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Plant Nutrient and Biological Water Quality of Legedadi Reservoir (Ethiopia): Spatio-temporal Variations

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Abstract

Legedadi reservoir, which is the most important single purpose reservoir, provides about eighty percent of the household water supply to Addis Ababa City. However, its water qualities are declining from time and time. For several years, the reservoir has grieved from irregular massive algal blooms, increased turbidity and undesirable odor and taste. The objective of this study was to investigate the spatial and temporal phytoplankton and nutrient dynamics in Legedadi reservoir. For this study, biweekly samples were collected from three sampling stations for ten months and pooled to a monthly data. Composite samples, prepared from discrete depths, were used for the analysis of nitrate, ammonium, orthophosphate and silica. Plankton net with 10 µm mesh size was used to collect sample for phytoplankton species identification and estimation of their relative contribution to the community.

All the limiting nutrients significantly varied both temporally and spatially ($P<0.05$) with most peak values coincided with the short and long rains. Although the reservoir didn't show green patches or algal scums on the surface, the phytoplankton biomass was found to be very high and significantly varied seasonally ($P<0.05$). Blue green algae, particularly *Microcystis* and *Anabaena* dominated the community (63-95%) throughout the study period particularly during the dry and short rainy months. This study showed that the algal bloom was initiated by the significant temporal variabilities of transparency and high levels of nutrients. The year-round persistent turbidity, relatively high temperature and low under-water irradiance favored blue green algae; particularly *Microcystis* and *Anabaena spp.* seem to be associated with the prevailing algal bloom.

Keywords: Water quality; Legedadi reservoir; Phytoplankton; Algal bloom; Turbidity; Plant nutrient dynamics

Introduction

Fresh water bodies including reservoirs are finite resources essential for agriculture, industry, and human existence. Sustainable socioeconomic development of a country without easily obtainable water of sufficient quantity and acceptable quality is not achievable [1]. Water quality of reservoirs is deteriorating due to both natural and anthropogenic effects. In reservoirs situated in arid and semiarid areas, where surface water is naturally scarce, salinization is a severe problem [2]. Agriculture, industries and urban settlements adjacent to or in the drainage basin of reservoirs can further aggravate the deterioration of reservoirs' water quality and human health problems by releasing contaminants through the discharge of waste waters in to these water bodies or their source water [3].

Legedadi reservoir, which provides the largest proportion of drinking and house hold water supply for the city of Addis Ababa, has suffered during the last two decades or so, from various problems including smell, excessive consumption of copper sulphate and chlorine, color, and nuisance algal blooms. The reservoir water has also failed to meet the world health organization's (WHO) requirements for potable water supply in several water quality parameters [4]. Repeatedly, the reservoir fails to meet the standards in terms of odor, taste and color. To gain adequate understanding of the dynamics of the intermittently occurring algal blooms and the underlying environmental variables, one needs to study the changes in species composition and relative abundance of phytoplankton resident in the reservoir in relation to some physico-chemical conditions over an extended period. In spite of these complicated problems, there has been no long term study conducted in the past. The objective of this study was therefore, to investigate the spatial and temporal phytoplankton and nutrient dynamics together with their interactions with their meaningful implications to the water quality.

Materials and Methods

Description of the study site

The reservoir under investigation was Legedadi, situated about 30 km northeast of Addis Ababa, the capital of Ethiopia (Figure 1). It is extremely irregularly shaped. Legedadi constructed is a single-purpose is built for a single-purpose to provide drinking and household water for the city of Addis Ababa since 1971.

The reservoir is located between 9°20' N and 38°45' E at an altitude of 2450 (m.a.s.l.), paved close to the main road to northeastern part of the country. The reservoir is constructed with a maximum depth 34 m close to the dam and minimum depth of 4m at the periphery. The reservoir covers an area of 200 km^2 in 9097.35 km^2 catchment areas. The live storage has a level range of 2446-2466 m above sea level (m.a.s.l.), which means a maximum draw down of 20 m. Theoretical residence time of the water is 200 days, at full supply level [4].

Measurement of plant nutrients

Nitrate-(NO_3-N), ammonium (NH_4^+-N), soluble reactive phosphate as orthophosphate (PO_4^{3-}) and soluble reactive silica (SiO_2) were

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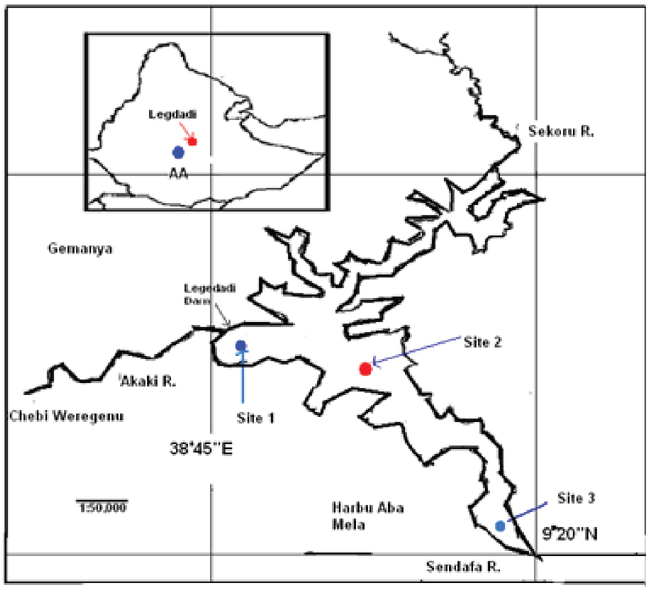

Figure 1: Map of Legedadi reservoir with sampling sites indicated.

analysed using a Hach Kit (DR/4000 spectrophotometer) following the instructions of the manufacturer in Addis Ababa Water and Sewerage Authority(AAWSA) Central Laboratory.

Estimation of phytoplankton parameters

Estimation of phytoplankton biomass: Phytoplankton biomass was estimated as chlorophyll a concentration spectrophotometrically from 90% acetone extracts of the particulate material remaining after filtration through Whatman glass fiber filters (GF/C). The filters were manually ground with a glass rod in a small volume of 90% acetone, placed in a parafilm-covered tube, and centrifuged at 3000 rpm for ten minutes. The extract was then decanted into a 25 ml volumetric flask and made up to the mark with 90% acetone. The absorbance of the centrifuged pigment extracts was measured at 665 nm (the red absorption maximum) spectrophotometrically and corrected for turbidity by subtracting the corresponding readings at 750 nm. The corrected values were used to calculate the concentration of chlorophyll a using the approximate equation [5].

Identification of phytoplankton species: Samples for the identification of phytoplankton taxa and estimation of the relative abundance of the different taxonomic groups of the phytoplankton community in Legedadi reservoir were collected with a plankton net of 10 and 25 µm mesh size from the near- surface region of the reservoir. The samples were stored in brown bottles and preserved using Lugol's solution [6] and placed in a refrigerator. The samples were examined with an inverted microscope and the identification of phytoplankton to genus or species level was made using different identification keys.

Estimation of phytoplankton abundance: Aliquots of parts of the preserved samples phytoplankton identification were used after sedimentation for the estimation of the relative abundance of phytoplankton with a Sedgwick-Rafter cell using an inverted microscope.

Results and Discussion

Plant nutrients

Nitrate concentration significantly varied both temporally and spatially with mean value of 0.62 ± 0.17, 0.54 ± 0.3 and 0.46 ± 0.06 mg/L at sites 1, 2 and 3 respectively ($P<0.05$) (Figure 2). The maximum concentrations were recorded during the dry season with intermittent rains of the year (March to June) which may be due to run off from the dry agricultural fields. Nitrate level is generally remarkably high in reservoirs, contrary to what is observed in natural tropical lakes [7]. Ammonium significantly varied both temporally and spatially (83.6 ± 92.6, 20.6 ± 9.6 and 25.1 ± 15.7 µg/L at stations 1, 2 and 3 respectively) ($P<0.05$) with maximum concentration found following algal bloom which may be due to the release of ammonium from the decomposition of the algal material (Figure 3). According to Kalff [8] a temporary rise in ammonium concentration can be observed following the collapse of algal blooms and during increased mixing.

Soluble reactive phosphate (SRP) varied significantly both seasonally and spatially ($P<0.05$) with maximum values recorded during the short and long rainy months of the year (Figure 4). The mean SRP at sites 1, 2 and 3 were 182 (± 114), 110.7 (± 48) and 105.6 (± 53.7) µg/L respectively. The remarkably high concentrations of SRP seem to be associated with the intensive human activities carried out in the catchment area such as agricultural activities involving the use

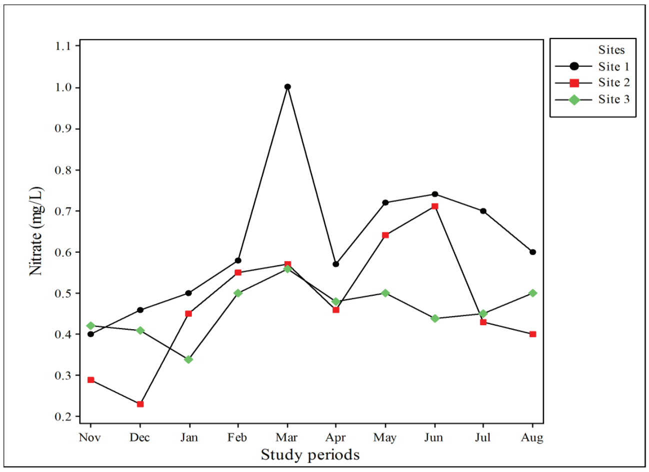

Figure 2: Temporal and spatial dynamics of nitrate in Legedadi reservoir.

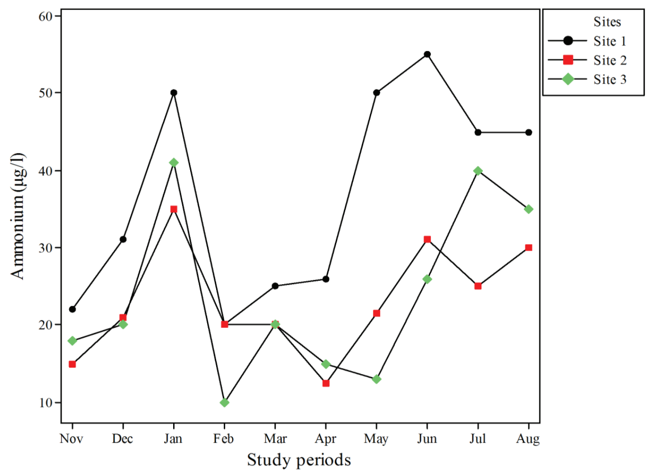

Figure 3: Temporal and spatial variabilities of ammonium in Legedadi reservoir.

of inorganic fertilizers, settlements, animal rearing and associated activities near the reservoir or its catchment. Since the reservoir is not fenced, grazer animals have direct access to the water and their wastes from barnyard pastures, feedlots and rangelands are all washed away during runoff and disposed directly into the reservoir water observed the release of SRP from sediments in the littoral region of Serrada reservoir subjected to cycles of drying and wetting. Similarly, the littoral sediments of Legedadi reservoir experience periodic exposure to the atmosphere and this may be partly responsible for the observed high levels of SRP and other inorganic nutrients [9,10]. Moreover, most of the major feeder streams at the upstream are used for watering animals, washing clothes, and other purposes and hence, obviously contribute to the generally high concentrations of SRP.

The concentrations of Molybdate Reactive Silica (MRS) were found to vary with a mean value of 17.9 (± 8.7), 16.9 (± 11.3) and 12.7 (± 8.7) mg/L at stations 1, 2 and 3 respectively (Figure 5). The high silica concentration, more than 10 mg/L, in African tropical lakes is attributable to the greater mobility of silica in tropical soils, large input of ground water and accelerated dissolution of silica in alkaline and high pH water [11].

Features of phytoplankton community

Phytoplankton biomass: Although the reservoir didn't show green patches or algal scumson the surface, the phytoplankton biomass was found to be very high. It significantly varied seasonally 27.5 ± 13.6, 18.7 ± 13 and 33 ± 15.6 mg/m^3 with the peak values recorded during the dry months of the year (Figure 6). However, the spatial variation among the sampling sites was not statistically significant (P>0.05). The later may be an indication the fact that the reservoir's regular wind-induced horizontal mixing. At every sampling period, the biomass at sites close to the dam and at the mouth of the rivers was considerably higher than the other site.

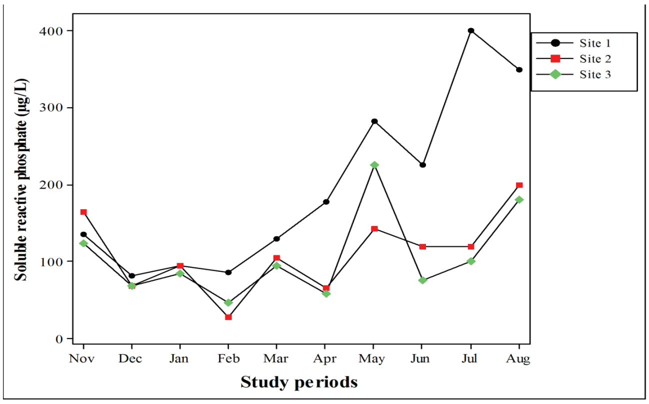

Figure 4: Temporal and spatial dynamic of SRP in Legedadi reservoir.

The minimum values of phytoplankton biomass during the rainy months could be the result of the cumulative effect of reduced underwater irradiance due to reduced underwater irradiance, shorter residence time of phytoplankton in the euphotic zone and hydraulic washout. The maximum biomass recorded was during dry seasons and were association with high plant nutrients in the reservoir particularly with nitrate which suggests that algal proliferation is initiated at the shallowest and the inlet of the reservoir.

Species composition and relative importance of phytoplankton groups: Table 1 lists species of phytoplankton identified during the study period. A total of 35 species of phytoplankton were recorded during the study period. The identified species belonged to 6 classes and 24 genera. The Blue-green algae, with 12 species were the most diverse and dominant taxonomic group. Phytoplankton diversity in Legedadi reservoir is low when compared to those of Ethiopian Rift valley lakes and reservoirs [12] and Kenyan highland reservoirs [13] and lakes [14].

The temporal changes in percentage contribution of the different algal groups to the total abundance of the phytoplankton community in Legedadi reservoir are shown in Figure 7. Temporal changes in the relative importance of the different taxonomic groups to the abundance of phytoplankton in the reservoir were observed, although the blue-greens were the most abundant and persistent.

Blue greens accounted for over 63% of the total phytoplankton abundance throughout the study periods except during periods of heavy rains and high water turbulence (Figure 7). Among the blue-greens, *Microcystis* and *Anabaena* were the most important in terms of both species diversity and percentage contribution to the total phytoplankton abundance. *Microcystis* and *Anabaena* are known as among the troublesome algal genera that commonly form blooms in lakes and reservoirs and are taken as signs of aging process in reservoirs [15].

The contribution of green algae, with eleven species, ranged from

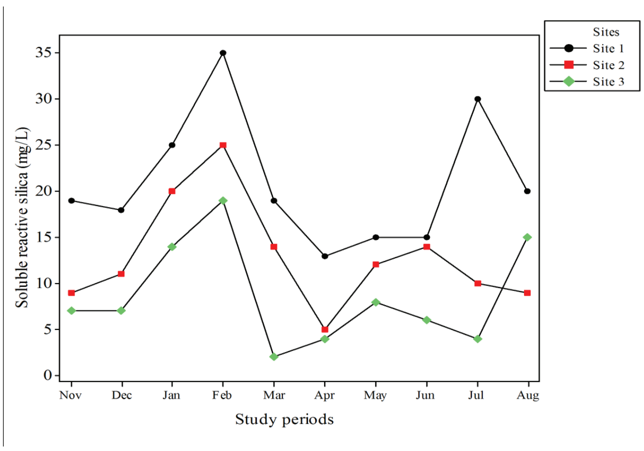

Figure 5: Temporal and spatial dynamics of silica in Legedadi reservoir.

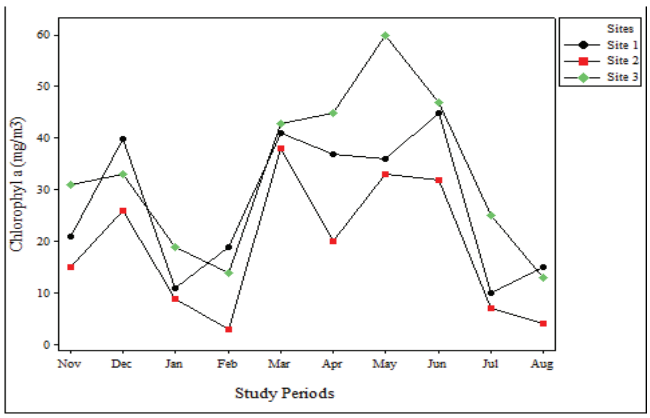

Figure 6: Temporal and spatial dynamics of phytoplankton in Legedadi reservoir.

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Cyanophyceae	Cholorophyceae	Bacilariophyceae
Anabaena circinalis Rab.	*Ankistrodesmus sp.*	*Cyclotella comta (Ehr.) Kütz.*
		Cyclotella ocellata Pant.
A. spiroides Kleb.	*Botryococcus cf. brauni Kütz*	*Cymbella gracilis (Ehr.) Kütz*
A. bituri Komárek	*Chlorela vulgaris Beij.*	*Diatoma sp.Nitz*
A. flosaquae Bréb	*C. ellipsoidea Gerneck*	
A. lemmermani Lemm.	*Chlorogoniu melongatum (Dang.) Dang.*	**Other minor taxa**
A.circularis (G.S. West) Miller	*Closterium sp.*	**Dinophyceae:** *Peridinium sp.*
Chroococcusturgidus (Kütz.) Näg	*Dichtyosphaerium pulchellumv. minutum Defl.*	**Cryptophyceae:** *Cryptomonas ovata Ehr.*
Gloeocapsasp.Merismopediacf.glauca	*Eremosphaera viridis De Bary*	
(Ehr.) Näg *Microcystis aeruginosa*	*Phacotus lenticularis (Ehr.) Stein.*	
(Kütz.) Kütz *M.cf.*	*Schroederia setigera (Schröd.) Lemm.*	**Euglenophyceae***: Colacium sp.; Phacus sp.*
Panniformis Komárek	*Scenedesmus sp.*	
Planktolyngbya sp.		

Table 1: Species of phytoplankton identified in Legedadi reservoir over the study period.

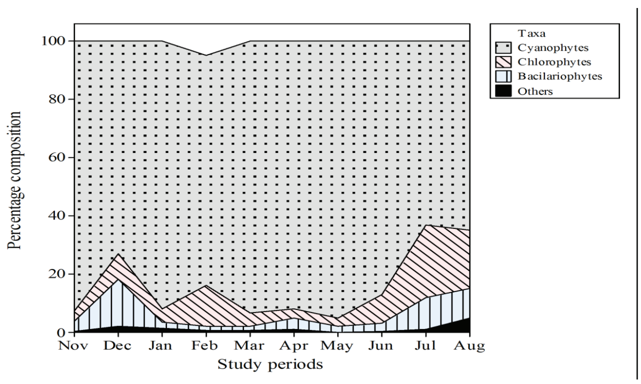

Figure 7: Seasonal relative abundance of phytoplankton taxa in Legedadi reservoir.

a minimum of 3% to a maximum of 25% with maximum abundance during heavy rains. The importance of diatoms was more or less similar to that of green algae, with minimum and maximum contributions of 1.45% and 16% although their peak abundance over the study period was observed in December [16]. Dinoflagellates, cryptomonads and euglenoids were poorly represented in the phytoplankton community in both qualitative and quantitative terms.

Conclusion

Most important water quality parameters in Legedadi reservoir plant nutrients and phytoplankton biomass were found to be high throughout the year and varied both seasonally and spatially. The year-round elevated turbidity selectively favoured the most nuisance cyanobacteria (*Microcystis* and *Anabaena*) to dominate throughout the year. The levels of growth limiting plant nutrients (ammonium, nitrate, soluble reactive phosphate and silica) were high enough to cause algal blooms in the reservoir throughout the year. In addition to the elevated levels of turbidity and nutrients, the seasonal variability of these conditions also offered additional factor to selectively favour cyanobacterial blooms in the reservoir.

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