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Assessment of seasonal variations in surface water quality of Laguna Lake Stations using factor analysis

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Abstract

Laguna Lake is one of the lakes that largely contribute to the socio-economic and environmental needs of the Philippines as it supports fisheries and aquaculture, recreation, power generation, and industries. In this study, the two-year (2018-2019) water quality monitoring data from Laguna Lake Development Authority was subjected to multivariate factor analysis. Initially, the dataset was divided into two categories, representing the dry and wet seasons. Factor analysis was then performed in order to identify major contributing factors that significantly influence the water quality of the lake during dry and wet seasons. Factor analysis for the two data sets (dry and wet) was able to identify three factors, namely, nutrient pollutants, influential water quality and nitrification. Results showed that the nutrient factor constitutes the biggest impact with a variance of 23.6% on the lake's water quality during dry season, following influential water quality (22.2%) and nitrification (20.3%). However the nutrient factor contributes the least impact with a variance of 15.1% on the quality of water during wet season while the influential water quality contributes the highest amount of variance (29.4%). Significant changes on BOD and pH were also observed between seasons. Hence, it can be recommended to have strategies for regular monitoring and maintenance of water quality in Laguna Lake. In addition, environmental programs, and policies concerning water, air, and land protection by stakeholders must be realized to ensure sustainability, and conservation of all forms of life particularly aquatic life species.

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Introduction

Surface water quality is a matter of critical concern in developing countries because of a growing population, rapid industrialization, urbanization, and agricultural modernization (Wang *et al.,* 2018). Of all water bodies, lakes and rivers are the most vulnerable to pollution because of their role in carrying agricultural run-off, and municipal and industrial wastewater (Huang *et al.,* 2010). Water quality experts and decision-makers are confronted with significant challenges in their efforts to manage surface water resources due to these complex issues (Elhatip *et al.,* 2007).

According to the Department of Tourism (DoT) (2021), the Philippines is home to some of the most sought-after tourist destinations, with its cool and pristine bodies of water that offer a sense of freedom in the great outdoors. Among these destinations are enchanting rivers and serene lakes located in areas with magnificent geologic landforms. However, with the booming economy (Boquet, 2017) and the transformation of these places into urban settlements (Hölscher and Frantzeskaki, 2021; Concepcion, 1976) in response to increasing populations, water pollution has become a pressing issue. The government is taking steps to mitigate these problems through policies and programs such as the Philippine Clean Water Act of 2004 (RA 9275) (Miguel, 2019). One example of this is the Laguna Lake, which is surrounded by key urban cities and agricultural lands that are supplied with water from rivers, creeks, and floodways, which are usually surrounded by densely populated areas (Cruz *et al.*, 2012).

Moreover, Laguna Lake is presently utilized as a catch basin (Santos-Borja and Nepomuceno, 2006) when flooding due to naturally occurring phenomena like typhoons and heavy rains that happen mostly during wet seasons (Miguel, 2019). This, makes the water pollution in Laguna Lake (Barril *et al.*, 1994; Barril and Tumlos, 2002) further complicated and the situation more problematic. Hence, to better understand how the dynamics of water quality in Laguna Lake play out during different seasons (Garcia-Ferrer *et al.*, 2003) a series of parallel measurements of seven (7) critical parameters (Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Fecal Coliform, pH level, Ammonia, Nitrate, and Inorganic Phosphate) were conducted during dry and wet seasons. Performing a series of various statistical approaches (inferential, correlational, and multivariate factor analysis) (Sevilla, Lee & Lee, 2010) to the critical parameters that define the water quality of the lake draws a quantified description of the situation. This study aims to determine which water quality parameters can provide a contrast between the wet and dry seasons. Furthermore, the study aims to determine the major contributing factors that affect Laguna Lakes' water quality during wet and dry seasons.

Materials and methods

Study Area

Laguna Lake as depicted in Fig. 1 is the largest lake in the Philippines and a critical body of water in terms of socio-economic and environmental significance (LLDA, n.d.). The lake is located in the heart of Luzon Island, surrounded by the provinces of Laguna, Rizal, and Batangas. With a surface area of approximately 911 square kilometers, Laguna Lake provides numerous benefits to the local population, including a habitat for fisheries and aquaculture, a recreational area, a source of power generation, and a support for various industries.

The lake is fed by numerous rivers, including the Marikina, San Juan, and Pasig Rivers. The surrounding area of Laguna Lake is predominantly agricultural, with rice fields, vegetable farms, and livestock operations, as well as urban areas with a large population. In 2010, the total population around the lake was over 15 million, according to the National Statistics Office (NSO). The presence of human activities and natural processes in the catchment area of the lake has the potential to impact the water quality and ecosystem of the lake, making it necessary to continuously monitor and assess the state of the water body.

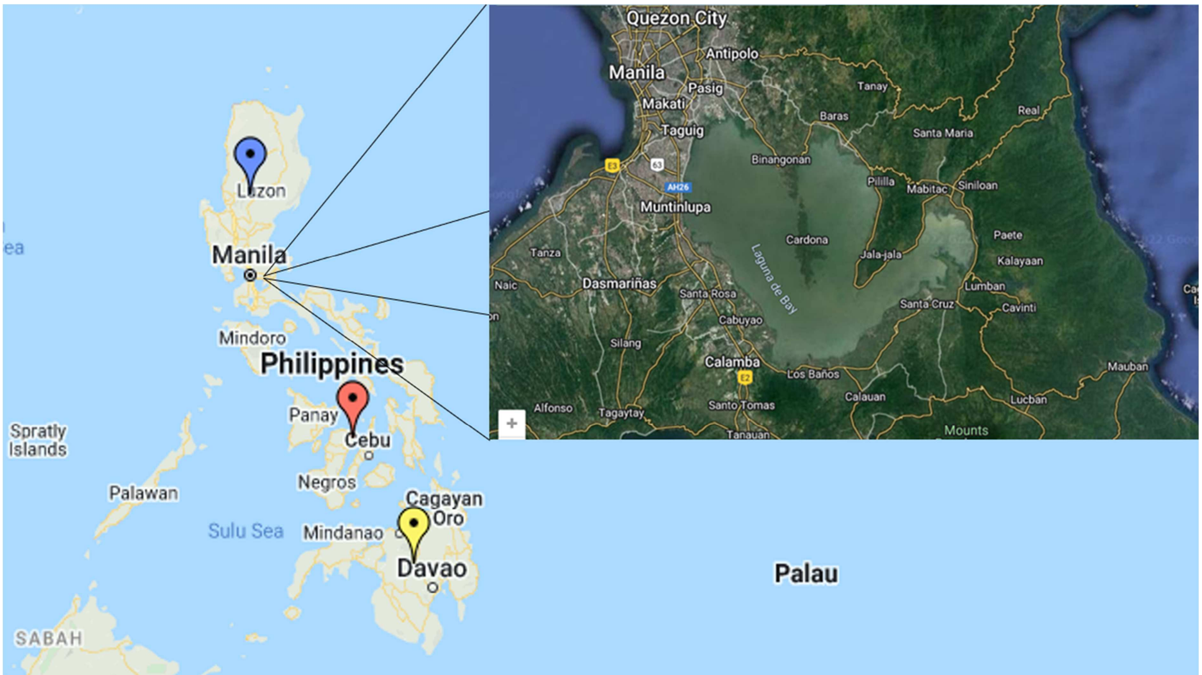

Fig. 1. The map of the Philippine archipelago with a blow-up image of Laguna Lake shaped like a crow's feet.

Data Collection

The data for this study was collected through the manual retrieval process from the Laguna Lake Development Authority (LLDA, 2022). Based on the availability, consistency and completeness of the data, the researchers utilized the LLDA's quarterly water monitoring report for the years 2018 and 2019 from nine monitoring stations in Laguna Lake. The dataset contains information on seven key water quality parameters (Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Fecal Coliform, pH level, Ammonia, Nitrate, and Inorganic Phosphate) that were measured to evaluate the water quality of Laguna Lake.

Data Analysis

In this paper, a data mining approach was utilized to assess the seasonal variations in the surface water quality of Laguna Lake. This approach aims to uncover novel insights without prior hypothesis (Sim, 2003). The data was analyzed using Minitab 16 and a range of statistical methods including descriptive statistics (mean, maximum, minimum, standard deviation), two-sample t-test), and factor analysis.

Initially, the dataset was divided into two categories, representing the dry and wet seasons. The Philippine climate experiences two distinct seasons - the rainy and the dry season. The rainy season starts in June and extends until November, characterized by high precipitation and higher humidity. Conversely, the dry season, which spans from December to May, is marked by lower rainfall, less humidity, and sunnier conditions (PAGASA, 2022). Descriptive statistics were used to compare the seven water quality parameters between the two seasons, and the two-sample t-test (Snedecor and Cochran, 1989) was used to determine if the mean between the two groups was significantly different.

Following that, a factor analysis was performed. In this study, factor analysis is employed to evaluate the similarities and differences in the composition of water samples collected from various monitoring stations. The objective of this analysis is to determine the underlying factors that have an impact on the water compositions and to understand the relationships between these observations. The method aims to simplify the complexities of the data by reducing the number of variables to a smaller set of factors that can directly explain the correlations between the observations (Yu *et al.*, 2003). We extracted the correlation matrix and rotated factors using principal component analysis and the varimax rotated procedure, respectively, to achieve a simple structure and meaningful result. Variables with factor loadings greater than 0.45 and |eigenvalues| greater than one are considered for interpretation. The statistical tools used in this study were based on the paper of Thivya *et al.*, (2015) in assessing the Spatio-seasonal variation of the geochemical process in a hard rock aquifer**.**

Results and discussion

Factor Analysis on the Water Quality Parameters

The varimax rotated results, the magnitude of the eigenvalues, and the percentage of the variation in the water quality of Laguna Lake Stations during the Dry and Wet Seasons are presented in Table 1 and Table 2, respectively. Based on the test of significance, it was determined that three significant factors (nutrient pollutant, influential water quality, and nitrification) accounted for 66.1% of the total variance in the Dry Season and 65.1% in the Wet Season, derived from a total of 216 samples and 7 variables.

Table 1. The varimax rotated factor matrix of the water quality in Laguna Lake Stations during dry season.

Variable	Factor 1	Factor 2	Factor 3
BOD	-0.093	0.209	-0.743
DO	0.416	0.732	0.280
Fecal coliform	0.072	-0.670	0.003
pH	-0.325	0.690	-0.281
Ammonia	0.217	-0.206	-0.774
Nitrate	0.815	-0.062	0.114
Inorganic Phosphate	0.806	-0.039	-0.316
Eigenvalue	1.6539	1.5513	1.4223
% Var	0.236	0.222	0.203

Nutrient Pollutant Factor

Factor 1 identified in the dry season was found to be the concentration of nitrate and inorganic phosphate, with factor loadings of 0.815 and 0.806, respectively. These two variables demonstrated a strong positive correlation with Factor 1, which has been dubbed as the river's nutrient pollutant. This factor has been found to have the most significant impact on the overall water quality of the river, accounting for 23.6% of the variance.

Table 2. The varimax rotated factor matrix of the water quality in Laguna Lake Stations during wet season.

Variable	Factor 1	Factor 2	Factor 3
BOD	0.427	-0.788	-0.032
DO	0.888	-0.126	-0.141
Fecal coliform	-0.476	-0.353	0.375
pH	0.879	-0.067	-0.061
Ammonia	-0.236	-0.806	-0.029
Nitrate	0.156	0.146	0.776
Inorganic Phosphate	-0.082	-0.057	0.540
Eigenvalue	2.0577	1.4405	1.0598
% Var	0.294	0.206	0.151

Nitrogen and inorganic phosphorus are essential nutrients for the growth of aquatic plants, which in turn give food and habitat for fish and other aquatic animals (Misra and Chaturvedi, 2016). But as too much nitrogen and phosphorus enter the environment, water can become contaminated (Manuel, 2014). Nutrient contamination has harmed lakes, affecting the ecosystem, human health, and the economy (Sampat *et al.*, n.d.). Aquatic plants bloom when there is an excess of nitrogen and phosphorus in the water, which causes their growth to outpace what the environment can support. Significant increases in the growth of aquatic plants have a negative impact on water quality, as well as on food resources, habitats, and the amount of oxygen that fish and other aquatic species require to live (Lambert *et al.*, 2010). Eutrophic waters are typically murky and may not support as many large animals, such as fish, as non-eutrophic waterways.

The DO parameter also has a positive moderate correlation with Factor 1, with a loading value of 0.416. This makes sense since the amount of DO in the lake is linked to the levels of nitrates and inorganic phosphorus. An excess of these substances leads to eutrophication, resulting in a significant rise in aquatic plant growth. During long periods of dry season, the high number of aquatic plants in the water contributes to higher levels of DO, as the plants produce oxygen through photosynthesis.

The aforementioned Nutrient Pollutants (Nitrate and Inorganic Phosphate), showed only a 15.1% variance during the wet season on Factor 3, with positive strong to moderate loadings of 0.776 and 0.540, respectively, having the least impact on the River.

Given that the dry season has the highest concentration of nitrate and phosphate and the wet season has the lowest concentration. The increase of these nutrient pollutants was due to the Laguna Lake's flow rate difference between two seasons and the backflow of Pasig River polluted waters to Laguna Lake during dry season. The Laguna Lake has high concentrations of nitrates and phosphates during the dry season because the rate of flush-out is slow, causing pollutants and other sediments to settle at the bottom of the lake more quickly than during the wet season (Houri and El Jeblawi, 2007; Gadhia *et al.*, 2012). This allows for stratified lakes like Laguna Lake to experience a vertical distribution of these nutrients in the upper, middle, and deepest strata during the dry season, leading to a mixing that makes the lake nutrient-rich at all levels (Herrera and Nadaoka, 2021). However, these nutrient pollutants have been observed to have the lowest concentration during the wet season. This is because the flow rate of water in Laguna Lake increases during the rainy season, from 10.8m to 12.4m, which leads to the discharge of water with flashy and high peak flows into its outlet river within hours. These results in the flushing out of nutrient pollutants from the lake into the rivers connected to it. In addition to the flushing out of pollutants during floods and the increase in river flow during the rainy season, the concentration of these nutrient pollutants in Laguna Lake is also diluted, resulting in very low concentrations compared to the dry season (Houri and El Jeblawi, 2007; Islam *et al.*, 2015).

Influential Water Quality Factor

Going back to the Dry Season, the DO and pH parameters have factor loadings of 0.732 and 0.690, respectively. Based on these variables, there is a high positive loading onto Factor 2 as well. It is considered as the river's Water Quality, and it has the second greatest impact on the river overall, with a variance of 22.20%.

The parameter Fecal Coliform displays a negative strong correlation in Factor 2, with a loading of -0.670. This indicates that Fecal Coliform is negatively impacted by DO and pH, as observed by Seo *et al.* (2019).

DO and pH are considered as the influential Water Quality factors that decrease the concentration of Fecal Coliform in the River. This inverse relationship between these parameters and fecal coliform has also been noted in other studies, where an increase in fecal coliform concentration is accompanied by a decrease in dissolved oxygen level and pH (Pearson *et al.*, 1987; Curtis, Mara and Silva, 1992; Šolić and Krstulović, 1992). The inverse effect is due to fecal coliform being mostly aerobic enteric bacteria that require oxygen for metabolic processes (Kalkan and Altuğ, 2020). When organic matter decomposes in the river, fecal coliform uses up the dissolved oxygen, leading to a decrease in its concentration (Pescod, 1992; Shaheed *et. al.,* 2017). Conversely, a high level of dissolved oxygen and pH suggests a low presence of fecal coliform in the area.

The positive loading of dissolved oxygen and pH can also be attributed to the algal bloom that is rampant during the dry season amongst rivers, especially in high nutrient-rich water systems (Bhateria and Jain, 2016; Coffey *et al.*, 2019; Klose *et al.,* 2012). Algae use nitrogen and phosphorus-rich water to proliferate in the rivers which results in higher DO and pH input as a product of its photosynthesis (Paerl *et al.,* 2001). This high-rate algal pond or river as described by (Oswald and Golueke, 1968; Fed *et al.*, 1971; Mc Garry and Tongkasame, 1971) creates an environment wherein the algae produce a lot of dissolved oxygen which may result to the formation of singlet oxygen and superoxide as a result of excessive light capture by the algal chlorophyll during summer by which two molecules of this superoxides can cause irreversible damage to the fecal coliform microorganism DNA (Cadenas, 1989; Deeuyper *et al.*, 1984; Cadenas, 1989). Aside from superoxides, algal photosynthesis in nutrient-rich rivers increases its pH level which can reach pH level 9 which is detrimental to the growth of fecal coliforms during summer (Parhad and Rao, 1974; Pearson *et al.*, 1987).

In contrast to the Dry Season, the parameters DO and pH had the biggest impact in the Wet Season, accounting for 29.40% of the variance with loadings of 0.888 and 0.879, respectively.

This is due to the effects of excessive rain during the wet season on the river's pH level and rainfall also positively affects DO concentrations in the river (Munoz *et al.*, 2015). Aside from the addition of oxygen from rain, DO and pH is seen to have an increasing effect during the rainy season in Laguna Lake due to fecal coliforms and other microbes that utilize DO to metabolize are being swept and flushed out to river outlets during flood and lake's outflow (Baxter, 1977; Ahipathy and Puttaiah, 2006; Wallace *et al.* 2013).

Nitrification Factor

Finally, Factor 3 of the Dry Season, with the least impact on the river, consists of the parameters Ammonia and BOD, accounting for 20.30% of the variance with factor loadings of -0.774 and -0.743, respectively. Both parameters have strong negative loadings on Factor 3 and are regarded as the Nitrification in the river. This is because Ammonia is converted into nitrite (NO_2-) and finally nitrate during river nitrification (NO_3–). Ammonia and BOD are directly proportional, as an increase in ammonia allows ammonia-oxidizing bacteria to thrive and produce proteins and enzymes to break down other nutrients in the environment, which in turn increases the rate of BOD (Soliman and Eldyasti, 2018; Verduzo *et al.*, 2021). The negative loading of both nitrification factors may indicate that, due to the high DO and pH in Laguna Lake during the time of the sample, there was very little interaction among the microorganisms (Fumasoli *et al.*, 2017; Ratzke *et al.*, 2020), leading to a low rate of BOD and ammonia consumption.

Ammonia and BOD have a greater impact on the river during the wet season (20.60% variation and loadings of -0.806 and -0.788, respectively) than during the dry season. The impact of both parameters is a strong negative on Factor 2. As we can observe from the data during the wet season, the dissolved oxygen from Factor 1 also increases drastically, which indicates that fewer microbes are utilizing oxygen in the lake due to being flushed out to other River systems connected to the lake. This leads to a lesser activity in ammonia consumption since there are fewer microorganisms to metabolize it. This, in turn, leads to a cascading effect, resulting in a decrease in the BOD as there is less metabolic activity in the lake and less oxygen is used as a source of energy.

Comparison of Water Quality Parameters between Dry and Wet Seasons

The pH levels in Laguna Lake varied seasonally as shown in Table 3, with the lowest recorded value being 7.10 and the highest being 9.70, with the greatest fluctuations occurring during the wet season. Similarly, the Biochemical Oxygen Demand (BOD) levels varied, with a range of 0.50 to 9.00, with the lowest values observed during the dry season. The results of the two-sample t-test revealed that there were statistically significant differences in both the BOD and pH levels between the dry and wet seasons. Water pH is a sensitive measure of its acidity or basicity. Even slight variations in pH can have significant impacts on the presence of toxic metals in the water (Sakthivadivela *et al.*, 2020). This, in turn, can have adverse effects on both aquatic life and human health. This study found a statistically significant difference in pH values between the dry and wet seasons, with a p-value of less than 0.01. This difference can be attributed to several factors, including changes in aeration and anthropogenic inputs. During the dry season, the lower pH is likely caused by a decrease in waste inputs and an increase in the concentration of dissolved chemicals due to evapotranspiration. Conversely, the wet season is characterized by higher pH levels due to the dilution effect of increased precipitation and reduced waste input. These findings highlight the complex interplay of environmental and anthropogenic factors that can impact water pH, and the importance of monitoring this parameter to maintain water quality.

Table 3. Maximum, minimum, average, standard deviation and two-sample t-test of the water quality parameters in Laguna Lake Stations during dry and wet seasons.

Water Quality Parameters	Dry Season				Wet Season				2-sample t-test	
	Max	Min	Avg.	SD	Max	Min	Avg.	SD	t	p
BOD	9.00	0.50	1.87	1.24	9.00	1.00	3.20	1.70	6.55	0.00
DO	10.6	4.50	7.94	0.84	16.1	5.60	8.23	1.69	1.62	0.11
Fecal coliform	307.0	1.90	24.13	39.15	244.70	1.80	31.75	37.78	1.45	0.15
pH	9.20	7.50	8.33	0.36	9.70	7.10	8.73	0.44	7.34	0.00
Ammonia	0.66	0.001	0.07	0.12	1.54	0.001	0.06	0.16	-0.40	0.69
Nitrate	0.73	0.04	0.17	0.17	4.43	0.004	0.17	0.05	0.11	1.91
Inorganic Phosphate	0.29	0.02	0.12	0.05	1.14	0.02	0.13	0.14	1.42	0.16

Biological Oxygen Demand (BOD) is a widely used indicator of water quality as it reflects the level of organic pollution present in a body of water (USEPA, 1997). The study conducted in Laguna Lake found that BOD levels were relatively low during the dry season, a result attributed to the efficient absorption of organic pollutants from various sources.

High BOD levels indicate a rapid depletion of oxygen in water, which can have adverse impacts on aquatic life and water quality. The study revealed that the average concentration of BOD was 1.87mg/L during the dry season and increased to 3.2mg/L in the wet season, however, it still remained below the permissible limit of 5mg/L as prescribed by the World Health Organization (WHO). These results indicate that the water in Laguna Lake maintained good sanitary conditions during both the dry and wet seasons, as evidenced by the low BOD values

Conclusion

Surface water quality of Laguna Lake for both dry and wet seasons is characterized by nutrient pollutant, influential water quality, and nitrification factors. Nutrient pollutant factor contributes the highest impact on the water quality during dry season while influential water quality has the highest impact during wet season. Moreover, BOD and pH level of water quality showed significant difference between the two seasons. This suggests a regular monitoring and maintenance of water quality in Laguna Lake that will include environmental programs, and policies on water, air, and land protection to ensure sustainability, and conservation of all forms of life particularly aquatic life species.

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