we made courtesy calls to (a) the Mayor of Tugaya, Lanao del Sur, (b) the MILF Commander of Nusa Base Command, Nusa Island, Balindong, Lanao del Sur, and (c) the ABC President, Masiu, Lanao del Sur. We also negotiated with the MILF Nusa Base Commander the rental of a boat during the conduct of our subsequent field work so as to ensure our protection and safety. Consequently, we were able to conduct our lake reconnaissance and dry run on 29 May 2016 and our first lake sampling and field measurements on 27 June 2016.

Sampling stations

For assessing the lake general water quality, it is sufficient to select one station near the midpoint or at the deeper part of the lake. Because of certain logistical constraints, these stations alternated between three locations: offshore of Tugaya (ca. 90 m deep), offshore of Taraka (ca. 60 m deep), and offshore of Masiu (ca. 90 m deep). In order to see any watershed effect of nutrient inputs to the lake, three stations were selected at the eastern side of the lake near the mouth of three inflowing rivers – Taraka river, Gata river, and Masiu river. Excluding Lake Lanao itself, the area of the catchment basin that drains into the lake, as computed from Frey (1969), is 1323.8 km2. Of this area, 26.2% is drained by Masiu river (subwatershed area of 347 km2), 21.6% by Taraka river (subwatershed area of 285.6 km2), and 15.7% by Gata river (subwatershed area of 208.3 km2). See Figure 1.

The stations' location coordinates were obtained by using a GPS handheld receiver (Garmin etrex 12 channel GPS model).

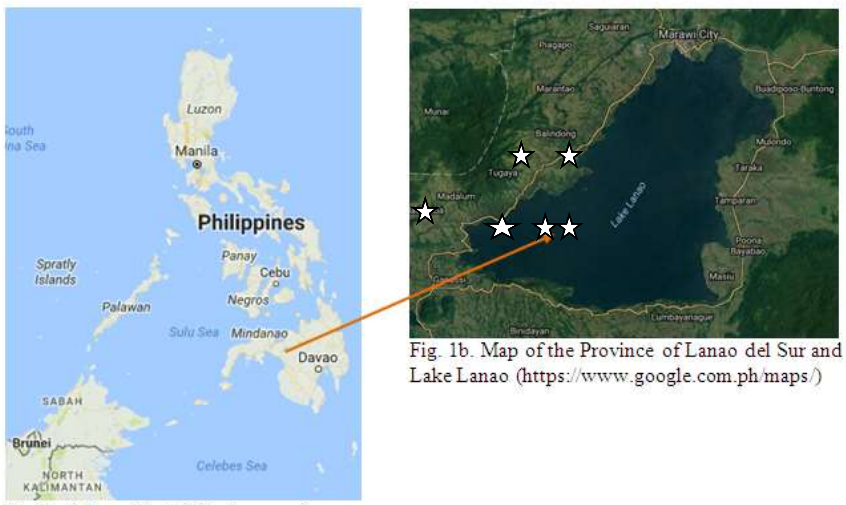

Fig. 1a. Map of the Philippines and neighboring countries (https://www.google.com.ph/maps/)

Fig. 1b. Map of the Province of Lanao del Sur and Lake Lanao (https://www.google.com.ph/maps/)

Figure 1. Location of the sampling stations. The three stars in the middle from left to right are the three offshore stations to represent the lake: Tugaya offshore, Masiu offshore, and Taraka offshore. The three stars near the shoreline from top to bottom are near the mouth of the inflowing rivers: near Taraka river mouth, near Gata river mouth, and near Masiu river mouth.

Sampling duration

Field measurements and collection of water samples for lab analyses were done five times over one year at approximately bimonthly intervals, specifically on 27 June 2016, 14 September 2016, 15 November 2016, 19 December 2016, and 26 February 2017.

Field measurements

Field measurements were done for the following parameters: Secchi disk depth, dissolved oxygen, pH, conductivity, and temperature. Secchi disk depth, which is a measure of water clarity, was measured with a Secchi disk. The Secchi disk was lowered until it disappeared from view, the distance noted, and lowered some more after which it is slowly raised until it appears into view, and this distance noted. The two distances are averaged as the Secchi disk depth or Secchi depth. Various considerations need to be taken into account in getting the Secchi depth, one of which is to have the same person get the measurement during every sampling period (Lind 1985). The other parameters were measured with portable meters on the water samples. Dissolved oxygen was measured with a DO meter (Lutron PDO-519, AI.08427; Made in Taiwan) that has a polarographic type oxygen electrode, with a range of 0 to 20.0 mg/L and resolution of 0.1 mg/L. pH was measured with a pH meter (HM Digital pH meter PH-200, CE 0134261) with a pH range of 0-14, resolution of 0.01 pH and accuracy of +/- 0.1 pH. Electrical conductivity (EC) was measured with an EC meter (Milwaukee EC 60; EC/ TDS/ Temp WP) that also measured Total Dissolved Solids (TDS) at the same time. The EC range was 20.00 mS/cm while the TDS range was 10.00 ppt. EC resolution was 0.01 mS/cm while TDS resolution was 0.01 ppt. Each of the three meters had a temperature reading and the values for the readings were averaged in order to give the temperature.

Collection of water samples for field measurement and lab analyses

Water samples were collected with a van Dorn water sampler from every meter of the top five meters and for every meter from 28-32 m, 32 meters being the length of the line of the van Dorn water sampler. The sampler was lost during the 4th sampling period, after sampling only the top 5 meters of the Taraka offshore station. Although an improvised water sampler was made for the 5th sampling period, it did not work and only surface water samples were obtained. Three replicate samples were collected each time. The collected water samples were used to measure those factors in the field measurements: dissolved oxygen, pH, conductivity and temperature. Readings were averaged for each meter reading of the top 5 meters and each meter reading for the bottom 28-32 meters. Another set of water samples (an integrated top 5 meter sample and an integrated 28-32 meter sample; three replicates) were collected and dispensed into sampling bottles, stored in a cooler, and immediately brought after the field work to the Water Analysis Laboratory of MSU at Naawan. These samples were analyzed for the following: nutrients (nitrate-N, ammonia-N, total phosphorus), alkalinity and chlorophyll-a.

Measurement of 5-day BOD

There was a one-time measurement of 5-day BOD (biochemical oxygen demand). A water sample in the field had its dissolved oxygen measured with the DO meter to give the initial DO. At the same time, a replicate water sample was placed in a BOD bottle, wrapped with Aluminum foil to keep in the dark, brought to the MSU lab and allowed to stand for 5 days. Its dissolved oxygen content was then measured with the DO meter. The difference in amount of the initial DO and final DO is the 5-day BOD.

RESULTS AND DISCUSSION

Physical characteristics

The coordinates of the offshore sampling stations selected to represent the lake are in Table 1. The Secchi depth measurements are shown in Figure 2. The Secchi depth ranged from 3.5 m to 6.61 m, with a mean of 5.14 m. The Secchi disk depth is a measure of water transparency and is influenced by the particles present in water. Although these particles can be both organic (algal cells), and inorganic particulates (silt and sediment), the Secchi depth is usually a measure of algal abundance and is a simple inexpensive method of estimating lake productivity. As presented later, the Secchi depth is an indicator of the trophic state of a lake and the Secchi depth values of Lake Lanao indicate it to be mesotrophic. The lower value of the Secchi depth in February implies the presence of more particles and greater productivity.

Table 1. Coordinates of the offshore sampling stations selected to represent the lake.

GPS	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Coordinates	$7^0$52.584’N $124^0$11.802’E	$7^0$52.368’N $124^0$11.359’E	$7^0$53.539’N $124^0$18.541’E	$7^0$54.375’N $124^0$18.187’E	$7^0$51.878’N $124^0$18.258’E

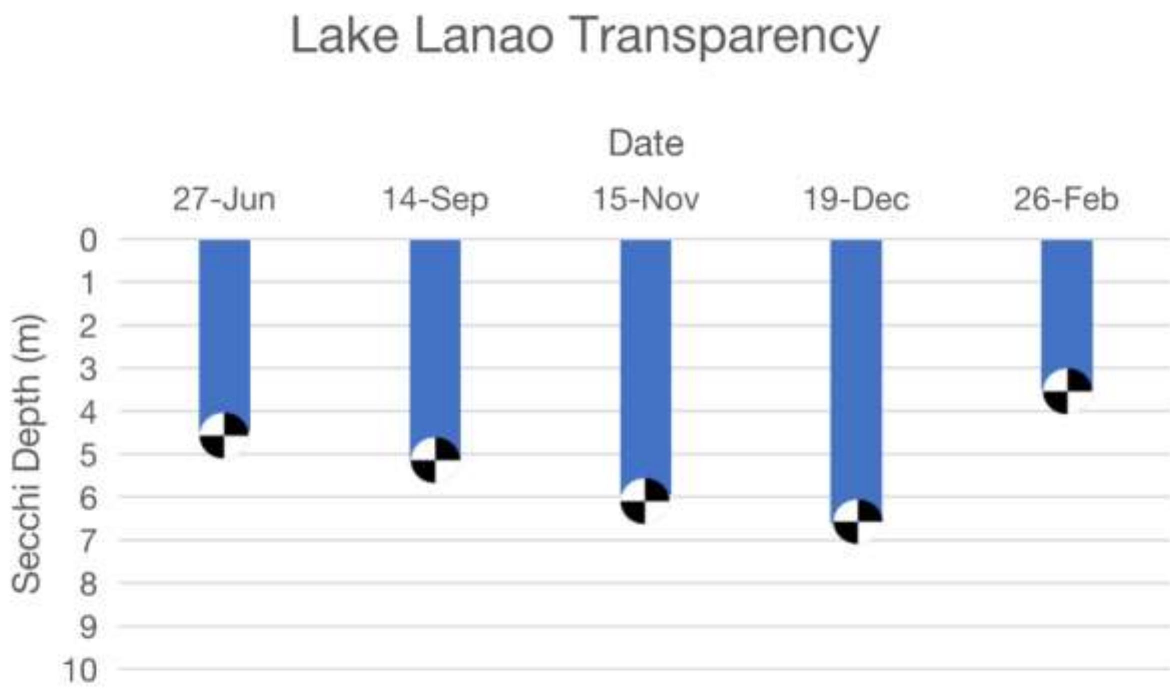

Figure 2. Lake Lanao transparency as measured by Secchi disk depth for the sampling period June 2016 through February 2017.

Temperature

The surface temperature of a water body reflects the air temperature. Thus, temperature changes in a lake is due to the change in seasonal air temperature. With increasing depth, there is a change in water temperature. As light strikes the water surface and goes through the water column, there is an attenuation and differential absorption of light and its conversion to heat. Depending on the depth of the lake, in deeper lakes such as Lake Lanao, there occurs a thermal stratification due to the differential heating (and resulting density differences) and non-mixing of the water as one goes down the water column during the summer months. After summer as the cooler season progresses, the upper water layer (epilimnion) cools and become homothermal with the lower water layers (metalimnion and hypolimnion), which then causes their mixing (turnover). Table 2 shows the mean temperature in the top 5 m and lower 28-32 m of Lake Lanao in an attempt to show if thermal stratification occurs. The mean temperature in the lower 28-32 m during June, September and November is slightly lesser, which could probably be indicative of a thermocline (metalimnion), though the thermocline could be lower than 32 m depending on the weather (Lewis, 1973). The coolest temperature (25.6^{0}C) of the surface water was in February 2017. Lewis (1973) found in 1970 that the lowest temperature at 24.5^{0}C occurred in early February while there was mixing of the lake. He observed that the lake circulated during January and February at the time of seasonal cooling, was intermittently stable during

March and April, and was stratified during all other months. Furthermore, during stratification the principal thermocline achieved equilibrium with storm winds at 40-50 m. Because of the formation of the three water layers during thermal stratification and their non-mixing, this makes the water layers different in their chemical make-up. In this study, it is possible that the observed lower temperature of the surface water in February 2017 indicates that it has mixed with the cooler deeper layer and that the lake was in a state of turnover.

Table 2. Mean temperature in the top 5 m and 28-32 m of the offshore sampling stations of Lake Lanao from 27 June 2016 through 26 Feb 2017.

Temperature, ^{0}C	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Mean, top 5 m	28.0	27.6	27.7	26.4	25.6 (surface water only)
Mean, 28-32 m	27.7	27.5	27.2		

Chemical characteristics

Dissolved oxygen

Dissolved oxygen in water comes from the atmosphere and as a byproduct of photosynthesis. From the air, oxygen can diffuse slowly or be mixed in rapidly through the action of wind that causes waves and through internal currents. However, whereas air contains 21% oxygen, water is able to contain only a tiny fraction of 1% oxygen. The amount of oxygen that water can contain (its saturation) also depends on temperature, cold water being able to hold more oxygen than warm water. Dissolved oxygen is of course a necessity for almost all aquatic organisms inasmuch as they carry out aerobic respiration. Oxygen consumption is greatest at night when there is no photosynthesis and there is only respiration. Oxygen is also consumed during decomposition of dead bodies of organisms and other organic matter and is therefore greatest at the bottom where this material has fallen. Dissolved oxygen in Lake Lanao was measured only during three sampling periods, due to logistical constraints (see Table 3). Inasmuch as at 25^{0}C, oxygen solubility is 8.6 mg/L (Michaud, 1991), it appears that the measured dissolved oxygen in Lake Lanao does not exhibit any deficiency that will be detrimental to aquatic organisms.

Table 3. Dissolved oxygen levels in Lake Lanao from 15 November 2016 through 26 February 2017.

Dissolved oxygen, ppm	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore

Mean, Top 5 m			7.3	7.7	6.4 (surface only)
Mean, 28-31 m			7.6		

pH

The pH of healthy natural waters is between 6.5 and 9.0 (Aldridge, n.d.). It is only values of pH below 4.5 and above 9.5 that are usually lethal to aquatic organisms. The pH of a water body reflects its water inputs and the chemical characteristics of the surrounding land, inasmuch as the pH of runoff from the land is affected by the type of minerals and soils the water contacts as it moves through the land. The CO_2 from the atmosphere and from the respiration of aquatic organisms dissolves in water as carbonic acid and lowers the pH. Conversely, photosynthesis, which uses up CO_2, will tend to increase pH. There is no great fluctuation in the pH though because of the lake's buffering capacity in view of the chemicals it contains. Table 4 shows the pH levels in Lake Lanao, which conform to most natural waters.

Table 4. pH levels in Lake Lanao from 27 June 2016 through 26 February 2017.

pH	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Mean, top 5 m	8.4	8.6	9.0	8.0	7.9 (surface only)
Mean, 28-32 m	7.4	8.3	8.8	8.0	

Alkalinity

Alkalinity refers to the buffering capacity of the natural water to neutralize acids and thereby maintain a fairly stable pH. This capacity is imparted by several solute species, such as bicarbonates, carbonates, and hydroxides, which combine with H+ ions in the water, causing it to have a more basic pH. These solute species come from the area's rocks and soils and the interconversions of the different forms of carbon dioxide in water (i.e., carbonic acid, bicarbonate, carbonate), the predominant forms depending on the pH. If an area's bedrock contains limestone (calcium carbonate), then the water body tends to be more alkaline. The alkalinity levels in Lake Lanao which ranges from 497 to 680 ppm CaCO3 (Table 5) show that the lake has good buffering capacity. An alkalinity reading of over 100 mg/L is considered very resistant to acid (Aldridge, n.d.).

Table 5. Alkalinity levels in Lake Lanao from 27 June 2016 through 26 February 2017.

Alkalinity, ppm CaCO3	27 June 2016	14 Sep 2016	15 Nov 2016	19 Dec 2016	26 Feb 2017
Mean, Top 5 m	496.7	500	680	623.3	600
Mean, 28-32 m	500	496.7	620		

Conductivity

Conductivity is a measure of the ability of water to conduct an electric current wherein the higher the concentration of ions in the water, the more electric current it can conduct. Thus, conductivity reflects the amount of total dissolved salts/solids (TDS) in water, which includes solutes such as sodium, calcium, magnesium, bicarbonate, chloride and others that remain as a solid residue after evaporation of water from the sample. TDS levels range between 0 and 1,000 mg/L and depend on the geology of the region, climate and weathering and other factors that influence the source and amount of dissolved material that is carried by runoff to the water body. Conductivity generally ranges between 10 and 1,000 µS/cm in most rivers or lakes that have outflows, such as Lake Lanao. The outflow would carry with it its total dissolved ions, which does not remain in the lake. The lake's flushing rate would influence how long it would take for the water volume of the lake to be completely replaced. Frey's calculated replacement time of 6.5 years will no longer hold true because Lake Lanao's mean annual discharge would have been affected by the construction of the Agus I hydropower Plant on the lakeshore near the mouth of Agus River, Lake Lanao's only outlet. In the case of lakes that have no outflows, for example, the Dead Sea, the total dissolved ions being carried by its inflows and runoff become concentrated in the lake, making it highly saline. In Lake Lanao, conductivity ranges from 78-130 µS/cm (Table 6). This is equivalent to a total dissolved solids (TDS) concentration of 39-65 ppm, based on the specifications of the portable EC/TDS meter that was used. However, it would be more ideal to have an empirically determined relationship between conductance and TDS. Hem (1985) did this empirical determination and fitted the obtained data as a straight line regression in the formula KA = S, where K is specific conductance in µmhos/cm or µS/cm and S is dissolved solids in mg/L or ppm, and obtained a value for A of 0.59. The value for A is said to be mostly between 0.55 and 0.75, the higher values being generally associated with water high in sulfate concentration. In practice, where the kinds and amounts of dissolved ions are assumed to be the usual ones, the value for A of 0.67 is generally used. If the value for A of 0.67 is used here for Lake Lanao, the conductivity measurements in Table 6 would have the corresponding TDS levels in Table 7. TDS ranges from 52.3 to 87.1 ppm, values that are usual in a freshwater lake.

Table 6. Conductivity measurements in Lake Lanao from 27 June 2016 through 26 February 2017.

Electrical conductivity (EC), mS/cm	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Mean, top 5 m	0.102	0.114	0.078	0.108	0.130
Mean, 28-32 m	0.108	0.130	0.116		

1 mS/cm = 1000 µS/cm

Table 7. Calculated equivalent total dissolved solids concentrations in Lake Lanao from 27 June 2016 through 26 February 2017.

Total dissolved solids (TDS), mg/L or ppm	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Mean, top 5 m	68.3	76.4	52.3	72.4	87.1
Mean, 28-32 m	72.4	87.1	77.7		

Conductivity measurements were also made near the mouths of three tributary rivers at the eastern part of the lake. Aside from giving an idea on the natural variability of the lake, this was done to see if we could detect an influence of the watershed on the values of this chemical factor. Excluding Lake Lanao itself, the area of the catchment basin that drains into the lake, as computed from Frey (1969), is 1323.8 km2. Of this area, 26.2% is drained by Masiu river (subwatershed area of 347 km2), 21.6% by Taraka river (subwatershed area of 285.6 km2), and 15.7% by Gata river (subwatershed area of 208.3 km2). Table 8 shows that in general, the conductivity values of the lake water obtained near the mouths of the tributary rivers are virtually the same as those in the station that represented the whole lake. Making the corresponding calculation also for the TDS concentrations (Table 9), TDS ranged from 45 to 92 ppm.

Table 8. Conductivity measurements in Lake Lanao near the mouth of tributary rivers from 27 June 2016 through 26 February 2017.

EC, mS/cm	27 June 2016	14 Sep 2016	15 Nov 2016	19 Dec 2016	26 Feb 2017

Near Masiu River mouth	0.127	0.11	0.113	No sample	0.137
Near Gata River mouth	0.125	0.123	0.067	No sample	0.13
Near Taraka River mouth	0.12	0.12	0.103	No sample	0.13

Table 9. Calculated equivalent total dissolved solids concentrations in Lake Lanao near the mouth of tributary rivers from 27 June 2016 through 26 February 2017.

TDS, mg/L or ppm	27 June 2016	14 Sep 2016	15 Nov 2016	19 Dec 2016	26 Feb 2017
Near Masiu River mouth	85.1	73.7	75.7	No sample	91.8
Near Gata River mouth	83.8	82.4	44.9	No sample	87.1
Near Taraka River mouth	80.4	80.4	69.0	No sample	87.1

Nutrients

Nutrient concentrations are most important in influencing the productivity of a lake, inasmuch as they are usually the limiting factors. Nitrogen and phosphorus are the most important among the macronutrients as they are usually in short supply relative to the needs of the lake's primary producers, the phytoplankton and aquatic macrophytes. The most abundant form of nitrogen in the environment is nitrogen gas but only nitrogen-fixing bacteria can utilize it. Dissolved inorganic forms of nitrogen must be in the form of nitrate and ammonia (formed mainly through metabolic processes carried out by microorganisms) in order to be utilizable. Phosphorus can be released from minerals through weathering, and carried to aquatic systems through soil runoff. Dissolved inorganic forms of phosphorus include orthophosphate, the usual form in which it is taken up by plants and algae. Because the Lake Lanao water samples were not filtered prior to laboratory analysis using the molybdate method, the phosphorus determined was Total Phosphorus. Total phosphorus less than or equal to 0.05 mg/L is considered healthy (Aldridge, n.d.). Table 10 and Table 11 show the amounts of nitrogen (as nitrate-nitrogen and ammonia-nitrogen) and phosphorus (as total phosphorus) measured in Lake Lanao at the different sampling stations. Nitrogen levels are low compared to that of total phosphorus, indicating a nitrogen limitation for growth of the primary producers.

The natural amounts of nitrogen and phosphorus in a lake can be increased due to artificial sources of nutrients that include discharges of sewage, animal waste, and agricultural fertilizers. Because nutrient concentrations often limit primary productivity, inputs of nutrients can lead to large increases in the growth of algae or aquatic plants. Eutrophication results when high concentrations of nutrients lead to excessive biological growth. Artificial (human-caused) or cultural eutrophication can degrade water quality and be detrimental to desirable aquatic species. The nutrient values observed in this study does not support cultural eutrophication of the lake.

Table 10. Nutrient level measurements in Lake Lanao from 27 June 2016 through 26 February 2017.

Chemical factor	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
NO3, ppm	0.0256	0.0256	0.017	0.021	0.029
NH3, ppm	0.067	0.0946	0.0933	0.088	0.088
NO3 + NH3-N, ppm	0.0926	0.1202	0.1103	0.109	0.117
Total P, ppm	0.038	0.035	0.0303	0.032	0.0197

Table 11. Nutrient level measurements in Lake Lanao taken near the mouths of tributary rivers from 27 June 2016 through 26 February 2017.

Near River mouth/ Nutrient, ppm	27 June 2016	14 Sep 2016	15 Nov 2016	19 Dec 2016	26 Feb 2017
Masiu River, NO3	0.025	0.0203	0.0403	Not taken	0.0167
M. R., NH3	0.0647	0.0727	0.1017		0.046
M.R., NO3 + NH3-N	0.0897	0.093	0.142		0.0627
M.R., Total P	0.0433	0.0423	0.0663		0.0267

Gata River, NO3	0.027	0.0117	0.019	Not taken	0.0147
G. R., NH3	0.0623	0.0723	0.096		0.0213
G.R., NO3 + NH3-N	0.0893	0.084	0.115		0.036
G.R., Total P	0.0443	0.031	0.05		0.0203
Taraka River, NO3	0.0293	0.0113	0.0283	Not taken	0.0203
T. R., NH3	0.066	0.114	0.1053		0.0333
T.R., NO3 + NH3-N	0.0953	0.1253	0.1336		0.0536
T.R., Total P	0.045	0.091	0.0607		0.0213

Chlorophyll-a and 5-day BOD

The amount of chlorophyll-a is a measure of the phytoplankton biomass in the lake, and thus of its primary productivity. The obtained values indicate a non-productive lake. Because of their less biomass, when the algae die, their decomposition does not deplete the oxygen so much in the water. The low 5-day BOD (biochemical oxygen demand) supports this and also shows the relative absence of organic pollutants entering the lake during that one-time measurement.

Table 12. Chlorophyll measurements of Lake Lanao taken from 27 June 2016 through 19 December 2016 and one-time measurement of 5-day BOD.

Chemical factor	27 June 2016 Tugaya Offshore	14 Sep 2016 Tugaya Offshore	15 Nov 2016 Taraka Offshore	19 Dec 2016 Taraka Offshore	26 Feb 2017 Masiu Offshore
Chl-a, mg/m^3	1.393	0.7345	0.565	0.678	
5-day BOD, ppm	Not taken	Not taken	Not taken	Not taken	Initial 7.8; Final 6.05 = 1.75

1 mg/m3 = 1 µg/L = 1 ppb

Table 13. Comparison of Lake Lanao values with Brown and Simpson to give lake classification.

Variable	Lake Lanao values	From Brown and Simpson, Table 1
Secchi depth, m		
Mean	5.14	4.2
Range	3.5 – 6.6	1.5 – 8.1; Mesotrophic
Total Nitrogen, µg/L	(Nitrate- + Ammonia-N)	
Mean	110	660
Range	93 – 120.4	310-11600; Oligotrophic
Total Phosphorus, µg/L		
Mean	31	27
Range	19.7 – 37.7	11 – 96; Mesotrophic
Chlorophyll-a, µg/L		
Mean	0.8626	1.7
Range	0.565 – 1.3937	0.3 – 4.5; Oligotrophic

Aesthetic aspect

The beauty of Lake Lanao has been marred by the sight of garbage along the shoreline of populated areas and floating in the water near the shore. There should be strict implementation by the resident communities of proper garbage disposal and solid waste management.

SUMMARY AND CONCLUSION

The values of various physical and chemical parameters of Lake Lanao follow those quantities usually obtaining in most nonpolluted lakes. Secchi depth ranged from 3.5 m to 6.6 m. Dissolved oxygen at the top 5 m was nearly saturated, indicating that there was no lack of oxygen for organisms in the littoral and limnetic zone. Similar to the pH of most natural waters that is between 6.5 and 9.0, Lake Lanao pH ranged from 7.4 to 9.0. Conductivity generally ranges between 10 and 1,000 µS/cm in most rivers or lakes that have outflows, such as Lake Lanao. Alkalinity values reflect a good buffering capacity of Lake Lanao. Comparing the inorganic nitrogen and total phosphorus levels in the lake show a nitrogen limitation for algal growth. The trophic state of a lake describes its productivity, i.e., how much algal biomass it contains, and consists of three categories as the lake becomes greener or more productive: oligotrophic, mesotrophic, eutrophic. Referring to the table prepared by Brown and Simpson, Lake Lanao is oligotrophic-mesotrophic. The trophic state index based on the equations formulated by Carlson further affirm the trophic status of Lake Lanao as oligotrophic-mesotrophic.

The values for various physical and chemical parameters of Lake Lanao showed good water quality and were in the range for that of a healthy lake. It is nevertheless trending towards eutrophication, which is a natural process in many freshwater ecosystems as they age. However, since human-caused nutrient loading can accelerate this process, cultural eutrophication can be controlled by community and management practices in the catchment basin that will restrict the input of pollutants into the lake.

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LITERATURE CITED

1. Aldridge, K. n.d. Wabamun Lake water quality overview. Accessed at http://www.wwmc.ca/pdf/WWMC%20Water%20Quality%20Overview.pdf on 27 February 2015.

2. Brown, T and Simpson, J. I. Determining the trophic state of your lake. Accessed at www.obvcapitale.org/.../Determining-the-trophic-state-of-your-**lake**.pdf on 2 March 2015.

3. Escudero, P, Garcia-Hansel, C.O., et al. First report of EUS (epizootic ulcerative syndrome) occurrence in Lake Lanao, Lanao del Sur, Philippines. Paper presented at the FIMFS 30th Annual Convention at University of Eastern Philippines, Catarman, Northern Samar on December 9-11, 1998.

4. Frey, D. G. 1969. A limnological reconnaissance of Lake Lanao. Verh. Internat. Verein Limnol. 17. (Reprinted with author’s permission in Mindanao Journal. 1974. 1(1):81-101.)

5. Garcia-Hansel, C. O., Metillo, E. B. Efforts towards the management of Lake Lanao and its watershed. IAMURE International Journal of Ecology and Conservation, [S.l.], v. 18, n. 1, mar. 2016. ISSN 2244-1581. Available at: https://www.researchgate.net/publication/305984302_.

6. Hem, J. D. 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd ed. U.S. Geological Survey Water-Supply Paper 2254. Available at https://pubs.usgs.gov/wsp/wsp2254/pdf/wsp2254a.pdf.

7. Lagmay, J. P., Hansel, C.G., et al. 2006. Hydrobiological assessment of Lake Lanao subsequent to its unusual greening in 2006. Mindanao Journal 29:85-100.

8. Lind, O.T. 1985. Handbook of common methods in limnology. 2nd ed. Kendall/Hunt Publishing Company, Dubuque, Iowa.

9. Lewis, W. M., Jr. 1973. The thermal regime of Lake Lanao (Philippines) and its theoretical implications for tropical lakes. Limnology and Oceanography 18(2):200-217. (Reprinted with author's permission in Mindanao Journal. 1974. 1(1):102-130.)

10. Michaud, J. P. 1991. A Citizen's guide to understanding and monitoring lakes and streams. Available at http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/index.html.