Fluctuation Dynamics on the Biophysico-Chemical Characteristics and Water Quality Evaluation of Lake Mainit, Philippines

Evangeline P. Sabejon[1], Rosalia L. Hugo[1], Jerry B. Manongas[1], Joan Cristine Libot[2], Cara Jane Matabillas[2], Carlos H. Donoso[3], Gregorio Z. Gamboa, Jr[3], Joycelyn C. Jumawan[2], Rey Y. Capangpangan[4,5*]

[1]College of Arts and Sciences, Surigao State College of Technology, Surigao City, Philippines
[2]Department of Biology, Caraga State University, Butuan City, Philippines
[3]College of Engineering, Surigao State College of Technology, Surigao City, Philippines
[4]Department of Chemistry, Caraga State University, Butuan City, Philippines
[5]Mineral Resources Management Research and Training Center, Caraga State University, Butuan City

Corresponding Author: rycapangpangan@carsu.edu.ph

Abstract

This study presents the seasonal data on the dynamics of the water quality in Lake Mainit. It was designed to evaluate the temporal variation of the biophysico-chemical parameters from eight sampling stations from the selected sites around Lake Mainit. Different physico-chemical parameters were investigated such as pH, temperature, conductivity, Oxidation Reduction Potential (ORP), salinity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), sulfate, phosphate, nitrates, and cyanide. Likewise, biological parameters, fecal coliform (FC) and total coliform (TC) were also analyzed. The obtained results were compared with the standards set by the local agency, e.g. Department of Environment and Natural Resources (DENR) Administrative Order 2016-08. The mean values of the different water quality parameters across sampling periods in all sampling stations are enumerated as follows: pH (7.61), temperature (29.4 ^{o}C), conductivity (0.153 μS/cm), ORP (284.5 mV), salinity (0.073 ppt), turbidity (15.46 NTU), chlorides (69.5 mg/L), hardness (158.7 mg/L), DO (12.45 mg/L), TDS (0.0955 mg/L), TSS (0.031 mg/L), SO_4 (489.4 mg/L), PO_4 (5.38 mg/L), NO_3 (29.3 mg/L), Free CN (0.027 mg/L), TC (3116.7 MPN/100 mL) and FC (1078.8 MPN/100 mL). Results have shown that significant variation across sampling periods were observed for the parameters turbidity, DO, sulfate, phosphate, TC, and FC. Also, the mean values of these parameters exceeded the set standards, while other parameters are all within the acceptable limits. Cluster Analysis showed three major cluster groups with significant linkage distance while Principal Component Analysis (PCA) revealed that there are five (5) principal components which represents a total variance of 71.04%. Overall, the water from Lake Mainit was found to be in a safe quality based on the acceptable standard value, and the lake can still be considered eutrophic.

Keywords: *biophysical, physico-chemical properties, temporal variation, water quality*

1. Introduction

Lake Mainit is an important natural resource shared by the provinces of Agusan Norte and Surigao del Norte, distinguished as the deepest (219.35 meters) and fourth largest (17,060 ha) lake in the Philippines, with a shoreline of 62.1 km long and a watershed area of 87,072 ha. Twenty-eight river tributaries contribute to the water volume of Lake Mainit, which is drained by a single outlet – the 29 km Kalinawan River that flows into Butuan Bay [1,2]. Due to massive anthropogenic activities in the surrounding area, the quality of the water in the lake is now perturbed that may affects the different life forms present in the lake. The degradation of water quality in lakes and rivers could be attributed to increased population, industrialization, irrigation, human activities like improper use of fertilizers, natural dynamics, mining and anthropogenic sources like domestic and municipal sewage. Monitoring of the water quality of the lake is highly imperative component in understanding the health status of the lake. As reported, a healthy aquatic ecosystem is dependent on the physico-chemical and biological characteristics [3]. The composition, distribution and abundance of aquatic organism are related to how the water interacts physically and chemically with other substances. Likewise, it has been noted that successful production of fish and other aquatic resources is dependent on the proper balance of physical, chemical and biological properties of water in ponds, lakes and reservoirs [4].Furthermore, poor water quality could also affect the aquatic diversity [5]. A declined fish biodiversity shows strong correlation to dirty water [6]. The *pijanga* or white goby, a dominant fish species in the Lake Mainit has declined from approximately 25 kg to 5-10 kg fish catch in recent years. There is a fear that endemic and rare fishes in the lake will be lost because of the existing threat to habitat degradation due to pollution from agriculture, mining, destructive fishing practices and use of chemicals and poisons. Likewise, low DO was pointed to be the main reason for the recent fish kill in Lake Mainit.

Due to its direct involvement or indirect influence on microbial growth, the water quality is significantly affected by the physicochemical parameters[7,8]. As reported, various severe diseases like diarrhea, cholera, dysentery, typhoid, among others are associated to contaminated water [9]. Hence, to maintain the good water quality necessitates a regular water quality monitoring on the biophysico-chemical parameters including the analysis of total and fecal coliform. The water quality parameters are correlated with each other and the significant correlations would be useful to analyze the water quality [10]. Though the water quality in the lake were assessed in terms of the physico-chemical and bacteriological parameter [11] however, the ecological integrity of the lake is being influenced by its physical and water quality conditions. To determine biological integrity, trophic level and recreational potential of these aquatic ecosystems, it is necessary to determine physicochemical and biological indicators. That impact, indicates changes in biological quality [12]. The oligo-eubiosis condition of Lake Rupanco in Chile represent good ecological integrity and is consistent with trophic level reported in previous studies based on physicochemical parameters and chlorophyll concentrations [13]. Lake Mainit serves as a catchment of heavy siltation coming from various tributaries.

Thus, this present study was carried out to evaluate the changes on the biophysico-chemical parameters of Lake Mainit. The physico-chemical parameters that were assessed were nitrates, ammonia, phosphate, DO, pH, biochemical oxygen demand, TDS, sulfate, water hardness, chloride, free cyanide and the bacteriological parameters (total and fecal coliforms) of the water. The observed values were compared to the local standard values set by the Department of Environment and Natural Resources (DENR).

2. Materials and Methods

2.1 Locale and Duration of the Study

Samples were collected from eight pre-selected sites around Lake Mainit, Philippines (Figure 1). Sampling stations were selected based on the diversity of the land uses, population density, areas of industrial or anthropogenic activities and with noted tributaries of the Lake Mainit that could potentially affect the water quality. Sample collection were conducted quarterly for four (4) quarters of 2018.

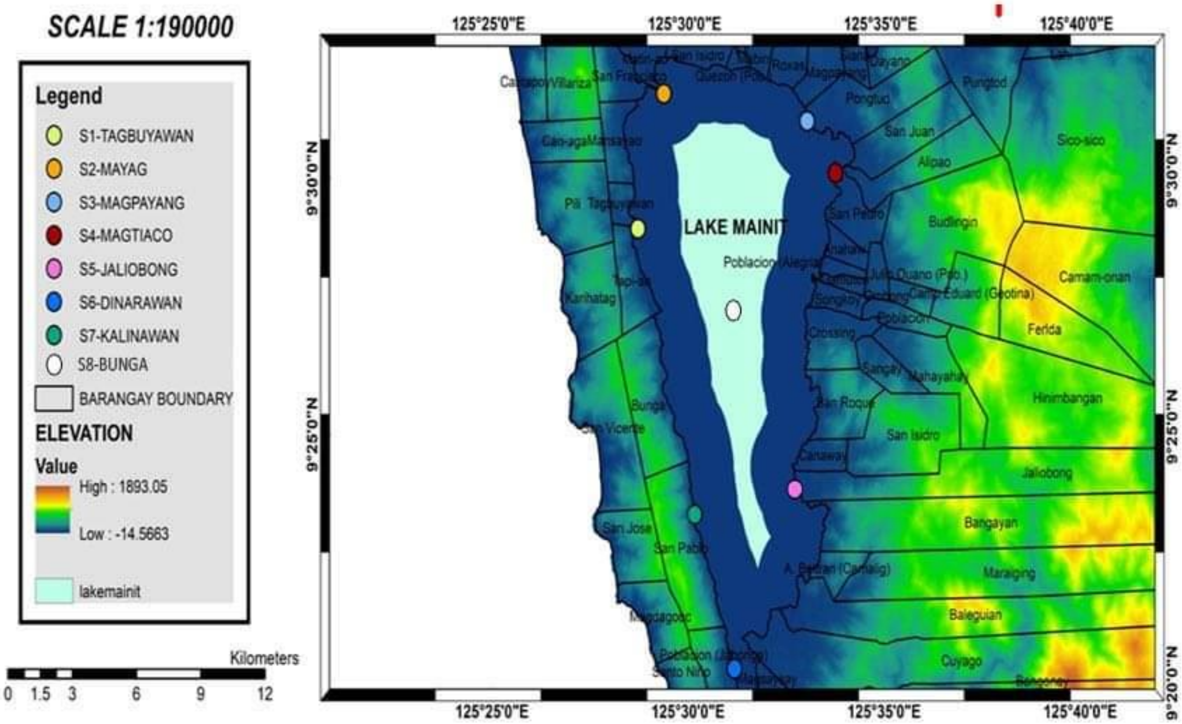

Figure 1. Map of the study area reflecting the different sampling sites in Lake Mainit

2.2 Sample Collection

Water samples were collected in the identified sampling sites. Sampling was done every morning of each quarter from April 2018 to December 2018. Samples were collected in previously cleaned polyethylene bottles of at least 1L capacity. All samples were stored in a chilled container during transportation.

2.3 Analytical Instruments

2.3.1. On-Site Analysis. On-site analyses of temperature, pH, salinity, turbidity, conductivity, total dissolved solids (TDS), oxidation-reduction potential (ORP), dissolved oxygen (DO) were carried out at the site of sample collection using the U-50 Multiparameter Water Quality Meter (Horiba). The water checker was calibrated prior to use. The sensors of the handheld multiparameter checker was immersed in the water sample and a stable reading was recorded. Three replicate measurements were obtained. After the measurement of each sample, the probe was rinsed with deionized water to avoid cross contamination among different samples.

2.3.2. Laboratory Analysis. The measurements of the parameters other than those measured on-site were carried out in the laboratory. The analysis of total suspended solids (TSS) was conducted using gravimetric method while nitrate and phosphate were analyzed using UV-Vis optical method. Potentiometric method was used for the analysis of free cyanide using the cyanide ISE. Likewise, water hardness was analyzed using EDTA titration, chloride using Argentometric method, Total nitrogen was determined using Kjeldahl Method, ammonia via titrimetric method and sulfate via turbidimetric method. Also, fecal and total coliform analyses was conducted using the multiple tube fermentation techniques. Whenever appropriate, all calculations were blank-corrected.

2.3.3 Bacteriological Analysis. For bacterial analysis, all water samples were collected in sterile glass container that were filled completely. Samples were then placed in an iced container during transportation for laboratory analysis (maximum holding time of 6 hours after sample collection).

3. Results and Discussion

3.1 Water Quality Evaluation

A total of eight (8) sampling sites of Lake Mainit were established where water samples were collected during the four different sampling seasons (Q1, Q2, Q3 and Q4). The dynamics and the seasonal variations in the physico-chemical properties (DO, BOD, pH, Temperature, TSS and TDS) of water samples from Lake Mainit is summarized in Figure 2. As shown, the average temperature in the water samples varies from 25.76 ^{o}C to 31.91 ^{o}C. The observed fluctuating temperature is probably associated to the varied environmental condition during sampling. Similarly, the pH value across sampling stations in all sampling periods are all within an acceptable range. The pH has direct and indirect effects on water quality and the biota of aquatic ecosystems and even short term reduction in pH can create lethal condition to biota [14]. It was observed however that a high pH value (8.23) was observed in the water sample taken from Tagbuyawan (Station 1) during the fourth sampling period (Figure 2). Also, the average DO values across sampling stations in all sampling periods ranges from 6.83 mg/L – 27.53 mg/L, and all of these values are all above 5.0 mg/L (minimum standard limit). DO values below the 5.0 mg/L minimum limit means it can cause stress to the aquatic organisms. The obtained results show that the water samples from Lake Mainit are still able to support aquatic life. Dissolved oxygen (DO) is needed by all aquatic life in water columns as well as by organisms in benthic processes in the ecosystem. [15]. The DO content of water is a measure of the water quality[16]. Moreover, the BOD results revealed that all samples during the second to fourth sampling periods are all within the 7.0 mg/L acceptable limit. However, it is notable that the BOD values in all sampling stations during the first sampling period are all above the acceptable value which may indicate a polluted water. Plausibly, high temperature and high phosphate concentration during the first sampling period contributes to the observed higher BOD values. As noted, BOD is affected by temperature and high phosphate concentration (The rate of oxygen consumption in a stream is affected by a number of variables: temperature, pH, presence of certain kinds of microorganisms and type of organic and inorganic material in the water [17]. The total suspended solids (TSS) concentration is in the range from 0.006 – 0.3 mg/L, and these results are all below the accepted value (80 mg/L). The result suggests that the water samples contain significantly lower amount of suspended particulate matter. Similarly, the maximum and minimum TDS values were recorded at 0.241 mg/L and 0.047 mg/L, respectively.

Other physico-chemical parameters such as the conductivity (0.01 – 0.632 μS/cm), ORP (193.67 – 341.67 mV), salinity (0 – 0.133 ppt), chloride (18.91 – 118.17 ppm), free cyanide (0.0248 – 0.0569) are all below the standard limit (Figure 3). However, the water hardness results indicate that the water samples, particularly in stations 2 and 3 during the first sampling season is very hard (356.84 mg/L). Also, most of the turbidity values exceeded the 25.0 NTU, a standard limit set by EPA. High turbidity may be due to human activities, decrease in water level and presence of suspended particulate matter [18] particularly during the second and fourth sampling periods. High turbidity during rainy season is significantly positively correlated with temperature, nitrate, PO_4 and free CO_2 [19]. The observed high turbidity can be attributed to high load of suspended solids due to heavy precipitation during sampling. Notably, the sulfate concentration in water samples across sampling stations exceeded

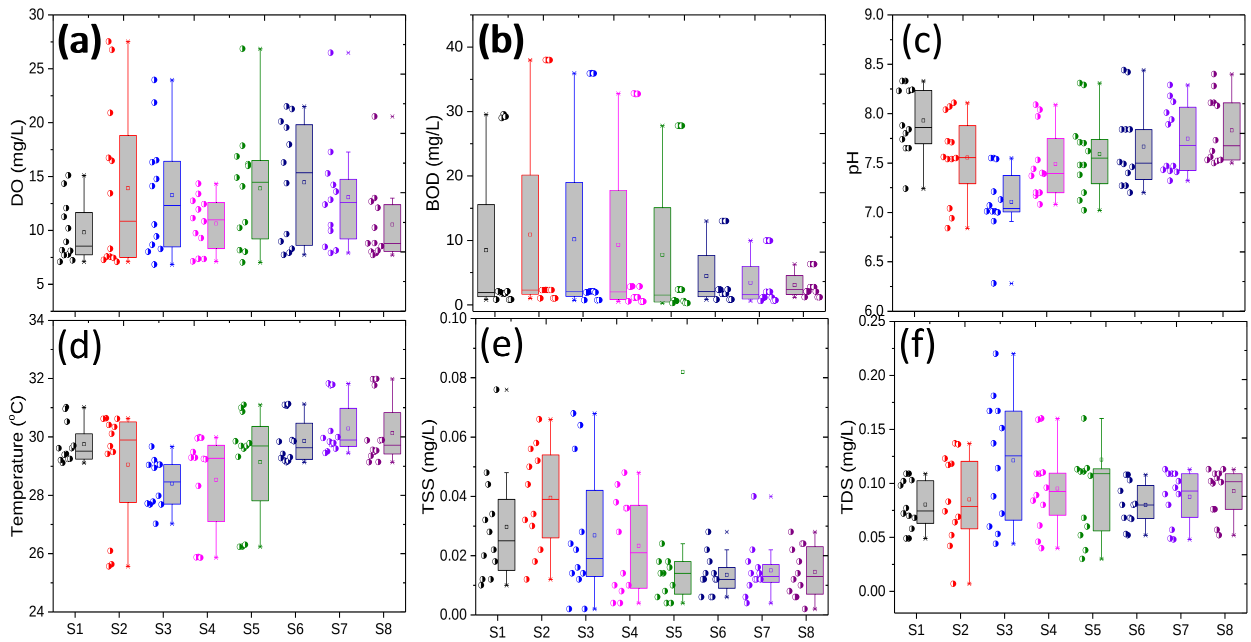

Figure 2. Box-Plot showing the variation of the different water quality parameters (a) DO, (b) BOD, (c) pH, (d) Temperature, (e) TSS, and (f) TDS

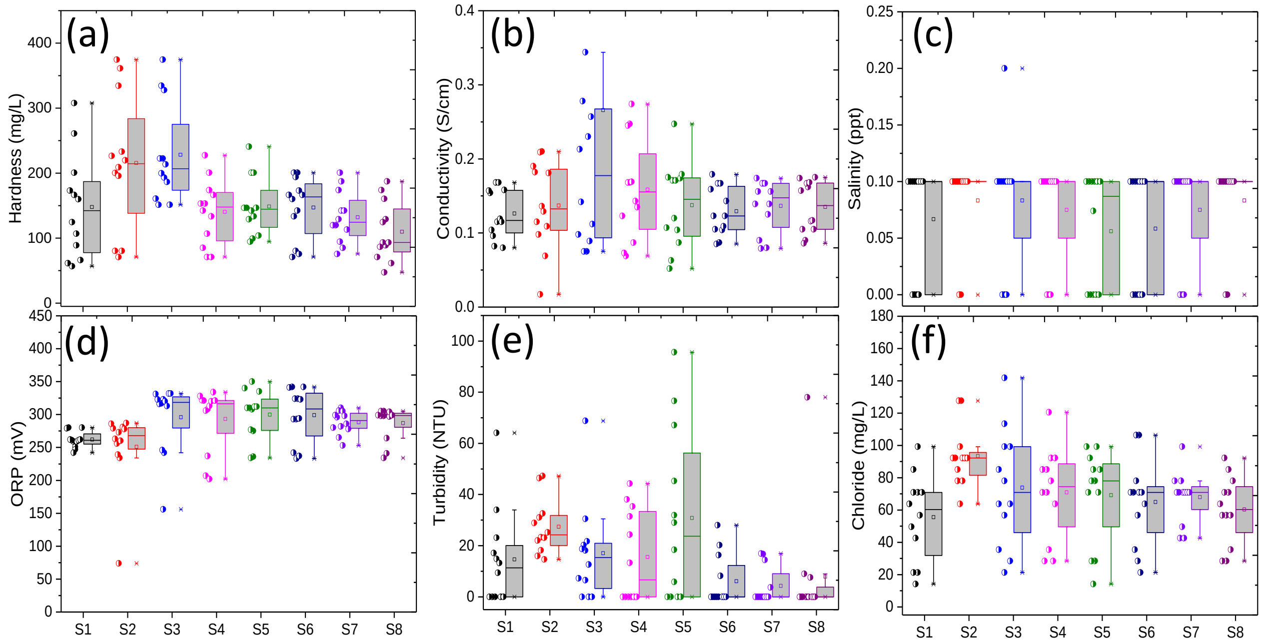

Figure 3. Box-Plot showing the variation of the different water quality parameters (a) Hardness, (b) Conductivity, (c) Salinity, (d) ORP, (e) Turbidity, and (f) Chlorides

the set standard limit by the DENR (275 mg/L). The most plausible reason for the observed results might be dictated on the nature of the water samples as most of the sampling stations are being characterized by the presence of mining operations, live stocks, agricultural activities and residential structures and establishments. As noted, discharge of industrial wastes and domestic sewage tends to increase sulfate concentration. In the area, seven places are having sulfate ion concentration more than 200 and the higher sulfate content maybe due to biochemical, anthropogenic sources and industrial process etc. [20].

3.2 Nutrient Content and other Chemical Parameters

Figure 4 shows the concentration level of nitrates in the water samples. As shown, the nitrate concentration across sampling stations in all sampling periods exceeded the set standard limit of 7.0 mg/LNitrate is both soluble and mobile, it is prone to leaching through soil with infiltrating water, and it can persist in shallow groundwater for years [21]. Moreover, the hydrogeological settings, seasonal trends and anthropogenic activities are major factors that influence the mobility and accumulation of nitrates [22]. Under rainfall or irrigation conditions, high levels of soluble nitrates (NO3-–N) leak through soil and into groundwater and then drain away with the groundwater flow. Nitrate leakage can cause nitrate pollution of groundwater; subsequently, the contaminated groundwater is likely to drain into rivers, resulting in further environmental damage to surface water [23]. In particular, the nitrate concentration in third and fourth sampling periods recorded at about 6 times higher than the set limit. Wastes from the residential and other establishments nearby might contribute to the observed higher level of nitrate concentration. As reported, the freshwater nitrates are contributed from discharge of sewage, industrial and human wastes, and runoff from agricultural fields. Most sources of nitrates come from human activity and can be traced to agricultural activities, human wastes or industrial pollution; in addition to animal waste, untreated human sewage can contribute to nitrate levels in surface and groundwater, leaking and poorly functioning septic systems are sources of nitrates [24]. In contrast, the concentration of nitrogen as ammonia are all below the standard limit of 0.5 mg/L. The results suggest that nitrate form of nitrogen predominates in all water samples in Lake Mainit which can also be explained to the fact that tremendous agricultural activities are prevalent in the surrounding area of the lake which maybe the primary source of nitrates. Moreover, the phosphate concentration exceeded the standard limit (0.5 mg/L) during the first and second sampling period and this can possibly be attributed to wastewater contamination from laundry detergents and high discharge of sewage from live stocks, small -scale mining, and agricultural land area. The obtained results corroborate to the fact that high BOD was noted during the first sampling period.

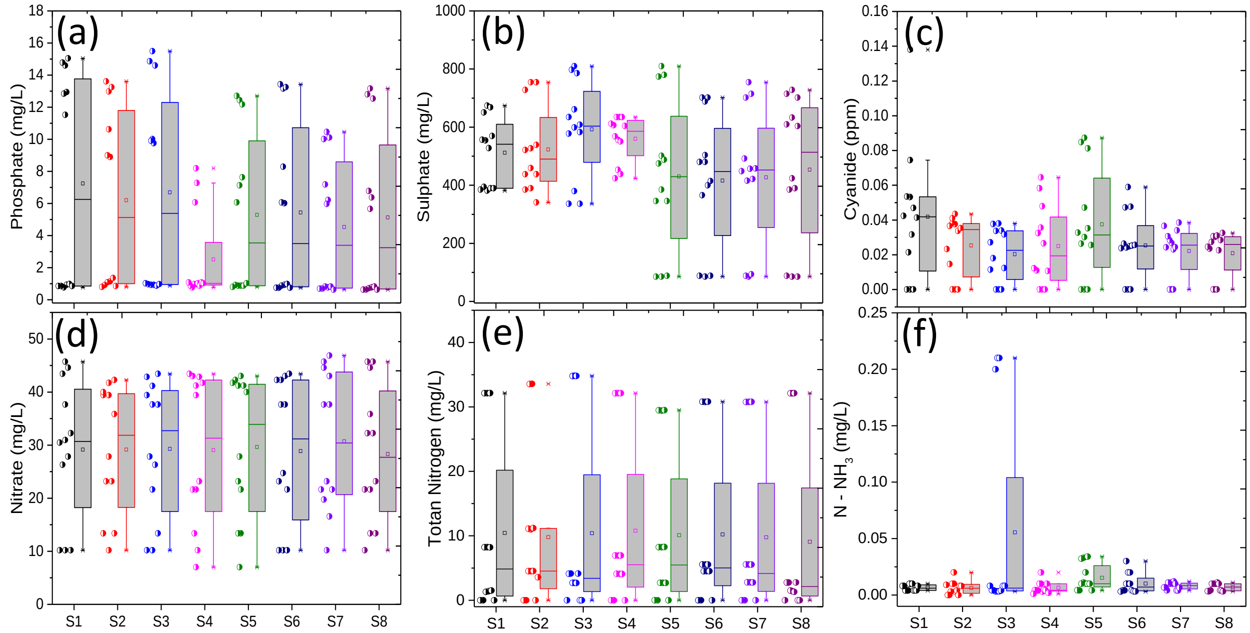

Figure 4. Box-Plot showing the variation of the different water quality parameters (a) Phosphate, (b) Sulfate, (c) Cyanide, (d) Nitrate, (e) Total Nitrogen, and (f) Nitrogen as ammonia

3.3 Bacteriological Content

Results of the bacteriological analysis are shown in Figure 5. The average total coliform count by multiple fermentation test varied from 219.18 – 5192.38 MPN/100 mL and the peak values were noted during the fourth sampling period. Similarly, the fecal coliform count in most of the sampling stations are all within the standard except for sampling station 3 during the fourth sampling period of which it exceeded the EPA standard (5000 MPN/100 mL). the result is in agreementwith Shitttu et al [25] and Sanders et al [26] who reported high coliform counts of 800 to 1600MPN/100 mL for fecal coliform; fecal counts were generally high especially for sites S2, S7 & S9(≥ 1600MPN/100mL which indicated the possibility of contamination with human or animal waste and also pathogenic bacteria. Higher values obtained in the fourth sampling period, particularly in stations 3 and 4 might be due to higher loads of contaminants from agricultural live stocks and human wastes via surface run-off due to precipitation. It is notable though that the obtained values are all within the EPA standard for total coliform (25,000 MPN/100 mL). Total coliforms are gram-negative, aerobic or facultative anaerobic nonspore forming rods believed to indicate the presence of fecal contamination. However, total coliforms have been found to be widely distributed in nature and not always associated with the gastrointestinal tract of warm-blooded animals. Moreover, the number of Total Coliform in the environment is still widely used as an indicator for potable water in the United States [27]. Coliform counts (total and fecal) is a good indicator of the water quality. Total and fecal coliform bacteria are sensitive and commonly used indicators of bacterial pathogen contamination of water. Total coliform, fecal coliform, E. coli & Fecal Streptococcus are presently being used to assess contamination in water quality management due to their simple and cost-efficient detection compared to other pathogens [28]. Total Coliforms (TC) are a group of closely related bacteria that are not harmful to humans. Total Coliform bacteria are commonly found in the environment (e.g., soil or vegetation) and are generally harmless. If only Total Coliform bacteria are detected in drinking water, the source is probably environmental [29]. TC are being affected by several factors such as environmental stress, lack of nutrients, among others. Fecal coliform (FC) count is widely used to monitor aquatic system for sewage contamination. Lenart-Boron et al (2016a) [30] in their 2-year study indicated the variability of nutrient concentration and abundance of bacteria in sampling site associated with anthropogenic pressure in a form of inflow of either fresh or distant in time contamination. It originates from intestinal tracts of homeothermic animals. *E. Coli* and intestinal enterococci have been thought to indicate fecal pollution from homeothermic mammals and birds and therefore signal the potential occurrence of pathogens from these group of animals [31]. The observed data suggest that higher TC and FC counts were observed in the fourth sampling period plausibly due to the transport of organic matter from various sources through surface run off from the catchment area, including some of the anthropogenic activities such as bathing and washing, improper disposal of animal and human wastes, among others. From the results obtained in the present study, it is also evident that interferences through human activities and the presence of agricultural livestock production in the area greatly contributed and influences the water quality of the lake.

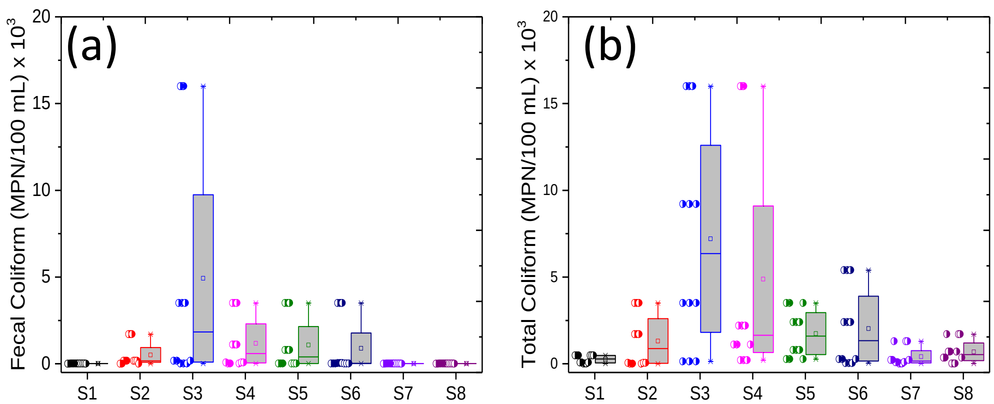

Figure 5. Box-Plot showing the variation of the bacteriological parameters (a) Fecal Coliform, and (b) Total Coliform

3.4 Statistical Analyses

3.4.1 Correlation analysis of the water's Physico-Chemical parameters

Correlation table shows that water hardness had weak to fair correlation to other physico-chemical parameters. Most of the correlation coefficients are less than 0.7 (absolute value) with most of the parameters except for Total Coliform (0.91) during the fourth quarter sampling period. Moreover,

Table 1. Correlation matrix of the different water quality parameters in the first quarter (first sampling period)

	Hardness	Chloride	TSS	SO4	PO4	NO3	Temp	pH	ORP	Cond	NTU	DO	TDS	ppt	CN	TC	FC	tN	NH3	BOD
Hardness	1.00																			
Chloride	0.17	1.00																		
TSS	0.34	-0.35	1.00																	
SO4	0.33	0.26	-0.28	1.00																
PO4	0.42	-0.36	0.30	0.32	1.00															
NO3	**0.52**	-0.02	0.41	0.35	0.40	1.00														
Temp	**-0.88**	-0.27	-0.21	-0.17	-0.15	-0.31	1.00													
pH	**-0.74**	-0.21	-0.14	-0.34	-0.29	-0.22	**0.82**	1.00												
ORP	-0.45	0.05	-0.11	-0.04	0.06	-0.46	0.47	0.31	1.00											
Cond	0.39	0.25	-0.06	0.40	0.21	0.27	-0.27	-0.47	-0.35	1.00										
NTU	**0.76**	0.06	0.19	0.12	0.37	0.20	**-0.82**	**-0.87**	-0.35	0.29	1.00									
DO	0.41	0.10	0.36	0.05	0.13	0.07	**-0.51**	**-0.74**	-0.24	0.18	**0.58**	1.00								
TDS	-0.09	0.07	-0.27	**0.56**	0.08	-0.12	0.12	-0.22	0.25	0.16	-0.09	0.22	1.00							
ppt	0.28	0.15	0.09	0.29	0.05	0.23	-0.24	-0.08	-0.01	0.17	-0.22	-0.10	0.11	1.00						
CN	0.23	0.29	0.15	0.18	-0.38	0.24	-0.18	-0.01	-0.22	-0.01	-0.07	-0.02	0.12	0.07	1.00					
TC	**0.62**	0.28	-0.07	**0.57**	0.14	0.24	**-0.59**	**-0.70**	-0.27	**0.66**	**0.50**	0.23	0.25	0.46	0.06	1.00				
FC	**0.75**	0.32	-0.03	**0.55**	0.12	0.28	**-0.78**	**-0.80**	-0.36	**0.56**	**0.64**	0.36	0.20	0.44	0.10	**0.95**	1.00			
tN	0.18	0.12	0.01	-0.43	-0.34	-0.12	-0.48	-0.26	-0.30	-0.15	0.41	0.23	-0.25	-0.21	-0.07	0.03	0.19	1.00		
NH3	**0.56**	0.14	-0.04	**0.56**	0.32	0.23	-0.44	**-0.61**	-0.17	**0.70**	0.44	0.16	0.26	0.44	-0.09	**0.96**	**0.86**	-0.10	1.00	
BOD	**0.76**	0.49	0.04	0.45	-0.09	0.42	**-0.80**	**-0.59**	-0.41	0.23	**0.52**	0.29	0.10	0.27	**0.55**	**0.58**	**0.74**	0.34	0.39	1.00

Table 2. Correlation matrix of the different water quality parameters in the second quarter (second sampling period)

	Hardness	Chloride	TSS	SO4	PO4	NO3	Temp	pH	ORP	Cond	NTU	DO	TDS	ppt	CN	TC	FC	tN	NH3	BOD
Hardness	1.00																			
Chloride	**0.54**	1.00																		
TSS	0.04	0.15	1.00																	
SO4	0.29	0.00	-0.27	1.00																
PO4	0.43	0.35	-0.02	-0.43	1.00															
NO3	0.02	0.10	0.11	0.25	-0.22	1.00														
Temp	0.07	-0.08	0.10	0.07	-0.15	0.31	1.00													
pH	-0.04	-0.13	0.12	-0.04	0.19	0.04	0.42	1.00												
ORP	-0.04	0.17	0.04	0.14	**-0.56**	-0.05	-0.17	-0.78	1.00											
Cond	-0.16	0.20	-0.32	0.04	0.22	0.04	0.05	0.33	-0.34	1.00										
NTU	0.00	-0.13	0.18	-0.24	0.06	-0.15	-0.23	-0.13	0.04	**-0.57**	1.00									
DO	-0.06	-0.14	-0.04	0.04	-0.11	-0.30	-0.39	-0.40	0.30	-0.37	0.22	1.00								
TDS	0.19	0.34	-0.23	0.04	0.30	-0.09	0.19	0.07	-0.11	**0.59**	**-0.68**	-0.12	1.00							
ppt	0.03	0.32	-0.07	-0.07	0.38	-0.12	0.16	0.20	-0.32	0.49	-0.40	-0.11	**0.72**	1.00						
CN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00					
TC	**-0.51**	-0.29	-0.02	0.13	**-0.53**	-0.05	0.01	-0.19	0.30	0.10	0.10	-0.05	-0.01	0.01	-	1.00				
FC	**0.51**	0.16	-0.03	0.38	0.30	0.08	0.13	**0.70**	**-0.69**	0.14	-0.06	-0.24	0.04	0.16	-	-0.42	1.00			
tN	0.20	0.08	0.19	-0.22	0.38	-0.07	0.05	**0.74**	**-0.65**	0.00	0.05	-0.10	-0.14	0.02	-	**-0.66**	**0.72**	1.00		
NH3	-0.38	-0.14	0.01	0.00	-0.48	-0.02	0.30	0.01	0.43	-0.08	-0.01	-0.30	-0.21	-0.24	-	0.40	-0.36	-0.24	1.00	
BOD	0.11	0.01	0.13	0.14	-0.08	0.25	**0.60**	0.29	-0.21	0.11	0.03	**-0.68**	0.08	0.20	-	0.44	0.22	-0.15	0.23	1.00

Table 3. Correlation matrix of the different water quality parameters in the third quarter (third sampling period)

	Hardness	Chloride	TSS	SO4	PO4	NO3	Temp	pH	ORP	Cond	NTU	DO	TDS	ppt	CN	TC	FC	tN	NH3	BOD
Hardness	1.00																			
Chloride	0.44	1.00																		
TSS	**0.50**	**0.68**	1.00																	
SO4	-0.45	-0.15	-0.05	1.00																
PO4	**0.77**	**0.74**	**0.67**	-0.45	1.00															
NO3	0.21	0.09	-0.06	0.15	0.08	1.00														
Temp	0.42	**0.79**	**0.64**	-0.06	**0.64**	0.20	1.00													
pH	-0.07	0.30	0.22	-0.14	0.20	-0.31	**0.50**	1.00												
ORP	-0.12	-0.33	-0.34	0.10	-0.24	0.29	-0.45	**-0.83**	1.00											
Cond	0.20	**0.58**	0.40	-0.06	0.33	0.30	**0.70**	0.13	-0.13	1.00										
NTU	**0.73**	**0.50**	**0.54**	-0.39	**0.68**	0.01	0.46	0.28	-0.46	-0.03	1.00									
DO	-0.12	-0.11	**-0.55**	-0.08	-0.07	0.36	-0.02	-0.15	**0.51**	0.03	-0.29	1.00								
TDS	-0.06	0.44	0.38	-0.11	0.18	-0.03	**0.58**	0.22	-0.14	**0.87**	-0.14	-0.05	1.00							
ppt	-0.13	0.18	0.33	0.18	0.06	0.14	0.31	-0.15	0.11	**0.59**	-0.20	-0.12	0.69	1.00						
CN	0.26	0.09	0.05	-0.10	0.04	-0.09	-0.01	0.28	-0.37	0.05	0.21	-0.30	-0.09	-0.40	1.00					
TC	**0.63**	0.37	0.26	**-0.63**	**0.61**	0.12	0.33	-0.23	0.16	0.27	**0.57**	0.11	0.20	0.14	-0.19	1.00				
FC	**0.78**	0.40	**0.60**	-0.38	**0.62**	0.05	0.27	-0.27	-0.08	0.22	**0.66**	-0.50	0.09	0.14	0.09	**0.72**	1.00			
tN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00		
NH3	**-0.65**	**-0.75**	**-0.80**	0.22	**-0.82**	0.06	**-0.81**	-0.37	0.44	-0.37	**-0.77**	0.30	-0.32	-0.19	0.00	-0.53	**-0.62**	-	1.00	
BOD	0.32	-0.04	0.47	0.09	0.21	-0.20	-0.11	-0.23	0.24	-0.17	0.03	-0.37	-0.13	0.08	0.03	-0.05	0.35	-	-0.22	1.00

Table 4. Correlation matrix of the different water quality parameters in the fourth quarter (fourth sampling period)

	Hardness	Chloride	TSS	SO4	PO4	NO3	Temp	pH	ORP	Cond	NTU	DO	TDS	ppt	CN	TC	FC	tN	NH3	BOD
Hardness	1.00																			
Chloride	-0.13	1.00																		
TSS	-0.24	0.04	1.00																	
SO4	0.31	0.11	0.26	1.00																
PO4	0.46	-0.08	-0.06	**0.75**	1.00															
NO3	-0.26	-0.20	0.02	-0.30	**-0.61**	1.00														
Temp	-0.37	0.48	0.27	-0.31	**-0.74**	0.38	1.00													
pH	-0.44	-0.10	0.32	-0.22	**-0.72**	**0.70**	**0.73**	1.00												
ORP	**0.51**	**-0.53**	-0.38	0.13	**0.58**	-0.33	**-0.87**	**-0.64**	1.00											
Cond	0.39	0.04	-0.17	**0.64**	**0.62**	-0.22	**-0.51**	**-0.54**	0.41	1.00										
NTU	0.05	0.11	-0.13	-0.08	0.41	**-0.61**	**-0.55**	**-0.69**	0.45	-0.06	1.00									
DO	0.41	0.30	-0.25	-0.15	-0.09	-0.18	0.34	-0.06	-0.06	-0.07	-0.04	1.00								
TDS	0.47	0.12	-0.06	0.55	0.48	-0.06	-0.30	-0.39	0.31	**0.81**	-0.16	0.03	1.00							
ppt	-0.09	0.09	0.10	0.20	-0.26	0.38	0.30	0.36	-0.25	0.42	-0.68	-0.01	0.44	1.00						
CN	-0.08	-0.14	-0.10	**-0.69**	-0.19	-0.29	-0.10	-0.30	0.20	-0.44	**0.57**	0.24	-0.41	-0.46	1.00					
TC	**0.59**	-0.33	-0.25	**0.61**	**0.75**	-0.29	**-0.71**	-0.49	**0.65**	**0.70**	0.00	-0.13	**0.50**	0.06	-0.44	1.00				
FC	**0.91**	-0.29	-0.21	0.43	**0.52**	-0.30	-0.44	-0.38	**0.59**	0.46	-0.06	0.29	0.45	0.00	-0.24	**0.78**	1.00			
tN	0.17	-0.43	-0.21	0.08	0.14	0.08	-0.20	0.11	**0.51**	0.03	-0.19	0.13	0.01	0.04	-0.09	0.29	0.29	1.00		
NH3	0.25	-0.14	-0.10	-0.25	0.26	-0.44	-0.49	**-0.60**	**0.50**	-0.10	**0.81**	0.10	-0.04	-0.55	**0.77**	-0.12	0.06	-0.10	1.00	
BOD	-0.34	0.37	0.25	-0.01	**-0.51**	0.31	**0.77**	**0.64**	**-0.62**	-0.18	-0.59	0.08	-0.03	0.37	-0.44	-0.37	-0.23	-0.08	-0.67	1.00

TSS – total suspended solids, SO_4 – sulfate (in mg/L), PO_4 – phosphate (in mg/L), NO_3 – nitrate (in mg/L), ORP – oxidative reduction potential (in mV), Cond – conductivity (in S/cm), NTU – turbidity (in Nephelometric Turbidity Units), DO – dissolved oxygen (in mg/L), TDS – total dissolved solids (in mg/L), ppt – salinity (in ppt unit), CN – cyanide (in mg/L or ppm), TC – total coliform (in MPN/100 mL), FC – fecal coliform (in MPN/100 mL), tN – total Nitrogen (in mg/L), N-NH_3 – nitrogen as ammonia (in mg/L), BOD (biological oxygen demand (in mg/L)

Total Coliform showed strong positive correlation to Fecal Coliform (0.95) and Nitrogen as ammonia (0.96) during the first sampling period and to water hardness (0.91) during the fourth sampling period. Likewise, conductivity is strongly correlated to Total Dissolved Solids (TDS) during the fourth sampling period. On the other hand, Temperature showed fair to strong negative correlation to turbidity (-0.82), water hardness (-0.88), Fecal coliform (-0.78) and BOD (-0.80), while it shows high positive correlation to pH (0.82) during the first sampling period. It is interesting to note that most of the parameters did not show any correlation with each other, signifying that most likely, these parameters are not affected by any of these parameters. Also, it is notable that there was a significant change (decreases) in terms of the value of their correlations during the succeeding sampling periods. The observed decrease in correlation during the second to fourth sampling period can be attributed to the drastic changes in environmental condition and seasonal fluctuations, e.g. temperature and degree of precipitation during that sampling period.

3.4.2. Cluster Analysis

Evaluation on the generated dendrogram from hierarchical cluster analysis (Figure 6) showed three major branches which can be labelled as A, B, and C.

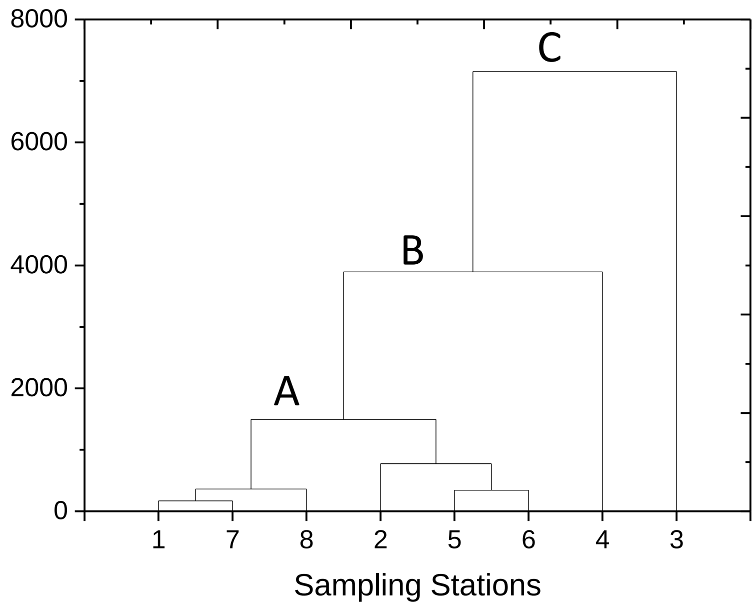

Figure 6. Dendrogram from hierarchical agglomerative cluster analysis of the different physico-chemical parameters of the water samples collected from the various sampling points in Lake Mainit

These branches may represent major cluster groups because the linkage distance at which they combine with each other is large. Also, these major clustering may also signify distinct characteristics which makes them different from one another. As shown, the Euclidean linkage distance among these three major groups are different, that is the order according to increasing linkage distance is as follows: A < B < C. The data suggests that these three groups are different.

Interestingly, group A can be further divided into two groups, though, these groups may show similar properties since their linkage distance do not significantly vary. The figure (Figure 6) also shows that sampling stations 1, 7, 8, 2, 5 and 6 may have similar fluctuation dynamics of the biophysico-chemical properties of the water samples collected from these sites, while sampling stations 3 and 4 manifested distinct dynamics from the rest of the sampling stations.

3.4.3. Principal Component Analysis (PCA)

Figure 7a shows the principal component loadings after conducting PC analysis. As can be seen in the scree plot (Figure 7b), the bend is noticeable after the fifth PC (Eigenvalues > 1). The obtained PCA results suggest that most of the parameters under investigation exhibit weak or ineffective loading contribution to their respective principal component (loadings < 0.5 are considered weak/ineffective loading). Further examination showed that the five (5) extracted PCs represent a total variance of 71.04%. Based on the PC loadings, 20 parameters were grouped into five PC groups. PC 1 consists of water hardness, chloride, phosphate (PO_4) and nitrogen as nitrates (NO_3) and PC 2 comprises of conductivity, DO, TDS, nitrogen as ammonia (NH_3), and BOD. Similarly, temperature, pH, turbidity, and salinity belong to PC 3, and sulfate (SO_4), cyanide, total coliform, and fecal coliform are grouped to PC 4 while PC 5 is composed of TSS, ORP, and total nitrogen. These results infer that the parameters that are grouped together show similar contribution to the collective behavior of the original set of variables being considered. Likewise, the respective PCs most likely represents how these individual parameters with significant contributions move together.

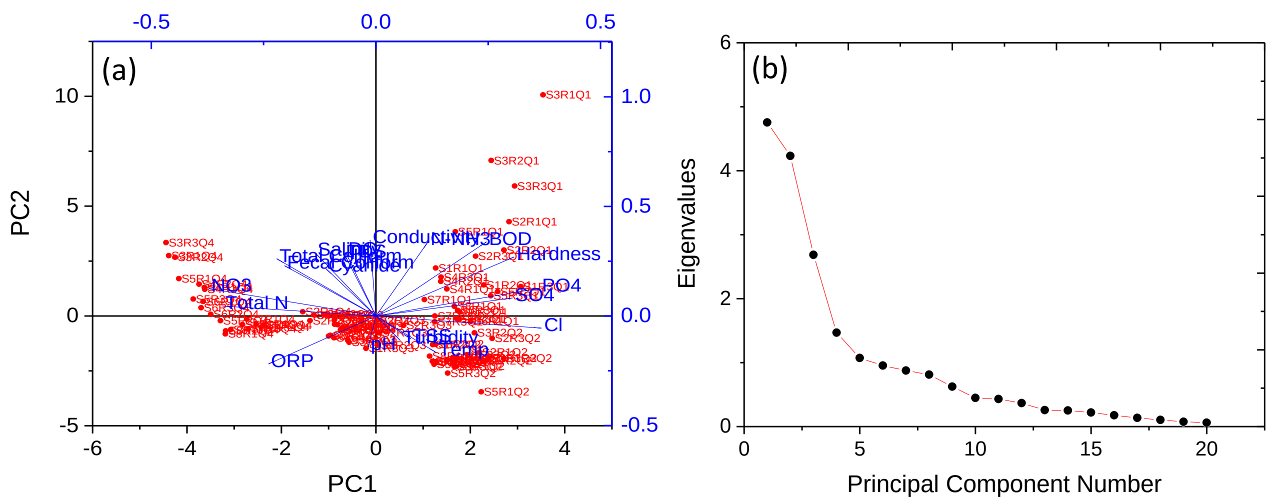

Figure 7. (a) Principal component loadings and (b) Scree plot showing the major principal components on the different physico-chemical parameters

4. Conclusion

In this present investigation, a total of 20 water quality parameters from 8 identified sampling sites were evaluated to assess the fluctuation dynamics of the water quality of Lake Mainit, Philippines. The results obtained suggest that there is a significant variation across sampling periods for the parameters turbidity, DO, sulfate, phosphate, TC, and FC. Also, the mean values of these parameters exceeded the set standards, while other parameters are all within the acceptable limits. Variations of the water quality results suggest that entry of the different potential pollutants from the different point and non-point sources may significantly vary. Likewise, there are three major cluster groups identified from cluster analysis, which may signify distinct characteristics which makes them different from one another. Stations 1,7,8,2,5, and 6 possibly exhibit similar fluctuation dynamics of the biophysico-chemical properties of the water samples, while stations 3 and 4 shows distinct dynamics from the rest of the sampling stations. Importantly, PCA results suggest that the 20 water quality parameters are grouped into 5 different principal components, which show similar significant contributions to the overall water quality of Lake Mainit. In general, this study provides fundamental implications of the different water quality parameters in describing the seasonal and temporal pattern of the biophysico-chemical characteristics of Lake Mainit. The data generated from this study can strengthen the current government's effort to preserve the water resource within Lake Mainit.

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