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Spatio-temporal Trends of Phytoplankton Community in Angat Hydroelectric Dam, Norzagaray, Bulacan, Philippines

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Abstract

Phytoplankton, a polyphyletic assemblage of species, are the primary producers occurring mainly in the upper strata of various bodies of water and are considered the earth's most important factor in the organic matter production. Numerous studies on the biology of phytoplankton had established its role in the sustainability of different aquatic ecosystems. However, few studies had been conducted focusing on phytoplankton biodiversity and its impact on water quality particularly in artificial water reservoirs such as freshwater dams. Angat Hydroelectric Dam (AHD) is one of the largest freshwater dams in the Philippines. Located in Norzagaray, Bulacan in the Central Luzon Region, the AHD supplies potable water in Metro Manila, irrigates 30,000 hectares of farmlands in Bulacan and Pampanga provinces, and powers a hydroelectric power plant. To understand the seasonal variation in phytoplankton community structure in the reservoir for the first time, an investigation on phytoplankton biodiversity in Angat Hydroelectric Dam from June 2018 to May 2019 was conducted. Phytoplankton and water quality analyses were determined every sampling date. Results showed that the phytoplankton community structure was dominated by the cyanobacteria with a total population of 123.658 x 103 cells/mL from the three different water layers throughout seasonal variation and spatial analysis. Furthermore, the increase in density of phytoplankton was positively correlated with water quality parameters such as temperature, nutrient content and depth.

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Introduction

Confining water of river systems aimed at storing freshwater for human and industrial operations in reservoirs denotes changes in physical, chemical, and biological components of water and the water's over-all quality [1]. Thus, freshwater ecosystems whether dwelling naturally or built artificially including their phytoplankton components are extremely susceptible to spatial and temporal changes [2]. Due to phytoplankton communities' great role in primary production in a food chain, this becomes a vital biological component of water bodies like sea and freshwater bodies. Phytoplankton is normally at the basal level of aquatic food web and is the most important factor for production of organic matter in aquatic ecosystems. Essentially, reservoirs require significant number of phytoplankton to have productive and sustainable fisheries [3].

Phytoplankton structures and distributions are highly related to the physical and chemical features of various bodies of water [4]. Variations of abiotic water conditions occurring naturally throughout the day and over the seasons of the year are either vertical or horizontal. These are considered related to stratification and mixing of the water column which could result to changes in the light availability and nutrient sources for the phytoplankton community growth and sustainability [5-6].

The Angat Hydroelectric Dam (AHD) located in Norzagaray, Bulacan is one of the largest dams in the Philippines with a height of 131 m, length of 568 m and width base of 550 m. This water reservoir facility was built in 1961 and began operating in 1967. The AHD supplies potable water to 12.8 million population of Metro Manila according to 2015 Philippine Statistics Authority, powers a hydroelectric power plant, and irrigates about 30,000 hectares of farmland in the provinces of Bulacan and Pampanga. AHD is also a part of the Angat-Ipo-La Mesa water system which is one of the largest water systems in Luzon Island. To this date, very few studies had been conducted to assess the phytoplankton community structure and distribution in this freshwater reservoir. Although monitoring of the water quality in AHD has been constantly done by various government agencies in the Philippines such as the Department of Environment and Natural Resources, Local Waterworks and Utilities Administration (LWUA), Bureau of Fisheries and Aquatic Resources (BFAR), documentations and scientific studies on both the temporal and spatial variations of the phytoplankton community in relation to changes in the physico-chemical parameters of the water in AHD are still insufficient.

This study aims to investigate the biodiversity of the phytoplankton community structure in Angat Dam, Norzagaray, Bulacan and its correlation with the changes in water quality in the reservoir. Furthermore, aggregate cell densities of the dominant phyla will be identified in the study to determine the structure of phytoplankton diversity in AHD. Parallel to this, monitoring of seasonal changes in water quality based on measurements of physico-chemical parameters will also be undertaken to elucidate phytoplankton distribution during alteration of seasons. Providing systematic information on this field will be beneficial for the monitoring of health of reservoir ecosystems and conservation of environment functions as phytoplankton community is one of the main sources of energy for other trophic levels.

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Materials and Methods

Sampling site

The Angat Hydroelectric Dam (AHD) also known as Angat Dam (14°52'15"N, 121°08'30"E), is a concrete water reservoir mound hydroelectric dam located in Barangay San Lorenzo, Norzagaray, Bulacan Province in the Philippines. It is part of the Angat River which drains the west flank of the great Sierra Madre Mountain Range. The southern area of the AHD which is part of the Angat Rainforest Ecological Park was the sampling site (14°54'48.3084"N, 121°10'25.9896"E) where there are less houses and community structures built (Figure 1) (Supplementary File).

Collection of water samples

Water sampling was done every second week of each month from June 2018 to May 2019, between 9:00 am to 3:00 pm. A three-liter Niskin sampler was used to collect water from each depth: surface (<2m), middle, and near bottom. Collection was replicated three times for each depth. The collected water samples were transferred in clean 20L pail containers for each depth. In each pail, three x 1L of water samples were collected and placed in clear plastic bottles for nutrient analysis, another set of 3 x 1L for ex situ determination of nitrates and phosphates, and another 3 x 1L of water samples for phytoplankton composition analysis. The water samples for phytoplankton composition analysis were fixed with 5 to 7 drops of 70% Lugol's solution per liter and were immediately sealed.

Physico-chemical water analyses

For measuring the physico-chemical properties of the water, a CTD Profiler (YSI Exo Sonde, Japan) device was used. The parameters included were temperature, dissolved oxygen (DO), pH, total dissolved solids (TDS), salinity and conductivity. Depth was determined using the YSI CTD Profiler by measuring the deepest part of the sampling area first, and then this was divided into surface, middle and bottom with range. For nitrate ($NO3^-$) and phosphate ($PO43^-$) analyses, the Hach Data Logging Spectrophotometer (DR 2800) protocol for nitrate and phosphate reading was followed.

For nitrate analysis, a cuvette (sample cell) was filled with 10 mL of water sample and added with NitraVer 5 nitrate reagent powder pillow and immediately sealed by a stopper into the cuvette's opening. The initial reaction for one minute was observed after mixing. Another reaction was observed for the next five minutes taking note of the amber color produced indicating the presence of nitrate (mg/L) in the sample. This was compared with the control prepared by adding another 10 mL water sample on the second cuvette with no nitrate reagent powder pillow. Taring was done before actual spectrophotometry reading. The same steps were followed for phosphate analysis using 1 mL of amino acid reagent solution added into the 10 mL water sample in the cuvette with the appearance of blue color in the sample indicating the presence of phosphate.

Phytoplankton density determination

Ten mL aliquots from iodine-fixed water samples in test tubes were centrifuged (2,000 rpm) for 10 minutes and appropriate amounts were loaded in Neubauer Counting Chamber [5, 7]. A one mL water sample that settled into the bottom of 10 mL centrifuged sample was used for the analysis and viewing of specimen under a compound light microscope (Olympus CH-20). Phytoplankton species were identified and verified with the use of various references on algal taxonomy [8 -10].

Phytoplankton species accumulation curve

The species accumulation curve (SAC), or collector's curve of a population, gives the expected number of observed species or distinct classes as a function of sampling effort [11]. In this study, it was used to estimate the number of species in the AHD sampling area as it allowed the researcher to assess and compare diversity across population or to evaluate the benefits of additional sampling. SAC was utilized in this study to indicate if the sampling period and frequency had caught and recorded certain percentage of the phytoplankton species living in AHD. Species accumulation curve is concerned with accrual or accumulation rates of different and new species in the sampling area. This general characteristic of an ecosystem and community depends on species identity.

Shannon-weiner (H) diversity index

The Shannon-Weiner (H) Diversity Index was used in the study to determine the species richness of phytoplankton community in AHD for one year in all three depths of the sampling site. Collected and counted cell densities of the phytoplankton phyla in AHD were used to calculate the Shannon-Weiner index in each month and at the different layers of the reservoir.

Statistical analyses

The data sets were computed and analyzed by Pearson correlation analysis, multiple regression and one-way ANOVA using Microsoft Excel and Past3 software. The level of significance was set at $P < 0.05$.

Results and Discussion

Phytoplankton composition and abundance in Angat Hydroelectric Dam (AHD)

Phytoplankton in AHD exhibited significant spatio-temporal abundance. A total of 26 species were identified under four groups: Bacillariophyta or diatoms (4 genera, 7 species), Euglenophyta (1 genus, 1 species), Chlorophyta (13 genera, 13 species) and Cyanophyta (5 genera, 5 species). The species were found at different water layers and varied seasonally (Table 1) (Supplementary File).

In terms of occurrence, the Cyanophyta dominated the surface and bottom level of the reservoir while Chlorophyta were most abundant at the metalimnion or middle layer all throughout the year. Among the 26 phytoplankton species identified, *Synechocystis* sp. (Cyanophyta) was the most abundant throughout the sampling period at 102.425 x 10^3 cells/ml, followed by *Chlorella* sp. (Chlorophyta) at 99.259 x 10^3 cells/ml, and the assemblages of *Chroococcus* sp. (Cyanophyta) at 17.342 cells/ml. The abundance of chlorophytes such as *Crucigenia* sp. at 3.917 x 10^3 cells/ml and *Oocystis* sp. (3.517 x 10^3 cells/ml) were also observed (Table 2) (Supplementary File). Dominant species were mostly unicellular/colonial type that belonged to Cyanophyta and Chlorophyta groups. In comparison, based on the assessment of cell density, Euglenophyta and Bacillariophyta groups appeared only occasionally and sporadically especially in the water samples of the different water layers (Table 1 and Table 2) (Supplementary File). This occurrence can be attributed to the characteristics of cyanobacteria such as their ability

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to survive extreme conditions like high and low water temperatures, high concentrations of sodium chloride, and can exist in freshwater localities with diverse trophic states [12]. Moreover, previous reports had pointed out the distribution and abundance of cyanobacteria affected by factors such as light intensity and nutrient availability interacting with other physical and chemical factors [13-15]. Also, the high affinity of many cyanobacteria for lower ratio of nitrogen and phosphorus in promoting cyanobacterial growth was considered [16].

Synechocystis sp., *Chlorella* sp., and *Chroococcus* sp. with 36.375, 29.483, and 14.725 x 10^3 cells/ml, respectively, were the most dominant species at the surface level, although its presence fluctuated every month (Table 1 and Table 2) (Supplementary File). Cyanophyta dominated in all three layers of water, followed by the Chlorophyta (Figure 2) (Supplementary File). On the other hand, the Bacillariophyta with 7.85 x 10^3 cells/ml was more abundant at the middle layer. However, its population was not detected at the bottom layer during the study period. *Trachelomonas* sp. was the only representative species of Euglenophyta found in AHD. It was noted at the surface layer with a density of 1.608 x 10^3 cells/ml, then dropped to 0.016 x 10^3 cells/ml at the middle layer, and was not observed at the bottom layer just like the Bacillariophyta.

A marked observation on the phytoplankton species abundance in AHD indicates a declining trend as the water depth increases with *Chlorella* sp. and *Synechocystis* sp. as the only species populating the bottom layer of the water. In addition, the water was characterized by the predominance of cyanobacteria during wet season (June-November) and hot dry season (March-May) while chlorophytes were observed to be subdominant on wet and hot dry seasons but dominant during cool dry season, that is on December-February (Figure 2) (Supplementary File). Most small phytoplankton species are known to increase their surface to volume ratio, thus may efficiently utilize nutrients [17-19]. By having a low Ks (half-saturation constant) value and high maximum growth rate (μ_{max}) for phosphorus in *Microcystis aeruginosa*, this would imply the cyanobacteria's high efficiency for utilizing nutrients such as phosphorus [19]. Thus, this may have contributed considerably for the growth and abundance of cyanobacteria during wet season and high dry season.

Phytoplankton group dominance based on seasonal variation and water depths

Five (5) species of cyanobacteria and thirteen (13) species of chlorophytes were highly present on the three seasonal variations and at all depths of the AHD. The species of cyanobacteria found in AHD were: *Synechocystis* sp., *Chroococcus* sp., *Lyngbya* sp., and *Merismopedia* sp., which were predominant all year round (Table 2) (Supplementary File). Chlorophytes were less dominant in terms of cell density but more dominant in species richness in which 13 species were identified in the water samples namely: *Chlorella* sp., *Crucigenia* sp., *Chlorococcum* sp., *Scenedesmus* sp., *Lagerheimia* sp., *Staurastrum* sp., *Ankistrodesmus* sp., *Cosmarium* sp., *Pediastrium simplex*, *Treubaria crassispina*, *Cylindrocapsa geminella*, and *Shroederia setigeria*.

At the surface layer of AHD, the abundance of Cyanophyta's percent compositon from June to Nov. 2018 varied from 56.10% to 73.36% (Figure 2) (Supplementary File). Cyanobacteria group increased and recorded its highest abundance in March (51.81%), April (71.89%) and May 2019 (55.56%) while Chlorophyta showed dominance and highest abundance from December (51.74%), January (62.35%) and February (70.88%) which are considered cool dry months.

The middle layer of the reservoir showed species abundance of the Cyanophyta from June to November 2018 – the wet season. During this time, the month of June had the highest dominance (80%) by the cyanophytes, followed by the month of November (79%), then October (68%), August (58%), July (53%) and September (49%). In December 2018, the Chlorophyta group thrived dominantly (78%), but in January 2019, it shifted to Cyanophyta (49%) then back to Chlorophyta on February 2019 (52%). With the approaching summer months, the Cyanophyta was again the most dominant phytoplankton group as it grew abundantly in March (69%), April (67%) and May 2019 (89%) consequently, with the recorded highest temperature at 29.5°C.

Similarly, the bottom layer of AHD was consistently dominated by Cyanophyta especially during the hot dry and wet season. During the rainy season, August 2018 had the highest abundance of Cyanophyta at 82% composition then a 100% composition shifted to green algae in November and December which continued until February 2019 (57%). From March to April, the warmest months of the year, cyanophytes again dominated the reservoir at 100% on March and April and 70% on May.

Phytoplankton Species Accumulation Curve (SAC)

Figure 3 (Supplementary File) presented the number of accumulated or identified phytoplankton species in all three layers of the water in AHD throughout the sampling period. The surface layer had a total of 26 recorded species identified with a plateau from December to March in which no new phytoplankton species was recorded and identified. June had the highest number of phytoplankton species recorded which was 7 followed by July in which 6 new phytoplankton species were identified. Though there had been a flat curve from December to March, new phytoplankton species emerged during the sampling dates in April and May, thus the rising trend line suggesting species richness of the water reservoir.

The middle layer of AHD displayed a similar rising trend line in which a total of 21 recorded new phytoplankton species were identified throughout the duration of the study. The month of June and July had the highest number of new species identified (5) followed by August and January in which 4 new species in each month were found and identified.

The flattened curve of SAC in the middle water layer occurred twice, first from September to December then from February to March, and by April and May 2019, the 2 recorded new species were identified. This fluctuation in the SAC may potentially indicate species richness of AHD.

Likewise, the bottom layer SAC also suggested species richness as the discovery of new phytoplankton species fluctuated in each month and the incidence of plateau is not continuous. A total of 12 recorded new phytoplankton species were found at the bottom layer of AHD with the month of August recorded for having the highest number of species discovery. As compared to the surface and middle layers, the bottom layer had the longest plateau beginning in the month of October. By February 2019, as 2 recorded new species were discovered and identified, the line increased but flattened again until May which was the last month of the sampling period. By flattening the curve, the above findings may be followed by the discovery of newly recorded species suggesting that the phytoplankton community of AHD may become abundant and thus, additional sampling sites are required.

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Limnological characteristics of AHD water during the period of study

Table 3 (Supplementary File) as cyanobacteria were considered summarizes the limnological characteristics of AHD water from June 2018-May 2019. Water temperature was high during the months of May, June and July and dropped in the months of December, January and February (Figure 4) (Supplementary File). On the other hand, nitrate and phosphate levels were high during rainy/wet months of July, September and October (Figure 5) (Supplementary File). Water conductivity, pH and total dissolved solids had an increasing trend during the wet season from June to November and lowest during the cool dry season from December to February. Salinity was generally consistent throughout the study period but there was a notable salinity increase at the bottom level. Nitrate levels were stable while phosphate fluctuated and showed increased level during cool dry months in all layers of the water in the reservoir. It was also observed that a spike in phosphate content occurred in October.

The highest temperature recorded was in June (31.19°C) during the wet dry season while the lowest was in February (22.97°C). Water conductivity, pH and total dissolved solids had an increasing trend during wet season from June to November and lowest during cool dry season from December to February.

Nitrate and phosphate content in the water was highest during wet season and lowest during cool dry season. The highest mean DO was recorded during the hot dry season and lowest during cool dry season from December to February. Salinity was highest in the month of August and lowest throughout the cool dry season. Using depth parameter, conductivity, TDS, pH, nitrate and phosphate level showed upward trend.

Variations of physico-chemical parameters in different water layers

Surface Layer. The warmest temperature of the surface level of AHD was recorded in June (31.9°C) while the coolest occurred in January 2019 (25.29°C) (Figure 4) (Supplementary File). During wet season, the temperature ranged from 27°C to 31°C. Meanwhile during cool dry season, the temperature slightly dropped ranging from 25°C to 26°C whereas in the hot dry season, temperature ranged from 27°C to 30°C. Water conductivity at surface layer was highest in the month of October (185µS/cm) followed by the month of June (174 µS/cm) and August (173 µS/cm), conductivity was lowest in February 2019 (135 µS/cm) (Figure 4) (Supplementary File).

Salinity was relatively similar in all months of the sampling period which ranged from 0.06 to 0.07 (Figure 4) (Supplementary File). Total dissolved solids (TDS) was highest in October 2018 (112mg/L) which occurred during the rainy season and lowest in February 2019 (87.5mg/L) during the cool dry season.. March had the highest DO (8.2mg/L) while January recorded the lowest at 4.3 mg/L. In general, the trend for TDS, conductivity, and salinity was the same for 12 months.

Water pH also fluctuated as seasonal variation occurred (Figure 5). During wet season, pH range was from 6.9 to 7.8, while in the cool dry season, this was from 4.3 to 7.5, and in hot dry season it ranged from 7.7 to 8.2. The lower pH during the dry season was thought to be caused by high decay of organic matter due to increased microbial activity, thereby increasing CO_2 and making the water acidic [20]. Nitrate and phosphate content in the water was high during wet season and and lowest during cool dry season. This occurrence is comparable to two tropical lakes in the Philippines, Lakes Paoay and Mojicap, wherein the amount of nitrates and phosphates peaked during the wet season which can be due to the runoff of fertilizers from agricultural areas during the rainy months [21].

Middle Layer. The middle layer of the reservoir had the warmest in July (26.26°C) while the coolest occurred in February 2019 (23.32°C). During wet season, the temperature ranged from 24°C to 25°C (Figure 4) (Supplementary File). Meanwhile during cool dry season and hot dry months, the temperature slightly dropped ranging from 23°C to 24°C. Water conductivity at the middle layer was recorded highest in the month of October (174 µS/cm) followed by the month of August (173 µS/cm) and May (164µS/cm), while conductivity was lowest in January 2019 (132µS/cm).

Measurement of salinity was relatively similar in all months of the sampling period which ranged from 0.06 to 0.08 ppt with the month of August as the highest measurement. Total dissolved solids (TDS) were highest in October 2018 (113 mg/L) and lowest in February 2019 (90 mg/L). The rainy or wet season displayed the highest TDS record from 94-112mg/L. Hot dry season had TDS of 93-108 mg/L while cool dry season had 86-96 mg/L. In addition, January 2019 had the highest DO (0.8mg/L) while September 2018 recorded the lowest at 0.1mg/L. From February to May 2019, DO level was stable at 0.2mg/L.Water pH was relatively stable throughout the sampling period. During wet season, pH range was from 7 to 8, while this was from 3.9 to 4.02 pH in the hot dry season. During the cool month of December to January, the pH ranged from 4.02. to 8.49.

Bottom Layer. As shown in Figure 4 (Supplementary File), the bottom layer recorded the highest temperature on October (23.56°C) while the lowest temperature was in February 2019 (22.97°C). All throughout the sampling period, the temperature was relatively constant at 22-23°C. Water conductivity at this level of the reservoir recorded highest in the month of August (507 µS/cm) followed by the month of September (451 µS/cm) and October (259 µS/cm), while conductivity was lowest in January 2019 (123 µS/cm).

As the layers of water got deeper, the presence of TDS were higher and pH also increased (Table 4, $p < 0.05$) (Figure 8) (Supplementary File) as cyanobacteria were considered. During wet season, nitrate and phosphate content in the water was highest while this was found to be lowest during cool dry season (Figure 5) (Supplementary File). Meanwhile, temperature and cell density also displayed positive correlation at significant level which was noted in the duration of the study when phytoplankton communities were found in high abundance during hot dry and cool dry seasons. In general, it can be reckoned that phytoplankton growth increases with the increase in temperature and that elevated temperature coincides with the general appearance of blue-green algal blooms during summer in most tropical lakes [22]. Likewise, climate and temperature were found to be higher and phytoplankton assemblage was also positively correlated with the DO. This was evident at the hypolimnion wherein phytoplankton groups diminished at lower depth of AHD.

Relationship between phytoplankton density and the physico-chemical parameters of the water in AHD

As seen in Figure 6 (Supplementary File), the phytoplankton population was higher when the temperature was warmer. The warmest temperatures (31.9°C) were recorded at surface level while the coldest were at the bottom level.

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Salinity did not largely affect the density of the phytoplankton population in all three layers of water. Likewise, it was observed that the highest records of salinity were found at the bottom layer where the phytoplankton population was less. The highest conductivity was also in the bottom layer of the AHD with less than 10.0 x 10^3 cells/ml of phytoplankton found. The highest phytoplankton density was recorded in the middle layer where all the physico-chemical parameters were ideal for the growth of phytoplankton. Phytoplankton abundance was highest during February 2019 (14.4 x10^3 cells/ml) and lowest in March 2019 (2.77 x 10^3 cells/ml). The months of June and November which were regarded as rainy months, recorded the second highest density of 13.5 x10^3 cells/mL.

At the surface layer of AHD, the cell density increased and pH (Figure 7) also increased during wet season. Likewise, a directly proportional trend was observed in which case there was low pH and low cell density during the cool dry season. However, during the occurrence of hot dry months, the pH remained low from March to May while the cell density fluctuate.

The middle layer of the reservoir which gave the highest phytoplankton density (14.4 x 10^3 cells/ml) showed the following parameters ideal for phytoplankton growth (Figure 6) (Supplementary File). It demonstrated the warmest temperature in July (26.26°C) while the coolest occurred in February 2019 (23.32°C). During wet season the temperature ranged from 24°C to 25°C. Meanwhile during cool dry season and hot dry months, the temperature slightly dropped ranging from 23°C to 24°C. The conductivity at the middle water layer was recorded highest in the month of October (174µS/cm) followed by the month of August (173 µS/cm) and May (164µS/cm) while this was lowest in January 2019 (132 µS/cm).

Measurement of salinity was relatively similar in all months of the sampling period which ranged from 0.06 ppt to 0.08 ppt with the month of August as the highest measurement. Total dissolved solids (TDS) were highest in October 2018 (113mg/L). In addition, January 2019 had the highest DO (0.8mg/L). Water pH (Figure 7) was relatively stable throughout the sampling period.

At the bottom layer of AHD, October recorded the highest temperature (23.56°C) while the lowest temperature was recorded in February 2019 (22.97°C). All throughout the sampling period the temperature is relatively constant at 22-23°C. Water conductivity at this level of the reservoir recorded highest in the month of August (507µS/cm).

Effects of Nitrate-N and Phosphate-P on phytoplankton densities

There were no drastic fluctuations in the levels of nitrate-N and phosphate-P in all the three layers of AHD during the sampling period (Figure 8) (Supplementary File). Similarly, it was observed that as the nitrate-N and phosphate-P level decreased, the phytoplankton population also declined. This was observed in all the levels of the AHD water. Thus, phytoplankton community showed an increased population whenever there was a rise in the amount of nitrate and phosphate in the water of AHD in all levels.

In the succession of cyanobacteria and chlorophytes, it was recorded that at surface level, there is the dominance of cyanobacteria and shift to chlorophytes at the middle level, then shifted back to cyanobacteria at the bottom level of the reservoir. This may be ascribed to higher amount of nitrate and phosphate in the bottom level of the water (Figure 8) (Supplementary File) as cyanobacteria were considered to be the most important nitrogen-fixing bacteria and can thrive in different types of environments from moist soils to marine water, deserts to deepest lakes [23]. Numerous species characteristically inhabit, and can occassionally dominate, both near-surface epilimnic and deep, euphotic, hypolimnic waters of lakes [24]. It is suggested that the resilience of cyanobacteria is the factor for its abundance in AHD.

The correlation and multiple regression analyses confirmed positive correlationship with temperature, DO, nitrogen and phosphate content which explained the significant effects of these physico-chemical factors on the phytoplankton biodiversity and assemblage in the different layers of water in AHD reservoir (Table 4) (Figure 8) (Supplementary File) as cyanobacteria were considered. TDS and pH also confirmed positve association with depth thus proving as driving factors in the composition of phytoplankton during seasonal variations.

In this study, attempts were also made to demonstrate the relationship between the seasonal distribution of phytoplankton at different water depths on the basis of several physico-chemical parameters (Figure 6, Figure 7 and Figure 8) (Supplementary File). AHD which collects water from the Angat River consequently created the Angat lake and this lake is catagorized as tropical warm monomictic lake. As discussed in previous studies [25-27], warm monomictic lakes undergo atelomixis. Described originally [28], atelomixis process is a strong water movement taking place once a day usually at night and ranging either to the whole water column on dry periods-called full atelomixis or is restricted to epilimnion or surface waters (rainy period-partial atelomixis), thus causing water temperature differences at varying depths. This movement of water might be considered an important factor in the seasonal succession on the composition and abundance of phytoplankton in AHD. This process was also observed in other tropical lakes [3, 25, 29].

The confirmed positive correlationship in the findings with temperature, DO, nitrogen and phosphate content explained the significant effects of these physico-chemical factors in the phytoplankton biodiversity and assemblage in the different layers of water in AHD reservoir. Similarly, TDS and pH verified the positive association with depth, thus indicating as driving factors in the composition of phytoplankton during seasonal variations. Comparable results were observed for the seasonal dynamics of phytoplankton in a reservoir in Andhra Pradesh, India [30].

Although considered statistically significant in its correlation with the phytoplankton density, nitrate and phosphate in AHD are within safe level along with TDS and pH, thereby generalizing that the water of AHD is safe for domestic and household use as per standards of Administrative Order 2016-08-WQG (Water Quality Guidelines) and General Effluent Standards (GES) of the Department of Environment and Natural Resources (DENR).

Shannon-Weiner diversity index

The fluctuating monthly Shannon-Weiner (H) indices during the study period are shown in Figure 9 (Supplementary File). The month of May 2019 gave the highest Shannon-Weiner Index of 1.3, while the lowest was in March (0.32) and April (0.03). March and April were considered the months with lowest biodiversity due to the fact that in this period the Chlorophyta and Cyanophyta groups dominated the three layers of water and outnumbered the other groups of phytoplankton (Bacillariophyta and Euglenophyta).

In general, the Shannon-Weinner index values of the AHD were considered to be low as there was only one sampling site for the water collection and limited sampling period. Nonetheless, the Shannon diversity index of AHD strongly suggests that this artificial water reservoir is oligotrophic despite its existence for fifty-two years. Furthermore, in this oligotrophic state of AHD, it was also apparent that the lake has not yet undergone eutrophication.

Species biodiversity and species richness index in AHD potentially suggests that there is a growing abundance of phytoplankton especially in the epilimnion during wet and hot dry seasons. As this was considered a baseline study on the AHD in relation to its phytoplankton community structure, further studies and longer sampling periods are needed to establish a robust biodiversity and species richness index in the reservoir which can be compared with other tropical lakes in the world.

Comprehensively, the fluctuating phytoplankton abundance in the AHD was driven by its spatio-temporal variations and the succession of phytoplankton dominance seasonally and spatially was correlated with some physico-chemical parameters such as temperature, dissolved oxygen, depth, nutrient concentration, total dissolved solids, and pH. Establishing the concrete spatio-temporal trends for the reservoir's phytoplankton community structure requires longer periods and more sampling sites.

Conclusion

This study reports on the first record of phytoplankton spatio-temporal trends in Angat Hydroelectric Dam (AHD), Bulacan Province, Philippines. The findings indicated that AHD's phytoplankton community structure was dominated by cyanobacteria as the major algal group in seasonal variation and spatial (depth) based analysis. Furthermore, the increase in phytoplankton density was positively correlated with temperature, nutrient content, and depth. The succession from chlorophytes to cyanobacteria as the water level increases is attributed to the increasing level of phosphate and nitrate in the deeper level of water. Lastly, the present study suggested that the water quality of AHD is safe and its current phytoplankton density is an indicator of the ecosystem health of the water.

Competing Interests

The authors declare that they have no competing interests.

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