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Original Article

# Temporal and spatial phytoplankton biomass dynamics in southern Gulf of Lake Tana, Northwestern Ethiopia

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**Abstract:** Southern Gulf of Lake Tana is southern part of Lake Tana in Northwestern Ethiopia. Water samples were obtained from eight sites of the gulf for six months during November to April 2010/11 twice a month to determine temporal and spatial variation in phytoplankton biomass of the gulf. Phytoplankton biomass data was estimated following total chlorophyll-a concentrations determination methods. There was no significant difference in sampling sites and interactions between sampling sites and months (*P*>0.05). However, there is a significant difference in sampling months (*P*<0.05). The absence of significant difference in sampling sites and the interactions might be due to the similarity in human or natural impacts, and phytoplankton growth and decline. But, the presence of significant difference among sampling months might be due to the difference in growth/decline periods of the phytoplankton. Southern Gulf of Lake Tana subparts are similarly impacted naturally or by humans who passed their time around the gulf. The Ethiopian government and concerned non-governmental organizations in general and local communities, in particular, have better cooperate their efforts for conservation and sustainable use of the gulf. Similarly, they have to play in awareness creation for stakeholders to reduce natural/human impacts to the lake gulf.

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## Introduction

A common symptom of increasing nutrient enrichment (eutrophication) is an increase in phytoplankton biomass (Nixon and Buckley, 2002). There is a long history of the application of total chlorophyll-a as an index of the productivity and trophic condition of estuaries, coastal and oceanic waters (Boyer et al., 2009). It is also very important parameters to understand the structure and tropic level of aquatic systems, the quality of water and environments (Fakioglu, 2013) and for forecasting the extent of global change impact on aquatic ecosystem functioning (Winder and Cloern, 2017).

Phytoplankton biomass is affected by different biological, physical and chemical factors such as the grazing effect of zooplankton and benthic filter-feeding animals (Levine et al., 1999), light conditions (Berger et al., 2006), flow velocity (Feipeng et al., 2013), temperature and nutrients (Lin-lin et al., 2012; Cao et al., 2016). According to Goericke (2002), planktonic populations are interacted by both resource limitation (bottom up) and predation (top-down).

Lake Tana, which is the largest lake in Ethiopia (Barker, 2004; Gordon et al., 2007), is surrounded by agricultural lands (Erkie, 2016) and fed from many small seasonal to large permanent rivers to the lake (Nyssen et al., 2015). It is recently losing its natural conditions (Vijverberg et al., 2009). However, significant inflow comes from three major rivers in the south, namely the Gilgel Abai, Rib, and Gumara, which carry a large amount of silt resulting from severe erosion, thereby increasing the turbidity of the water in the Bahir Dar Gulf (Berhanu et al., 2001).

Assessing phytoplankton biomass, could be beneficial for environmental managers and other stakeholders to understand the lake conditions and hereby alleviate human and natural hazards to the lake. The objective of this research was to assess spatial and temporal phytoplankton biomass variability in Southern Gulf of Lake Tana,

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Table 1. Morphometric and physicochemical characteristics of Lake Tana.

| Morphometric characteristics | | Physicochemical characteristics | |
|---|---|---|---|
| Maximum depth (m) | 14 | Lake temperature (°C) | 22.8±1.19 |
| Mean depth (m) | 8 | Conductivity (µSCm-L) | 84-230 |
| Lake area (km$^2$) | 3156 | Total alkalinity (mg/L) | 85-159 |
| Catchment area (km$^2$) | 16500 | $Na^+$(mg/L) | 7-9 |
| Lake volume (km$^3$) | 28.4 | $K^+$ (mg/L) | 1 |
| Water residence time (year) | 3 | $Ca^{++}$ (mg/L) | 14 |
| Evaporation loss (mm) | 1248 | $Mg^{++}$ (mg/L) | 12 |
| Altitude (m) | 1830 | $HCO^-_3$ +$CO^-_3$ (mg/L) | 91 |
| Latitude ($^0$N) | $10^0$58’-$12^0$47’ | $Cl^-$ (mg/L) | 1.25 |
| Longitude ($^0$N) | $36^0$48-$38^0$14’ | TDS (mg/L) | 50-138 |
| Runoff coefficient (K) | 0.22 | δ D | 34.6 ‰ |
| Rainfall (mm/year) | 1500 | Turbidity (NTU) | 20-29 |
| Max. length (km) | 78 | $NO^-_3$ (mg/L) | 0.2 to 2 |
| Max. width (km) | 67 | $PO^-_4$ (mg/L) | 0.05-2.82 |
| Annual precipitation (mm) | 1375 | Dissolved Oxygen (mg/L) | 3.5-8.5 |
| Major water use | Hydropower, navigation | BOD (mg/L) | 3.2-23.7 |

Kebede et al. (2006), Shimelis et al. (2008) and Dagnew et al. (2014).

Southwestern Ethiopia.

## Materials and Methods

Lake Tana is located between 10°58`00"–12°47'00"N and 36°45'00"-38°14'00"E (Dagnew et al., 2014) on the basaltic plateau of the north-western highlands of Ethiopia at an altitude of 1,830 m above sea level (Vijverberg et al., 2009). It is characterized by low nutrient concentrations, high silt and a low primary production (Ayalew et al., 2007). The lake is the largest and third largest in Ethiopia and the Nile basin (Abeyou, 2008), respectively. It is also the source of the Blue Nile River, which is the longest river in the world (Vijverberg et al., 2009). Morphometric and physicochemical characteristics of the lake are shown in Table 1.

Climate around the study area is unimodal pattern or "seasonal rains" characterized as rainy in summer (June-August) and dry in the winter (January-March). The absolute, mean minimum and maximum temperature in an area, where is nearby to Southern Gulf of Lake Tana, are 5.9, 12 and 31°C during the study year. Similarly, the rainfall pattern ranges from 0 ml (Decebber, February and March) to 417.2 ml (August) (Fig. 1).

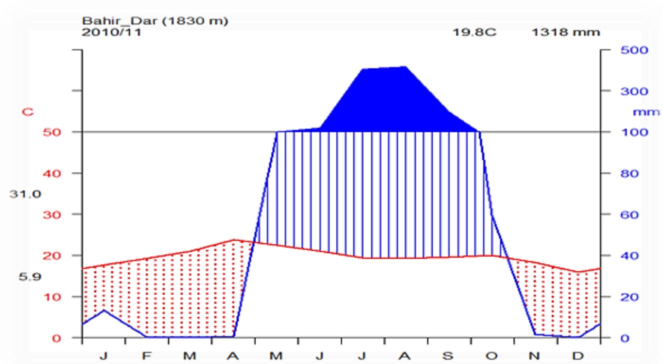


Figure 1. Climate diagram of the study area.

**Fieldworks and site selection:** Sites were selected based on the presence/absence of human-induced pressures along the southern Gulf of Lake Tana. Site 1 (Debre Mariam area) is characterized by impacts from agriculture. Site 2 (West Gojjam Prison Station) is characterized by human wastes. Site 3 (Shum Abo Recration) is characterized by transportation and recreation around the site. Site 4 (Titu Recreation Center and port for Tana Transport Organization) is characterized by both transportation and hotel construction on the shoreline of the lake. Site 5 (Bahir Dar City, Legislative Area) is characterized by swimming, washing clothes and bathing. Site 6, sites 7 and 8 were are characterized by hotel construction (the Blue Nile Resort relatively undisturbed and was control site for the data analysis), wastes from hospitals (Flege Hiwot Referral Hospital) and runoff from agricultural lands (Tana Medhanie Alem Integrated Development Association), respectively.

**Sampling procedures and programs:** Sampling of water was done using mesh net (pore size 55 µm) starting from site 1 to site 8 and adding sampled water into 8 pure sample bottles, for phytoplankton biomass determination in the morning from 5 AM to 7 AM. Water samples were put into a sampling bottle filled with ice to prevent chlorophyll degradation due to light and temperature during transportations to the laboratory. The samples were transported to the laboratory for analysis within a maximum of two hours after collection. Sampling was done every two weeks in eight sites for six months from November 2010 to April 2011. A total of 96 (8 sites*2 times*6 months) samples of water were analyzed for phytoplankton biomass following chlorophyll-a concentration determination methods as proposed by Lorenzen (1966).

**Phytoplankton biomass determination:** The water samples in the Botany Laboratory at Bahir Dar University were filtered through Millipore microfilters (47 mm diameter; 45 µm pores) using a vacuum pump (TS8002). The filtrate was fourfold and placed in the tissue grinder and 3 ml of 90% acetone was added to the filtrate. It was ground until the filter fibers are separated and another 4 ml of acetone was added and put into the refrigerator (Haier or HYCD-215) at -29°C for 24 hours. The ground filter was put into centrifuge tubes and added into the centrifuge (IEC Model CL Centrifuge) to remove suspended particles. The centrifuge was revolved for 10 minutes in 3000 rpm to clarify samples. One cuvette was filled with 90% acetone for calibration and the rest cuvettes with their respective samples. The spectrophotometer (NV-203) was put on for at least five minutes before being used for measuring light absorption into the sample. The cuvette with acetone was put into spectrophotometer and the reading was adjusted to read zero. The respective samples were put to the spectrophotometer and the absorbencies were recorded at wavelengths of 750, 665, and 630 µm. The recorded samples were drawn out and two drops of 0.1N of HCl acid was added to samples. Again the absorbance at 750, 665 and 630 µm was recorded. The content of total chlorophyll-a was calculated using the formula provided by Jeffrey and Humphrey (1975).

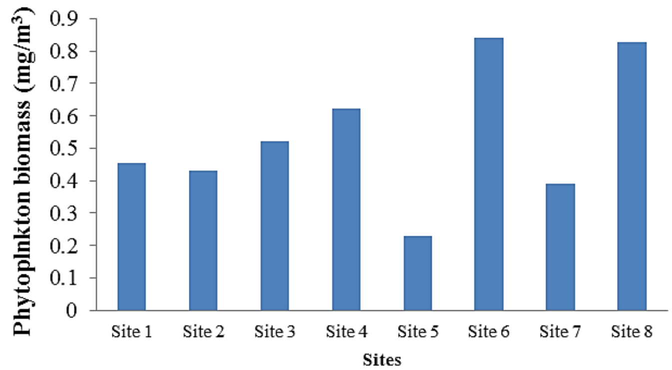


Figure 2. Spatial phytoplankton biomass distributions in the Southern Gulf of Lake Tana.

Other parameters such as temperature, rainfall, wind speed and humidity data were obtained from the nearby meteorological station (National Metrological Agency Bahir Dar Branch).

**Statistical Data Analysis:** The data was compared for Spatial and temporal phytoplankton biomass variation, correlation of phytoplankton biomass with temperature, rainfall, and wind speed and humidity conditions. Similarity and difference between and among sites and months were determined by cluster analysis and one-way analysis of variance (ANOVA) using R (R Core Team, 2016). Bar graphs and table were used to present the summary of the result and presented using Microsoft Excel (2013) and R (R Core Team, 2016) to compare the relative phytoplankton biomass variations among sites and months.

## Results and Discussions

**Spatial phytoplankton biomass in southern Gulf of Lake Tana:** Phytoplankton biomass distribution in the southern Gulf of Lake Tana was all most equal in all sites. Mean phytoplankton biomass was calculated and presented in the bar graph (Fig. 2). Sites 6 and 8 had relatively high and same while the remaining sites low mean values (Fig. 2).

Cluster analysis among sites showed that sites 2 and 4 are very similar. However, site 6 is very different from other sites. In a practical situation, sites 2 and 4 were areas where boats accumulated for transportation and it was amazing that they were similar in cluster analysis. Similarly, site 6 was relatively undisturbed area and it was placed in

Table 2. Biomass correlation with temperature (°C), wind speed (m/s) and humidity (%).

| N = 96 | Temperature | Wind speed | Rainfall | Humidity |
|---|---|---|---|---|
| Temperature | | | | |
| Wind speed | 0.94 | | | |
| Rainfall | -0.1 | -0.11 | | |
| Humidity | -0.71 | -0.69 | 0.58 | |
| Phytoplankton biomass | -0.1 | -0.16 | 0.37 | 0.39 |

Table 3. Site conditions in the southern Gulf of Lake Tana from November 2010 to April 2011 (where E=eutrophic site and O=oligotrophic site) (Polovina et al., 2001).

| Months | Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 |
| November | e | e | o | e | e | o | e | o |
| December | o | o | o | o | o | o | o | o |
| January | o | o | o | o | o | o | o | o |
| February | o | o | o | o | o | o | o | o |
| March | o | o | o | o | o | o | o | o |
| April | o | o | o | o | o | o | o | o |

Table 4. One way ANOVA for phytoplankton biomass (mg/m3) in southern Gulf of Lake Tana among months (November-April) of the year 2010/11 and sampling sites (where *** = very significant and--- = not significant).

| **Source (N=96)** | **DF** | **SS** | **MS** | **Lambda** | **F-value** | **P-Vale** |
|---|---|---|---|---|---|---|
| **Time (month = T)** | 5 | 251.062 | 50.212 | 44.879 | 1.000 | <0.001*** |
| **Space (Site = S)** | 7 | 32.126 | 4.589 | 5.743 | 0.310 | 0.5752--- |
| **Interactions (T+S)** | 35 | 181.204 | 5177 | 32.391 | 0.889 | 0.5902--- |
| **Residual** | 48 | 268.524 | 5.594 | | | |

different positions by the analysis (Fig. 3).

The correlation analysis indicated that phytoplankton biomass is positively associated with environmental humidity and rainfall (R = 0.37 and 0.39, respectively) in one way and negatively correlated with temperature and wind speed (R = -0.1 and -0.16, respectively). In other words, increasing humidity and rainfall increase phytoplankton biomass, whereas elevation of temperature and wind speed decrease increase phytoplankton (Table 2). The result also showed that there is a very strong relationship between temperature and wind speed around the study area i.e. the Southern Gulf of Lake Tana (R = 0.94).

All sites except site 3 (impacted by transportation) were eutrophied in November. In the rest months, all sites were oligotrophic (Polovina et al., 2001) (Table 3). The gulf was also classified as high, good, moderate, poor and bad conditions (Karydis, 2009). Hence, all sites except site 8 (Moderate) were bad in November 2010 (Table 4).

The highest and the lowest phytoplankton biomass values of the southern Gulf of Lake Tana were recorded in November (21 mg/m$^3$) and March (0.001 mg/m$^3$), respectively. The monthly variation in total phytoplankton biomass was characterized by the lowest (0.001 mg /m$^3$) in February and March 2011 and peaked (21 mg /m$^3$) in November 2010 and the annual mean biomass of total phytoplankton in this gulf was 0.90 mg/m$^3$ (Fig. 4). Annual phytoplankton biomass growth and decline was estimated by finding monthly average phytoplankton biomass. It was found that peak mean phytoplankton biomass in November (8 mg /m$^3$) and lowest in March (0.04 mg /m$^3$). The growth trend was decrement toward March from November and again increased toward a peak in April (Fig. 3).

The temporal cluster analysis showed that November (leveled as 1), December (leveled as 2) and April (leveled as 6) have high similarity. This means phytoplankton biomass returned back to its original state (November) after three months (January, February, and March). In other months (January, February, and March), it was nearly the same when compared to the first cluster (Fig. 5).

Table 5. Water quality of sites (where h=High, g = Good, m = Moderate, p =Poor & b = Bad).

| Months | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 |
|---|---|---|---|---|---|---|---|---|
| November | b | b | b | b | b | m | b | b |
| December | g | g | h | g | g | h | h | b |
| January | g | g | h | h | h | h | h | h |
| February | h | h | h | h | h | h | h | h |
| March | h | h | h | h | h | h | h | g |
| April | m | g | p | m | p | m | g | g |

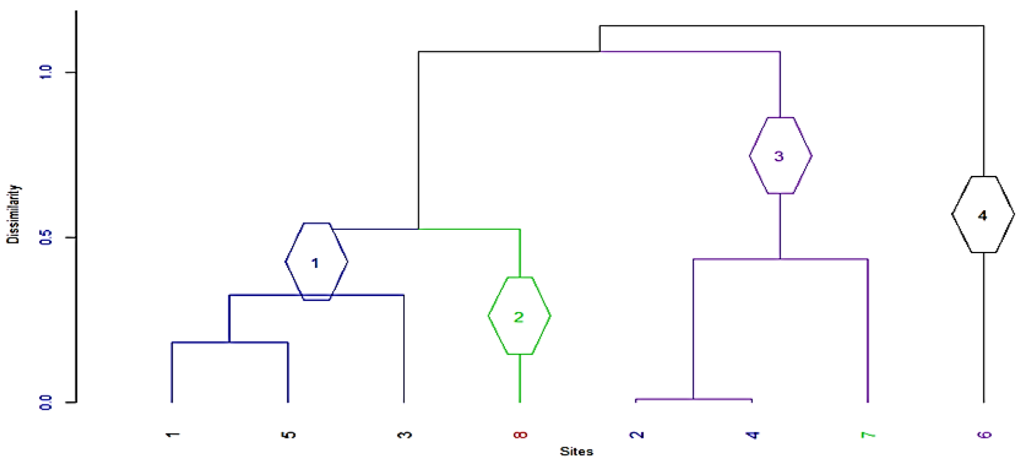


Figure 3. Phytoplankton biomass spatial cluster analysis.

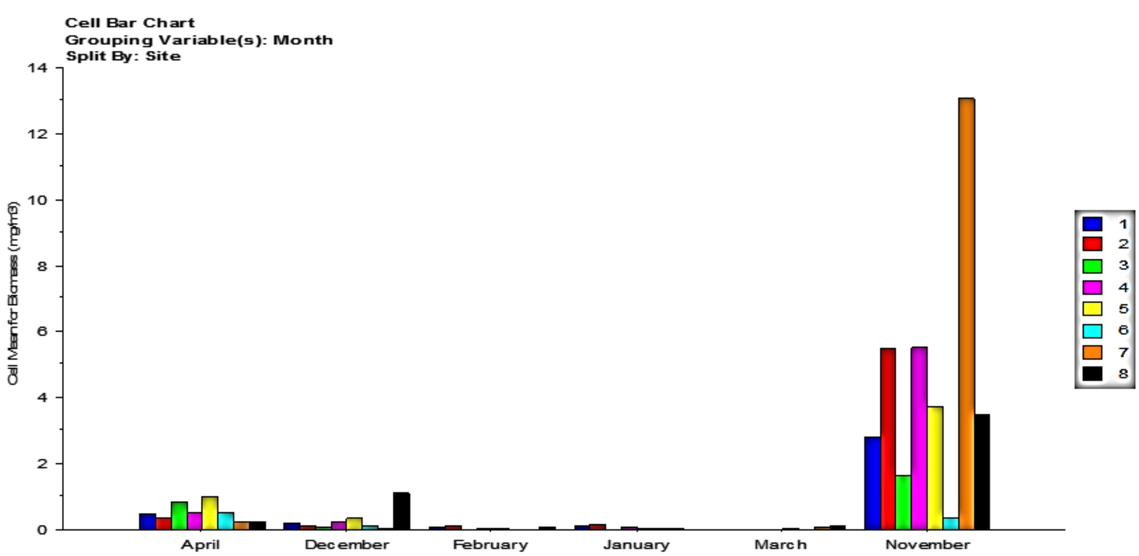


Figure 4. Temporal algal biomass in Lake Tana Southern Gulf (where numbers are sample sites).

**Anthropogenic impacts on phytoplankton biomass significance test:** Statistically, there was a significant difference in phytoplankton biomass concentration in the southern Gulf of Lake Tana among the six months ($F = 9.4$, $P < .05$ and $R^2 = 0.34$) (Table 4), but there was no spatial and interaction significance difference in the study area. Phytoplankton biomass did not vary widely among all sites in southern Gulf of Lake Tana. According to the trophic classification of Polovina et al. (2001), the gulf can be classified as oligotrophic gulf although the gulf is eutrophic in November. The peak condition of total chlorophyll-a in this month is

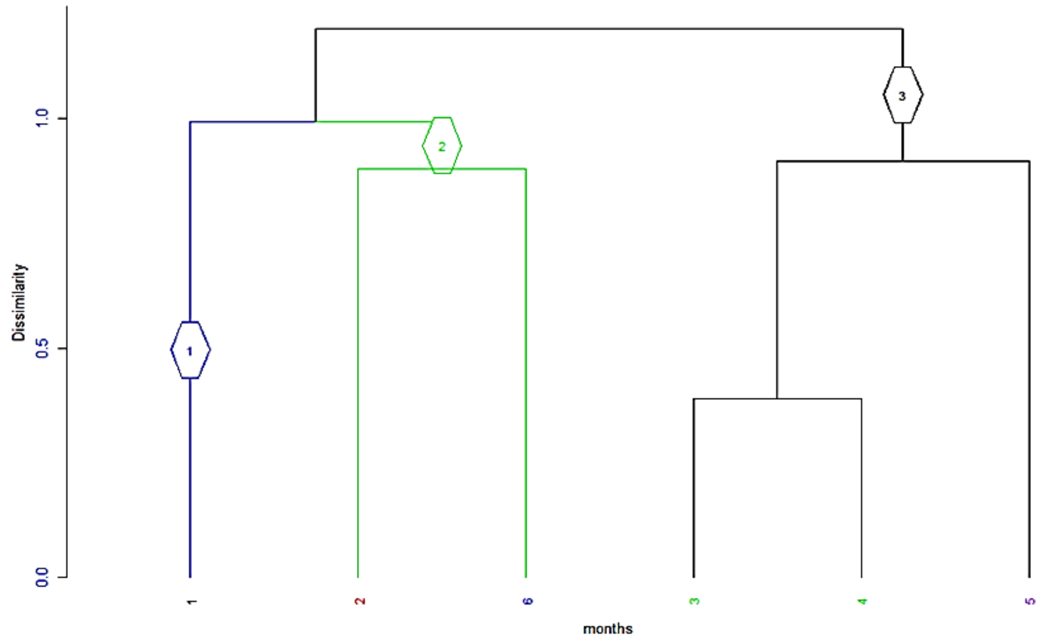


Figure 5. Cluster analysis showing similarity and differences among months (where 1=November, 2=December, 6 April in the first cluster and December=3, January=4, February=5).

in line with the study by Ayalew et al. (2007) who found that highest production rates in the post-rainy season (Oct.–Nov.), which coincided with algal blooms (Microcystis) and higher chlorophyll levels in the lake. This may be attributed to the low discharge of nutrients to the gulf because of low rainfall and hence low runoff which probably could carry nutrient-rich soil to the lake from surrounding agricultural areas in the remaining studied months (except November). A similar study by Tarekgne (2012) from July 2009 to May 2010 on the eastern side of Lake Tana showed that there was no significant difference of nutrients on spatial base but showed temporal significance variation. This study was in line with Tarekgne (2012) results and agrees with phytoplankton biomass data analysis for the southern Gulf of Lake Tana.

## Conclusions and Recommendations

The results showed that all study sites range between oligotrophic to eutrophic though the gulf was most of the time oligotrophic. Thus, this gulf might be most of the time nutrient limited. The absence of significant difference in sampling sites of the Gulf indicated that there are similarity in phytoplankton grazers, anthropogenic and and/or natural impacts and phytoplankton growth conditions of Southern Gulf of Lake Tana. However, the presence of significant variations among monitoring months in terms of phytoplankton biomass showed that there is a dissimilarity in anthropogenic/natural impacts and phytoplankton growth on the gulf due upon month basis.

There is a need for more work to be done at the southern Gulf of Lake Tana in general and Felege Hiowt Referal Hospital and West Gojam Prison stations areas in particular for removing inputs pressures from surrounding area to the Gulf ecosystem. Such works can be policy, decision, and management and thus bring sustainable growth and protection of the aquatic biodiversity and resources of the Gulf for future generations. Since the gulf receives nutrients from the rivers during flood season, runoffs from various sources like for example hospitals and prison stations, there is a need to balance, at least minimize the hydrological changes and prevent such inputs to the gulf.

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