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Analyzing the Temporal and Spatial Trends of Water Quality and Eutrophication in Laguna de Bay, Philippines, 2000-2012

ABSTRACT

Pollution levels may vary greatly in large waterbodies over long periods of time. Hence, classifying pollution must be inclusive of crucial locations and temporal variabilities. This study applied various statistical techniques to look into the spatial and temporal trends of nine physicochemical parameters within the lake: Biochemical Oxygen Demand (BOD, mg L^{-1}), Ammonia (NH_3, mg L^{-1}), Chloride (Cl, mg L^{-1}), Nitrate (NO_3, mg L^{-1}), Inorganic Phosphate (PO_4, mg L^{-1}), Total Nitrogen (TN, mg L^{-1}), Total Phosphorus (TP, mg L^{-1}), Turbidity (Turb, NTU), and Chlorophyll a (Chl a, µg L^{-1}). Trends were analyzed using data from 2000 to 2012 in five selected stations spread out across the lake. The Trophic State Index (TSI) values of the stations within the study period were also derived from TP, TN, Chl a, and the average of the three parameters. In terms of temporal analysis, general trends, relative monthly values (MV), percent annual changes (PAC) of the nine parameters and their derived TSI values were assessed and analyzed. Spatial trends were assessed by calculating the relative station values (RV) and their standard deviations (SV), principal component analysis (PCA), and hierarchical agglomerated cluster analysis (HACA). BOD and Chl-a have shown statistical growth over the period of 12 years while Cl revealed a consistent decrease in concentration. Moreover, results also showed that Stations 1 and V located at West Bay is the most polluted of all five stations studied, most likely because of its proximity with the highly urbanized and densely populated National Capital Region. This was further supported by HACA results, wherein the two have overwhelmingly similar trends in terms of nutrient and pollutant loadings. Lastly, PCA results revealed that the lake's current condition can be attributed to BOD, TP, and Chl-a. The generated results comprehensively describe the significant changes in pollution levels within the 13-year period and the relationships between the pollution status of stations located at the lake.

Key words: *spatio-temporal water quality, lake eutrophication, Laguna de Bay, Trophic State Index*

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INTRODUCTION

The degradation of lacustrine environments remains one of the most prevalent environmental issues worldwide (*Egerton 1987, Dissanayake et al. 1982, Dar et al. 2013, Fischer et al. 2016, Prapurna and Shashikanth 2002*). The problem roots from a variety of factors affecting several aspects of the lake, be it physical, chemical, or biological in nature. One of the most persistent lake pollution problems is eutrophication, which is caused by imbalance in nutrients within the lake ecosystem (*Kung and Ying 1991, Lau and Lane 2002, Padedda et al. 2017*). This dramatic increase in nutrient loading in global waters over the last 50 years is attributed to increased discharge of domestic wastes and erosion from agricultural practices and urban expansion and development (*Yang, et al. 2008*). Extreme rates of eutrophication can considerably reduce the life of a lake through algal blooms, water quality deterioration, and sedimentation (*Alongi et al. 2005*). Hence, continuous monitoring, proper management, and various investigations are being carried out in lake ecosystems (*Zhou and Zhao 2011, Dubois et al. 2018, Karakoç et al. 2003*). However, the complexity of data coupled by the spatial and temporal variations in water quality renders data interpretation and conclusions difficult. Using univariate and multivariate statistical tools, such as discriminant analysis (DA) and cluster analysis (CA) allows for a better understanding of the complex water quality data available. These techniques can provide relevant inferences on trends and variations needed to identify possible sources of pollution, and in turn determine proper countermeasures and tools for reliable water management and pollution abatement (*Simeonov et al. 2004*).

As a major fishing country belonging consistently to the top 15 in the world in terms of production, lakes are important in water and fishery resources in the Philippines (*Padilla 1996, Anticamara and Go 2016*). Management is therefore of utmost concern, especially for the huge population that usually rely on lakes for their livelihood. The largest and one of the most economically important lakes in the Philippines is the Laguna de Bay (also referred to as Laguna Lake). The Laguna Lake Development Authority (LLDA) is responsible for the management and development of the lake's resources, and therefore continuously monitor its water quantity and quality. Various studies such as that by *Tamayo-Zafaralla et al.* (*2002*), *Sly et al.* (*1993*), and *Herrera et al.* (*2015*) have concluded that Laguna de Bay is in a highly eutrophic state and continue to worsen by the minute. The lake's pollution levels have also been the subject of many studies, ranging from the determination of pollution levels up to its effects on macro-fauna, including humans. Reports of fish kills have been released as early as the 1930s, and further exacerbated by the introduction of aquaculture (*Barril and Tumlos 2002, Cuvin-Aralar et al. 2001, Santiago 1991, Santos-Borja 1994, Zimmer and Bendoricchio 2001, Herrera et al. 2011*). Despite this abundance in research, however, few have employed multi-variate statistics to describe and yield statistically robust conclusions on the spatial and temporal variability of the lake's water quality.

The objective of the present study is to characterize and comprehensively describe the lake's water quality parameters through various statistical analyses of their spatial and temporal variability, and therefore determine the influence of pollution sources on the lake.

MATERIALS AND METHODS

Area of the Study

Laguna de Bay is located between 13°14' to 14°50, and 120°50' to 121°45 and between 10.5 to 12.5 m in elevation (**Figure 1** and **Table 1**). The total catchment area is 3,880 km^2 wide while the lake itself has an area of 900 km^2, making it the largest and most economically important lake in the Philippines. The approximately 100 rivers and streams that make their way to the lake contribute to the 3.2 billion m^3 volume of freshwater within it. The lake is volcanic in origin and is believed to have been formed around 1 million years ago as a result of two major volcanic eruptions called as the Laguna Caldera. Up to present times, various maars, most notably Tadlac Lake, still exist as remnants of the explosion (*A. Santos-Borja 2008*).

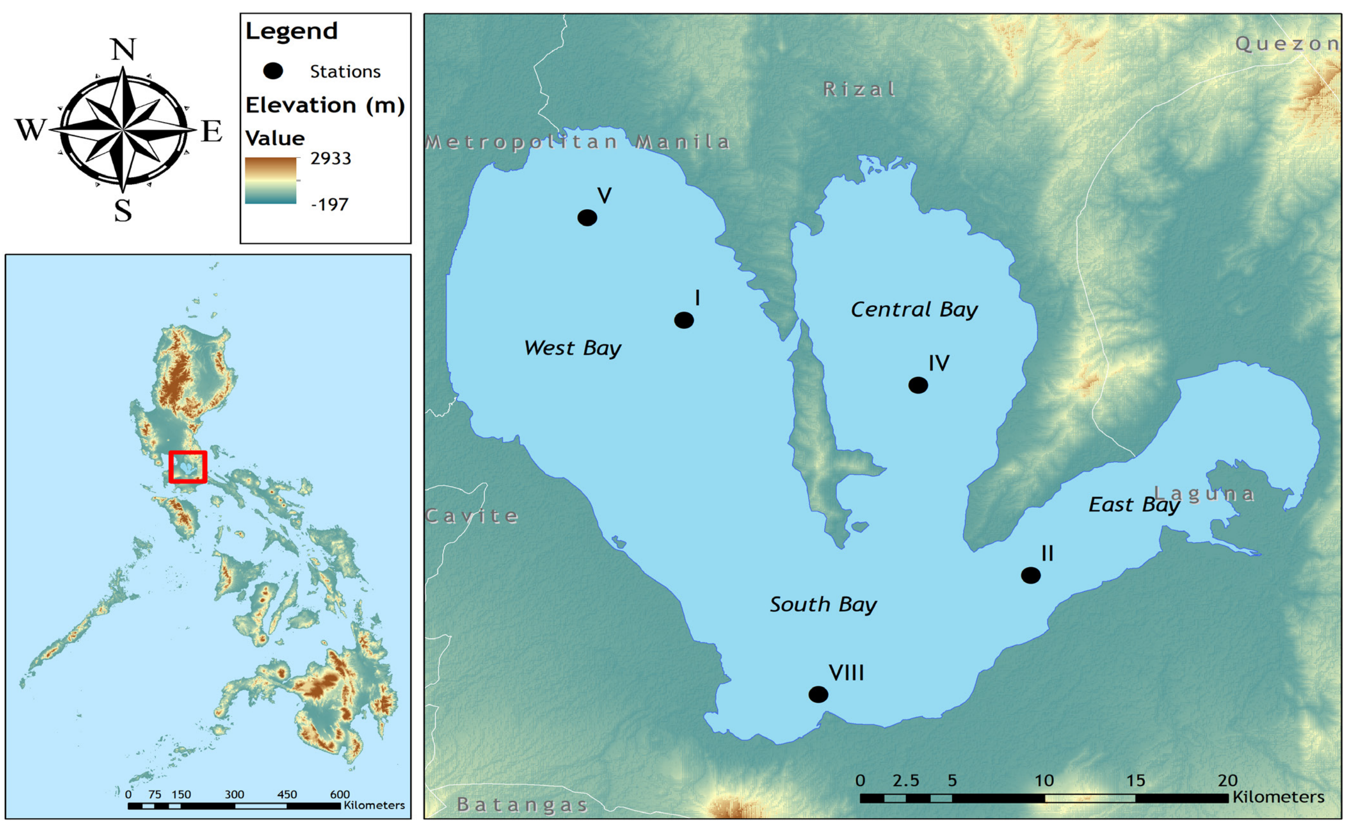

Figure 1. Location of Laguna de Bay and the sampling stations.

Table 1. General characteristics of Laguna de Bay.

Characteristics	Value
Catchment Area	3,880 km^2
Surface Area	900 km^2
Volume	3.2 billion m^3
Shoreline	220 km
Average Depth	2.5 m
Max. Depth	20 m
Surface Elevation	< 2 m
Lowest Rainfall	1,285.91 mm
Highest Rainfall	5,178.95 mm
Catchment Population	8.6 million

The lake is also situated at the center of economic development as the National Capital Region makes up ta significant portion of the western to northwestern coasts, and other cities to the north and South coasts. This leads to continuous urban sprawl which has led to extensive land conversions of forested and agricultural lands. In fact, a 116% increase in built-up areas along with a 35% reduction in forested lands was observed within a period of 7 years (2003 – 2010) and can be further exacerbated by economic development (*Iizuka, et al. 2017*). Around 8.6 million people depend on the lake for a vast array of uses, which consequently contributes to the degradation of the lake (*Laguna Lake Development Authority 2016*).

Data Used

Historical monthly water quality data were obtained from the monitoring department of the Laguna Lake Development Authority (LLDA). The dataset used comprised of five continuously monitored stations spread across the lake from January 2000 to December 2012. Stations I and V are located at the western lobe while Stations IV and II are located at the middle and the eastern lobe, respectively. Station VIII is positioned on the south tip of the lake, near the fish sanctuary. Despite the presence of other stations, these sites were chosen because of the availability of data that last more than a decade. Due to the shallow and well-mixed nature of the lake, only surface water was sampled throughout the period.

Nine physicochemical parameters were analyzed in this study, namely Biochemical Oxygen Demand (BOD, mg L^{-1}), Ammonia (NH_3, mg L^{-1}), Chloride (Cl, mg L^{-1}), Nitrate (NO_3, mg L^{-1}), Inorganic Phosphate (PO_4, mg L^{-1}), Total Nitrogen (TN, mg L^{-1}), Total Phosphorus (TP, mg L^{-1}), Turbidity (Turb, NTU), and Chlorophyll a (Chla, µg L^{-1}). The parameters were chosen because of two reasons: all of the parameters either directly or indirectly contribute or represent the state of eutrophication and pollution within the lake; and they are continuously monitored and have historical records of more than a decade.

Spatio-Temporal Statistics

The relative monthly average ($MV_{v,m,s}$) values were calculated for each parameter to measure the monthly variations for each station using Equation 1:

$$MV_{v,m,s} = \frac{\bar{X}_{v,m,s}}{\bar{X}_{v,s}} \quad (1)$$

where $X_{v,m,s}$ is the average value of the parameter/variable (v) for each month (m) of the study period for each station (s) and $X_{v,s}$ is the average parameter value for the entire study period of each station. *MV* values that are greater than 1 signify relative peak seasons of the year of that specific parameter.

On the other hand, variations between stations $RV_{v,s}$ were computed using Equation 2:

$$RV_{v,s} = \frac{\bar{X}_{v,s}}{\bar{X}_v} - 1 \quad (2)$$

where $X_{v,s}$ is the average parameter value for the entire study period of each station and X_v is the average value of that parameter for the whole study period and including all stations. Positive *RV* values indicates relatively higher parameter values than the average of all stations. Variations in deviations were also assessed using Equation 3:

$$SV_{v,s} = \sqrt{\frac{\Sigma\left[\frac{X_{v,s} - \bar{X}_{v,s}}{\bar{X}_v}\right]^2}{n-1}} \quad (3)$$

where $SV_{v,s}$ is the ratio of the standard deviation of $RV_{v,s}$ over the standard deviation over the entire study period.

Trophic State Index (TSI)

The trophic state of Laguna de Bay was computed for all TN, TP, and Chl a values using the Carlson Trophic State Index functions (*Carlson 1977*). The indices were derived for TP and Chl a concentrations Equations 4 and 5:

$$TSI(TP) = 10\left(6 - \frac{ln\frac{48}{TP}}{ln2}\right) \quad (4)$$

$$TSI(Chl) = \left(6 - \frac{2.04 - 0.68 lnChl}{ln2}\right) \quad (5)$$

respectively. From Carlson's functions, the relationship between TSI and TN was derived by Kratzer and Berzonik (1981) as shown in Equation 6:

$$TSI(TN) = 54.45 + 14.43 lnTN \quad (6)$$

which was used in this study. The mean of the three TSI values were also averaged and analyzed.

Percent Annual Change (PAC)

Temporal trends were assessed by determining the percent annual change (PAC) of all parameters, as well as the TSI values for all stations. The data were first deseasonalized by subtracting the average parameter value for a certain month for each station from the values of the month of interest. These "residual" values were then fit onto a regression line with respect to time (years) and were tested for statistical significance. The slope of the fitted regression line multiplied by 12 designates the annual change in the parameter, and further multiplied by 100 to get the percent annual change. Dividing these values over the average value in the entire period of the specific site gives the PAC for that parameter.

Principal Component Analysis (PCA)

Principal component analysis (PCA) is a multivariate statistical approach designed to transform variables into new, uncorrelated ones (or principal components) with fewer dimensions (*Kazi et al. 2009*). It is used to study interdependencies and underlying relationships between multiple variables and have proved to be applicable in many research topics and disciplines (*Rencher 2002*).

In this study, PCA was employed using the Past 3 software to summarize the correlation between the components in the samples. However, the concentration of the parameters varies greatly, and statistical results shall therefore be biased in favor of high-concentration parameters. Hence, the monthly values of each parameter were standardized in terms of the z-scale prior to the statistical analysis (*Simeonov et al. 2004*). This process transforms all parameter values into dimensionless data with a mean of 0 and SD of 1, thereby reducing the effects of difference on variance of the parameters and removes the effects of varying units. Separate PCA analyses were also done for each of the five sampling stations, the result of which shall be the basis for cluster analysis.

Hierarchical Agglomerative Cluster Analysis (HCA)

Cluster analysis was applied to the water quality parameters to examine the inter-parameter and spatial differences between them. The technique's primary purpose is to identify and classify groups of variables that indicate similar behavior and characteristics (*Lee et al. 2001*). The method is described by *Güller et al.* (*2002*) as "an efficient means to recognize groups of samples that have similar chemical and physical characteristics." The results of HACA is usually displayed as a tree diagram called a dendrogram and may be generated using a variety of algorithms (*Rokach and Maimon 2005*). Specifically, this study used the hierarchical agglomerative cluster analysis (HACA) for the normalized datasets using Ward's method and squared Euclidian distances for similarity analysis using the Past 3 Software.

RESULTS AND DISCUSSION

General Trends

Extensive variations were observed in the maximum, minimum, mean, and standard deviation values of the parameters (**Table 2**). Notable differences were observed in maximum Cl levels, wherein values in West Bay stations (I and V) were 2-4x the values in other areas. This also holds true for mean NH_3, and NO_3 values, where concentrations in the West Bay stations were significantly higher than those in the Central, East, and South Bays. The Central Bay Station (IV) also showed the least or second least maximum concentration values in 6 out of 9 parameters included in the study (BOD, NH_3, Cl, NO_3, PO_4, and TP).

Relative Monthly Variations

Most of the parameters also exhibit high relative differences with respect to monthly values (**Figure 2**). Many of the parameters peaked their MV values between the late dry (May) and early wet seasons (June): MV_{BOD} peaks at around late May to July; MVCl peaks from May to June; MV_{PO4} peaks from May to July; and MV_{Chl-a} peaks at around May to June. Their peaks coincide mostly at the dry-to-wet shift periods of the year which occurs usually between May and June in the Philippines (*Flores and Balagot 1969*). Peaks of BOD values occur from May to June for most stations, which corresponds to the presence of algal blooms, hence the high demand for oxygen (*Rajan 2016, Deka 2015*). High chloride values during summer can be attributed to two main reasons: low flow; and salt-water intrusion from Manila Bay through Pasig River (*E. Herrera et al. 2015, Santiago 1991*). This is especially highlighted in Station V and I, where the peak occurs at May (3.66) and June (2.36), respectively. The two stations are located at the West Bay, where Station V

Table 2. Basic statistical properties of the water quality parameters across 5 stations in Laguna Lake, Philippines.

	Site	I	II	IV	V	VIII
	Max	11.00	12.00	10.00	10.00	11.00
BOD	Min	0.20	0.05	0.10	0.10	0.15
	Mean	2.33	1.88	2.61	2.61	2.06
	SD	1.75	1.65	1.87	1.87	1.54
	Max	0.99	1.09	0.45	1.14	0.29
NH_3	Min	0.00	0.00	0.00	0.00	0.00
	Mean	0.08	0.04	0.04	0.09	0.03
	SD	0.13	0.10	0.05	0.18	0.03
	Max	5022.00	2046.00	2046.00	8556.00	1860.00
Cl	Min	18.30	0.07	17.00	16.00	14.00
	Mean	357.28	225.80	317.02	413.61	222.81
	SD	559.15	276.29	334.98	883.44	247.69
	Max	0.87	1.20	0.86	2.10	1.20
NO_3	Min	0.00	0.00	0.00	0.00	0.00
	Mean	0.15	0.11	0.12	0.18	0.12
	SD	0.20	0.17	0.17	0.30	0.18
	Max	0.57	0.74	0.35	0.77	0.24
PO4	Min	0.00	0.00	0.00	0.00	0.00
	Mean	0.09	0.06	0.07	0.10	0.08
	SD	0.09	0.07	0.06	0.10	0.05
	Max	7.20	6.70	7.40	8.00	7.30
TN	Min	0.10	0.10	0.03	0.50	0.10
	Mean	1.93	1.97	2.23	2.34	2.09
	SD	1.16	1.11	1.47	1.31	1.17
	Max	3.33	3.55	1.69	4.97	7.51
TP	Min	0.00	0.00	0.00	0.05	0.02
	Mean	0.26	0.24	0.22	0.31	0.31
	SD	0.32	0.37	0.21	0.45	0.68
	Max	222.00	165.00	205.00	169.00	157.00
Turbidity	Min	5.00	4.00	6.00	12.00	4.00
	Mean	41.48	40.06	32.83	47.04	44.02
	SD	33.68	27.36	28.74	32.04	34.16
	Max	368.35	277.13	287.56	267.58	245.76
Chlorophyll A	Min	2.78	2.61	3.65	2.78	3.48
	Mean	62.24	53.66	55.62	58.69	55.51
	SD	60.84	48.21	52.12	51.97	48.87

is nearer to the outlets (and in turn, is nearer to salt-water intrusion), than Station I. Relative PO_4 concentrations also peaks in dry and early wet seasons. This can be attributed to the enhanced release of P from lake sediments during high pH (summer) seasons *(Ping 2006, Sondergaard et al. 2001*). This is also the case for NH_3, as it is usually released constantly all throughout the year but is most predominant when pH is high (*Kadam and Boone 1996*). There is, however, considerable differences in trends when it comes to TP, where both organic and inorganic forms of phosphorus were measured. MVTP peaks at July to August for Stations IV, V, and VIII, and at December for Stations I and II. This coincides with the country's most storm-active months. Increased runoff during the wet season transports more phosphates from fertilizers, detergents, and other anthropogenic materials (*Zhang et al. 1984, Zimmer and Bendoricchio 2001*). In terms of Chl-a, it is expected that the maxima occur during summer or just before the wet season, where lake productivity is at its highest. Both BOD and Chl-a shows a continuously increasing trend from January to April and has troughs on September or October, or during the wet season.

On the other hand, the relative monthly values of nutrient yield (MV_{NO3}, MV_{TN} and MV_{TP}) peaks at various points. MV_{TN} shows a relatively static trend, with highs and lows at various months for the five stations. This trend can be credited to the continuous TN yield from tributaries (mostly from fertilizers), coupled with the continuous mixing of shallow lake waters. On the other hand, the patterns of MV_{NO3} seems to be the reverse of

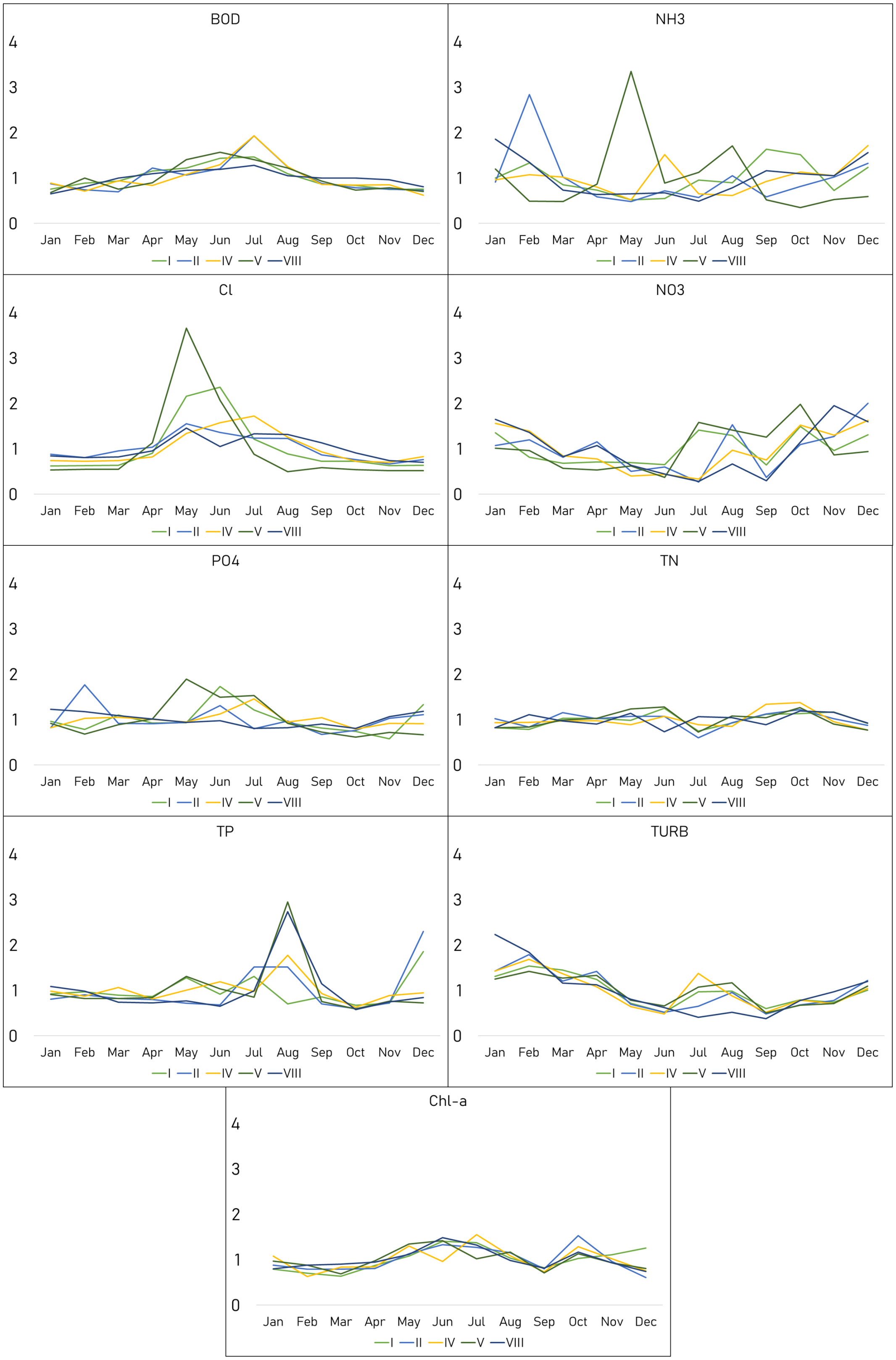

Figure 2. Monthly Variation (MV) values for each parameter from 2000-2012.

MV_{PO4} trends, wherein MV_{NO3} peaks from July to December, in contrast with May to July (MV_{PO4}). It can be surmised that NO_3 becomes a limiting growth factor during wet season, whereas PO_4 is the main limiting growth factor during the summer season (*Kolzau et al. 2014*). MV_{Turb} consistently peaks during the dry months (January to April), with a second peak during the start of the rainy season (July to August). The highest peaks during the dry season can be credited to the dominant stronger winds and sediment resuspension (*Cunanan and Salvacion 2016*), while the smaller peak during the rainy season is attributed to the stronger flows caused about by the rains and dominant storms (*Chow-Fraser 1999*).

Relative Station Variations

It is easily observable that parameter concentrations are relatively higher at Stations I and V (located at West Bay) while Station II consistently shows lower relative concentrations (**Figure 3a**). This consistency shows that the West Bay continues to be the most polluted section of the lake, while East Bay (the furthest area from West) is the least. Maximum and minimum RV values were observed for NH_3 and Cl concentrations for all the parameters: $RV_{NH3,I} = 0.43$; $RV_{NH3,V} = 0.51$; $RV_{NH3,IV} = -0.28$; $RV_{NH3,VIII} = -0.47$; and $RV_{Cl,II} = 0.27$. Values close to zero were observed for Chl-a concentrations for all the stations ($-0.02 < RV_{Chl\text{-}a.} < 0.09$) This implies a relatively well-distributed photosynthetic productivity throughout the lake.

Relative Variations in Standard Deviation

Comparison of deviations among data values at individual stations are shown in Figure 3b. Stations V and VIII shows the highest SD values ($SV_{Cl,V} = 1.69$, $SV_{TP,VIII} = 1.56$, and $SV_{NH3,V} = 1.55$). This shows that NH_3, Cl, and TP concentrations varies the most relative to other stations, and that Stations V (West Bay) and VIII (South Bay) show the most variations in water quality parameters.

Trophic State Index Values

TSI derived from TN values, or TSI(TN), are the highest in terms of magnitude, while TSI(TP) have the lowest values (**Figure 4**). TSI derived from Chl-a values are considered to best represent the trophic state of a lake, although combining TSI values derived from nutrients can also provide a more comprehensive view into the state of the lake (*Carlson 1977*). TSI(Chl) values show that the lake can be classified as between mesotrophic and eutrophic most of the time, with some dips toward the oligotrophic state during the wet season.

Percent Annual Change

Percent Annual Change (PAC) values were calculated for all nine parameters and four derived TSI values (**Figure 5**). Significant positive PAC values of BOD were observed for all 5 stations (ranges from 3.6% to 6.3% in magnitude). A plausible explanation to this growth is the consequential growth of population, human settlements, and industries surrounding the lake. The Waste Load Model designed by *Ruijh and Boot* (*2000*) revealed that the lake's BOD loading was accounted by 69%

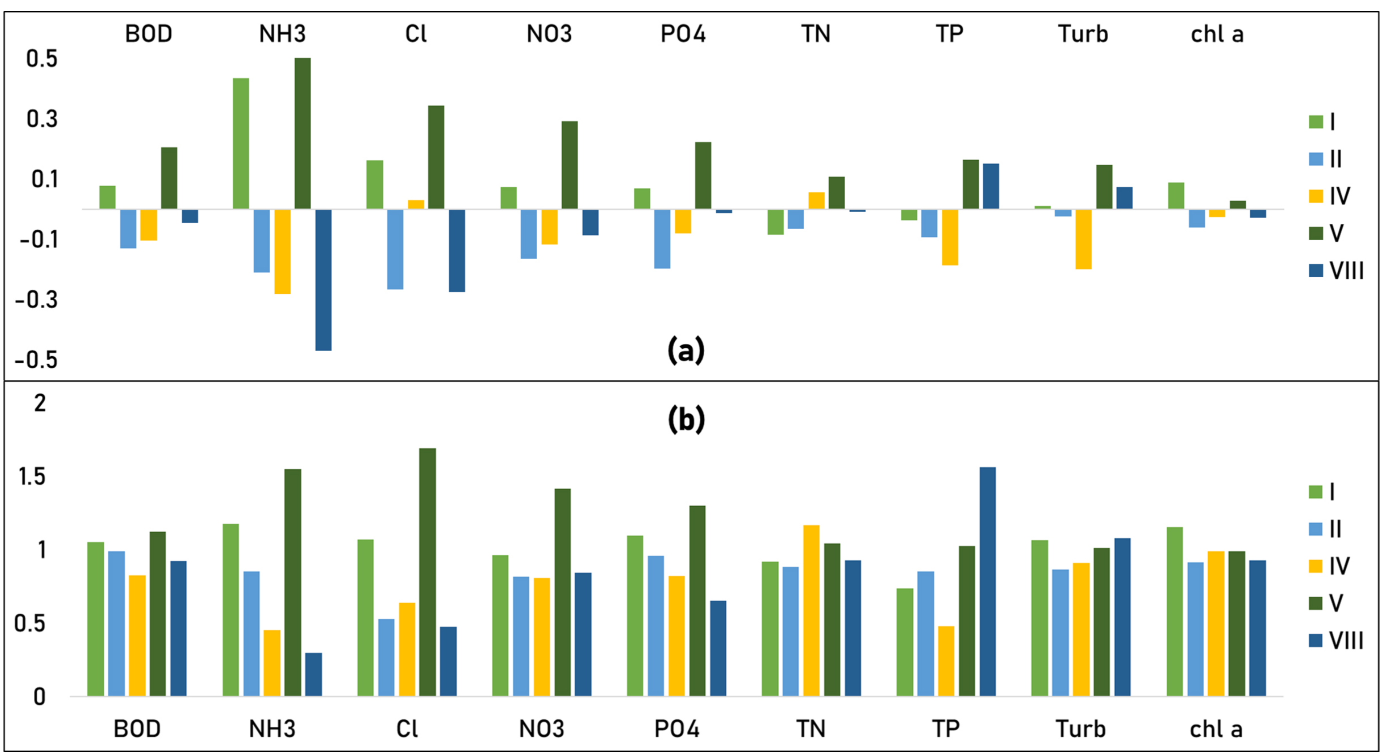

Figure 3. RV (a) and SV (b) values of the five sampling stations for all parameters.

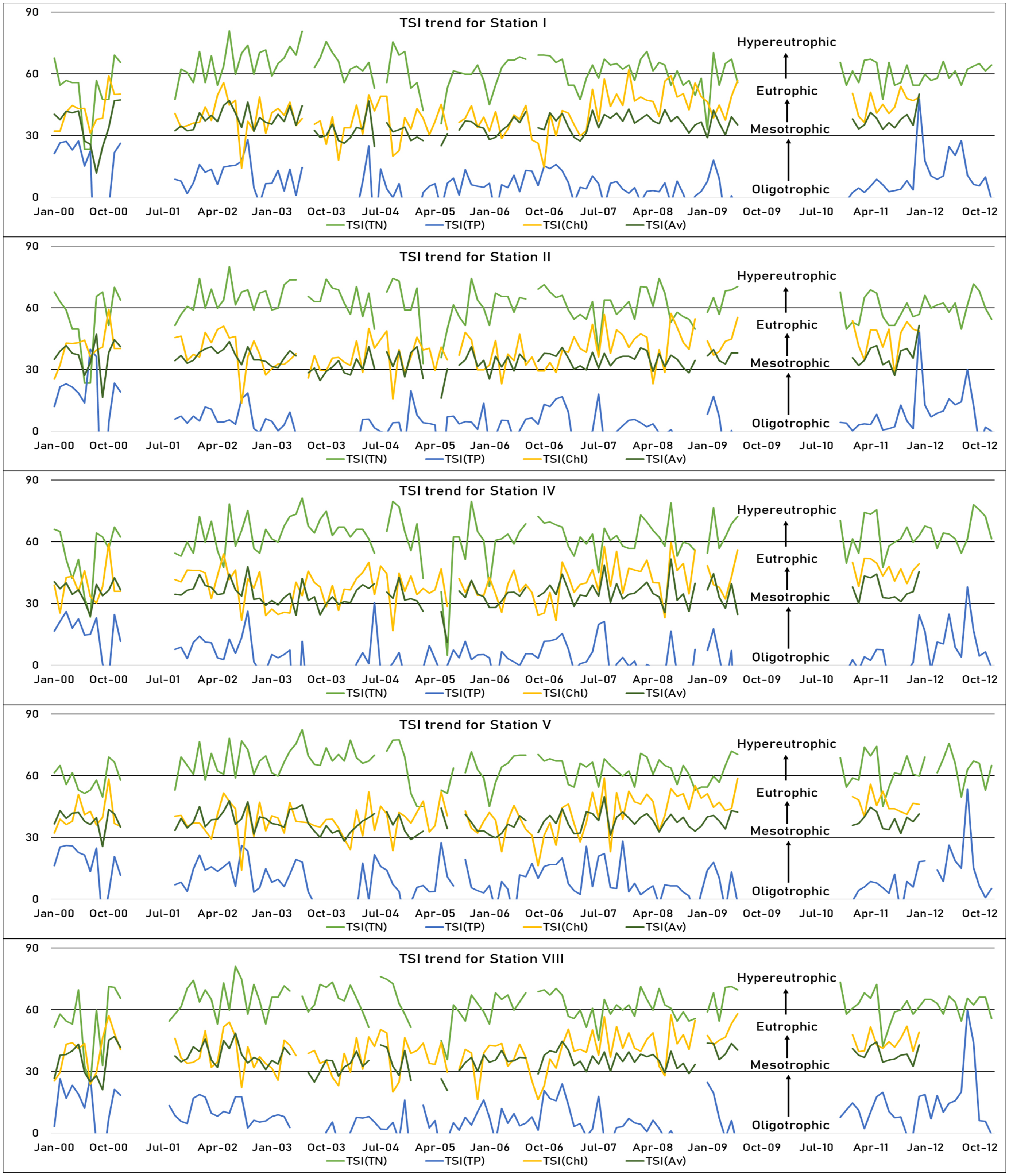

Figure 4. Trends of TSI from TN, TP, Chl-a, and combined values for all stations.

households, 19% from industries, and 11% from runoff. This is particularly damaging for the lake, as elevated BOD levels indicate high microorganism content and organic matter decomposition.

Ammonia levels increased for all stations, but is only statistically significant for Station I (+11.8%) and a significant increase for Station VIII (7.98%). This trend is in accord with *Barril and Tumlos*' (*2002*) findings for the years 1986-1996. Natural sources of NH_3 include the

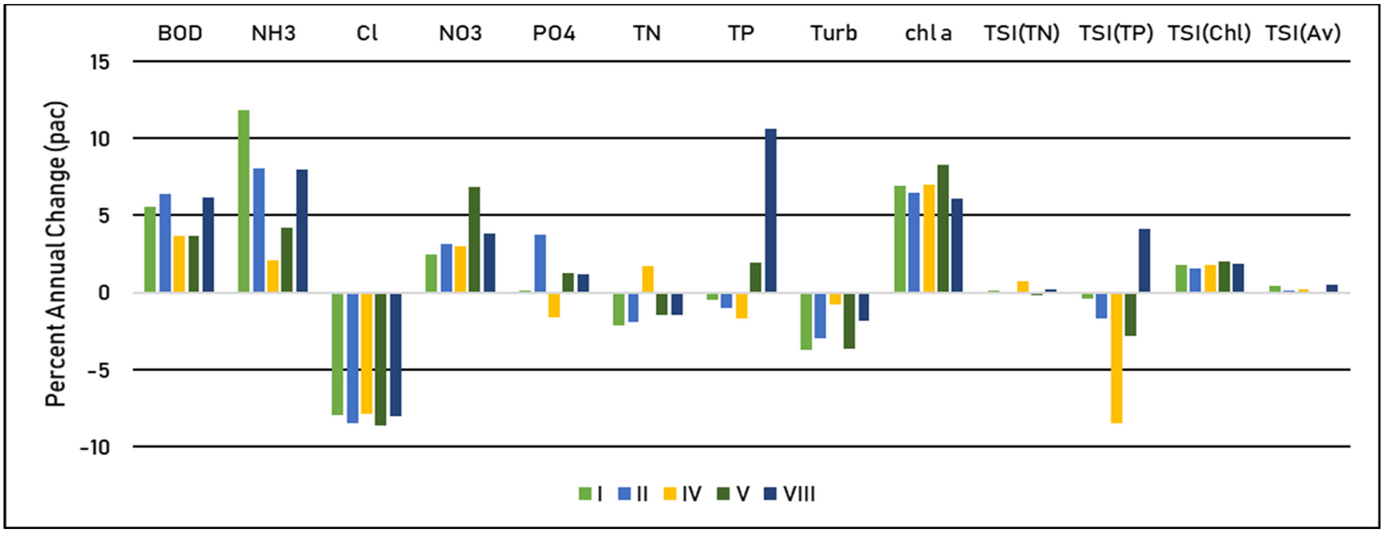

Figure 5. PAC values for the 9 parameters.

decomposition of organic forms of nitrogen contained in lake sediments and is therefore more abundant at the water near the bottom (*Domogalla et al. 1925*). Anthropogenic causes for the increase in ammonia include the use of commercial fertilizers and other industrial applications (*Good and Beatty 2011*). In contrast with other nutrients which affects aquatic life in an indirect manner, elevated concentrations of ammonia are directly toxic to them (*Yang et al. 2010*). This is particularly alarming as Stations I and V are located nearest to fish pens and fish cages, and ammonia's toxicity mechanisms in fishes are well-documented (*Arillo et al. 1981*). Hence, among the other forms of nitrogen, the management of ammonia discharge towards the lake is in dire need of control.

Ever since the construction of the Hydraulic Control Structure (HCS) at the Pasig-Napindan-Marikina confluence, the volume of seawater that backflows towards the lake has been controlled. Results of PAC analyses for all 5 stations show a consistent and significant decrease in Cl levels (-7.9% to -8.6% in magnitude).

NO_3, PO_4, TN, and TP levels were found to have non-significant and varying trends for all the stations. It can therefore be surmised that on the basis of the data available, nutrient levels (with the exception of NH_3) have not changed much for the duration of the study.

Despite the lake's increasing pollution levels, turbidity demonstrates a decreasing trend for all 5 stations, although none exhibited a statistically significant trend.

The PAC values for Chl-a reveal consistent significant annual increase for all the stations, ranging from 6.1% (Station VIII) to 8.3% (Station V) in magnitude. The derived TSI(Chl) values also shows the same trend direction, with annual growth of 1.5% (Station IV) to 2.0% (Station V). This agrees with findings of other studies focusing on lake productivity and phytoplankter composition (Paringit and Nadaoka 2003). Moreover, only the TSI values derived from Chl-a exhibited statistically significant growth (positive) consistently for all 5 stations.

Principal Component Analysis

Principal component analysis was applied using the covariance matrix of the normalized water quality data (**Figure 6**). The first component (PC1), which is mainly attributed to the Chl-a, TP, and BOD values, explained 49.21% of the total variance (**Table 3**). This implies that the lake's current condition can be attributed to the significant changes in its productivity (as characterized by Chl-a, and TP concentrations, and an increase in decomposition of organic matter measured by BOD), thereby explaining its increasingly eutrophic state. This result is supported by their respective PAC, where Chl-a and BOD exhibited consistent increase for all stations. The second component (PC2) explains 23.69% of the variance and is attributed to the particles and salts suspended on the water column, specifically Turb and Cl. The third component (7.10% variance explained, with a cumulative variance of 80% along with the first two components) is also considered to be a major component based on Kaiser's criterion of having an Eigenvalue that is greater than 1 (*Kaiser 1960*). PC3 is composed mainly of variations in NH_3, NO_3, and PO_4 levels, thereby representing the organic nutrients group.

Individual PCA also shows similar results with respect to groupings, with some variations on PC1, or the component representing Chl-a (**Figure 7**). Stations

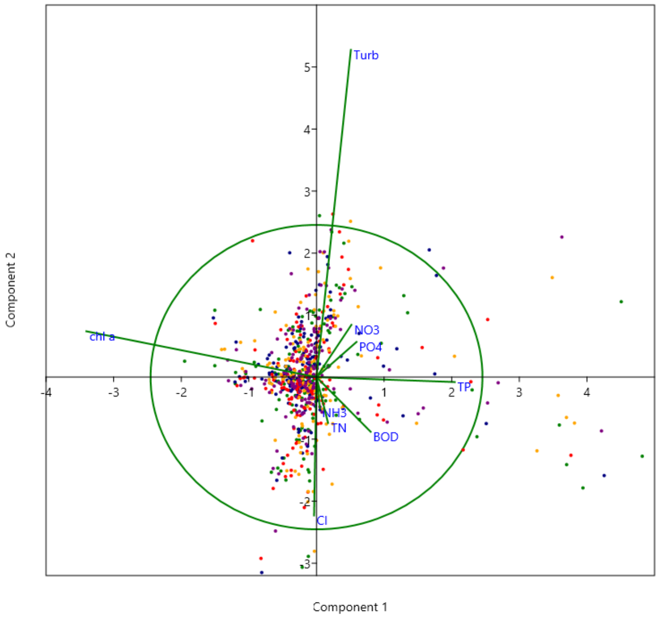

Figure 6. PCA Plot of water quality values across Laguna de Bay plotted against the first two components.

Table 3. Eigenvector and eigenvalues of water quality parameters across Laguna de Bay, Philippines.

	PC 1	PC 2	PC 3
BOD	0.192	-0.147	-0.075
NH_3	0.012	-0.083	0.697
Cl	-0.009	-0.372	0.248
NO_3	0.124	0.141	0.373
PO4	0.142	0.095	0.537
TN	0.041	-0.123	-0.015
TP	0.491	-0.013	-0.007
Turb	0.122	0.880	0.019
Chl a	-0.818	0.123	0.138
Eigenvalue	8.26997	3.98076	1.19326
Variance (%)	49.208	23.686	7.1001
Cumulative (%)	49.208	72.894	79.994

V and VIII shows relatively steep PC1 to PC2 drop in their respective Scree plots, implying that the variations accounted by Chl-a concentrations in these stations are greater than the Chl-a variations in other stations.

Cluster Analysis

The PCA scores of each station was subjected to HACA using Ward's method and Euclidian distance (**Figure 8**). Three groups which exhibit mutual dissimilarity were derived from the cluster analysis: The first group is composed of Stations I and V (both of which is from West Bay); the second group is composed of Stations II and IV (Central and East Bays, respectively, the third cluster including Station VIII (representing the southern portion of the lake). The first group (I and V)

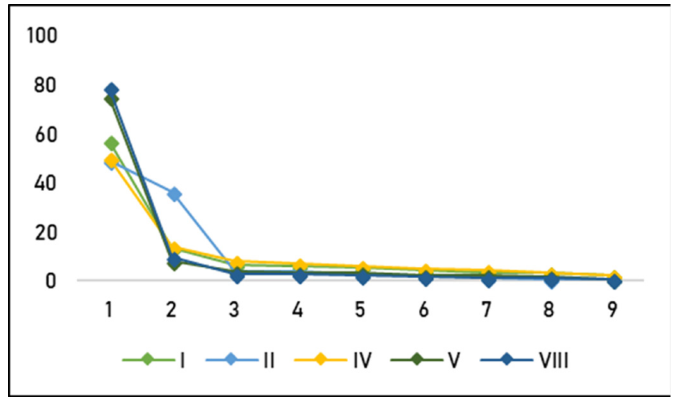

Figure 7. PC1 Scree plots of PCA analyses for each station.

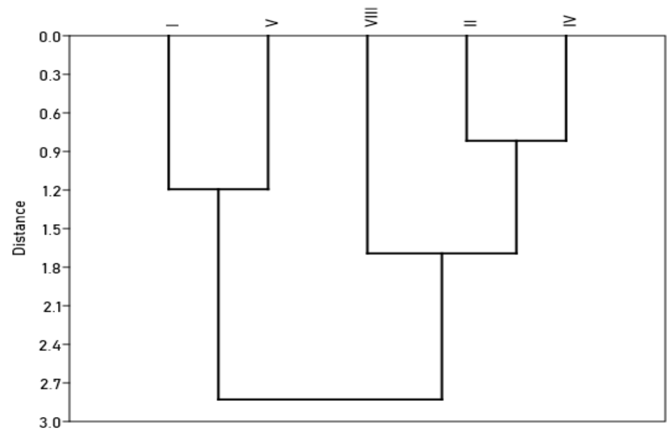

Figure 8. Dendrogram of the cluster analysis based on the stations' PCA scores.

receives the most pollutant effluents from the country's densest area (National Capital Region) both from domestic and industrial sources. On the other hand, the second cluster from the Central and East Bays receives mostly agricultural and domestic runoff. The third cluster was observed to be unique as the surrounding coasts varies in land use and land cover – from the four adjacent cities to the southwest of the Bay (Calamba, Cabuyao, Sta. Rosa, and Biñan), and an agriculturally dominated southeast section (municipalities of Bay and Calauan). The results of the cluster analysis can be used as a basis for a more efficient monitoring of the lake by determining clusters which exhibit mutual dissimilarity from each other. Thus, costs and the use of other resources may be reduced.

CONCLUSIONS AND RECOMMENDATIONS

Proper monitoring is crucial in the pollution abatement and improvement of the current status of thecountry's water resources. Comprehensive analysis of its track record can yield results that may be useful for proper rehabilitation and protection project planning.

However, with the lake's unique topographical shape and the country's rapid shift to industrialization and continuing landscape change, trends in water within the basin tend to be inconsistent and irregular in space and time. This inconsistency can render the interpretation of data difficult and more subject to error. This study found various statistical techniques to unfold the underlying state and trends of the lake by taking into account the spatial and temporal variabilities of the data, as well as determining the major factors contributing to the lake's degraded state over the last 13 years. A highly variable monthly trend on most of the parameters, showing the lake's responses on both the climate (e.g., season) and manmade changes (e.g., agricultural calendar). Variations on stations and their respective standard deviations demonstrate the lake's highly variable spatial nature, which can be attributed to the vast range of climatic and anthropogenic settings within the approximately 100 tributaries flowing towards the lake. Results of the cluster analysis also discriminated the differences between these stations, showing the uniqueness of West Bay's condition in contrast with the other lobes. Moreover, the study also found out that the lake's chlorophyll concentration, along with its trophic state continually increase over the years (values varies from 6.4% to 8.3% growth each year) thus leading to its degradation. The many domestic and agricultural wastes and runoff flowing into the lake pave the way for eutrophication. Multivariate analysis overwhelmingly shows that chlorophyll concentration across the lake is the major contributor to its current condition. Chl-a along with TP and BOD comprise the first component from PCA which explains 49.21% of the total variance. It is therefore recommended that chlorophyll concentrations must be closely monitored and that nutrient and organic matter loadings of the tributaries be tightly managed controlled in order to delay the lake's eutrophication rate. Further research and action are also recommended on the local tributaries regarding their sub-watershed's control measures and management.

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