ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULITY OF SCIENCE
DEPARTMENT OF BIOLOGY

WATER QUALITY AND PHYTOPLANKTON DYNAMICS IN GEFFERSA RESERVOIR/ ETHIOPIA.

A Thesis Presented to the School of Graduate Studies, Addis Ababa University in Partial fulfillment of the requirements for the degree of Master of Science in Biology (Fisheries and Aquatic sciences)

By

Nigatu Ebisa

June, 2010

Addis Ababa

WATER QUALITY AND PHYTOPLANKTON DYNAMICS IN GEFFERSA RESERVOIR/ ETHIOPIA.

A Thesis Presented to the School of Graduate Studies
In Partial fulfillment of the requirements for the degree of
Master of Science in Biology
By
Nigatu Ebisa

June, 2010
Addis Ababa

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNWOLEDGEMENTS

I would like to express my deepest and heartfelt gratitude to my research advisor, Dr. Demeke Kifle, for his consistent guidance, for making available some of the materials required for my field and laboratory work and willingness to offer critically constructive comments, excellent scientific guidance support in fruitful ideas and affably authoritative advices, identification of species and starting from title selection to finalization of this thesis. I was able to go this far because of his assistance, encouragement, and guidance.

I would like to greatly thank to FASS PhD Students Girum Temiru, Getachow and Tadesse Ogato and MSC students Nebiyou Mehammed and Afework Kara for their guidance, support and providing necessary materials in all my work.

The Department of Biology, AAU, is gratefully appreciated for assisting me with material and other resources during my thesis work and also AAWSA (Addis Ababa Water and Sewerage Authority) laboratory for allowing me to do laboratory work, materials and chemicals for nutrients analysis.

My sincere thanks and heartfelt appreciation go to my family, for their financial and moral support who has always been genuinely concerned with my education and professional career specially my father Ebisa Nemomsa my sister Aberash, Shitaye and Ancale Belina and also Mitiku Cawaqaa. Also last not least, I would like to thank my friend Yonas Teferra and Sintayehu Mekonnen who have always provided support.

Finally, I would like to thank Geffersa’s workers for their assistance during my field work.

Above all, I praise the LORD!

ABSTRACT

Dynamics of phytoplankton and physico-chemical parameters of water quality were studied in Geffersa Reservoir from October, 2009 to June, 2010 using samples collected at bi-weekly intervals. Secchi depth (vertical visibility) varied from a minimum of 0.20 of the minor rainy season to a maximum of 0.66m during the dry period. Turbidity, which fluctuated between 7.2 and 189 NTU, exhibited a seasonal pattern, which was more or less similar to that of phytoplankton biomass measured as Chl a ($r= 0.649$, $r^2= 0.415$ at $p= 0.0070$). The concentrations of NO_3-N, NH_3 + NH_4^+-N and Soluble Reactive Phosphate (SRP) varied from 10.0 to 300, 146 to 866 and 29 to 201 $\mu g\ L^{-1}$ respectively while Molybdate-reactive silica ranged from 2.5 to 13.4 m L^{-1}. Turbidity, TDS, and other chemical parameters were found to be far below the upper permissible limits for drinking water supply sources. The phytoplankton community whose species diversity was found to be low was primarily constituted by green algae, blue-green algae and diatoms, the contributions of the species-rich green algae ranging from 1 to 95 % and with major species belonging to the genera Crucigenia, Kirchneriella and Ankistrodesmus. The second and third most abundant algal groups were the blue-green algae and diatoms, which were dominated by two species of Microcystis, M. aeruginosa and M. panniformis. and by a species of the filamentous genus Melosira, M. agassii, followed by Fragilaria capucina and Rhopalodia gibberulla. Among the flagellate groups, dinoflagellates were the most important, with Peridinium cinctum and P. bipes as the quantitatively most important species. Among the cryptomonads, Cryptomonas marsonii and C. ovata were found in large numbers, Chl a biomass of phytoplankton averaged 12.41 $\mu g\ L^{-1}$ and varied from a minimum of 2.29 $\mu g\ L^{-1}$ to a maximum of 40.67 $\mu g\ L^{-1}$ with its fluctuations being correlated more with ammonia +ammonim ($r =0.662$, $r^2 = 0.44$ at $p=0.0045$) than with nitrate ($r=-0.4093$, $r^2= 0.1675$ at $p= 0.1028$) or phosphate ($r= 0.435$, $r^2=0.289$ at $p= 0.0800$). Rotifers were the most abundant and species-rich zooplankton group with mean percentage contributions of 66.82 while the contributions from copepods and cladocerans were 24.51% and 8.67% of the total abundance of the zooplankton respectively. The causal relationships among physicochemical and biological variables are discussed and recommendations made.

1. Background and Justification

Water is essential to sustain life. The ecological, social and economic benefits that freshwaters provide are numerous. Reservoirs are among finite freshwater resources used for municipal water supply, power generation, industrial water supply, agricultural irrigation, commercial and recreational fisheries, and other recreational uses. Reservoirs are those fresh water bodies formed or modified by human activity for specific purposes, in order to provide a reliable and controllable resource (Thornton, 1987).

Sustainable socio-economic development of a country is unlikely without freshwaters of sufficient quantity and acceptable quality (Cederlöf, *et al.,* 1998). Currently, freshwater is not only in short supply in this country, but its quality is also deteriorating. The rapid growth of human population and the consequent speedy expansion of activities related to industry, agriculture and urbanization have resulted in adverse impacts on water resources and in the emergence and rapid growth of water pollution problems (WHO, 1996). Agricultural development activities carried out as a response to food shortage (insecurity) in Ethiopia have demanded the widespread use by farmers of fertilizers and pesticides on agricultural lands. The fertilizers applied on the agricultural lands with a view to boost crop yield eventually find their ways into nearby water bodies and pollute them. The most common consequence of enrichments of water bodies with algal nutrients (from fertilizers) (eutrophication) is the excessive growth of algae in lakes and reservoirs (Vollenweider, 1981; Lampert and Sommer, 1997), one of the commonest water quality problems which is beginning to attract public attention in Ethiopia. Algal blooms, visible massive growths of algae, represent a very serious problem in lakes and reservoirs of commercial and recreational value. When they occur, they not only form floating scums and impart undesirable taste and odour to the water (Berglind *et al.,* 1983), but are also associated with reduced water clarity and oxygen levels and the consequent loss of fisheries (de Bernardi and Guissani, 1990; Carmichael, 1988), fatal poisoning in wild and domestic animals (Gorham and Carmichael, 1979; Suess, 1981; Ryder, 1981; Fritz *et al,* 1992) and occurrence of dermatitis and toxicity (Perl *et al.,* 1990; Bell and Codd, 1994) in humans. Amha Belay and Wood (1982) reported the death of seventy-five zebras after drinking water at the shore of a highly productive Ethiopian Rift Valley lake, Chamo, during the time when the water was exceptionally discolored by a nearly monospecific phytoplankton community dominated by the blue-green alga *Microcystis aeruginosa* (Kutz.) Kutz. The same alga was found to be responsible for the nuisance and/or toxic algal blooms that occurred in Koka Reservoir (Demeke Kifle, unpublished data: Adane Sirage, 2006) and Legedadi Reservoir (Melaku Mesfin and Amha Belay, 1989; AAWSA, 1994: Hadgembes Tesfay, 2007).

Ethiopia has rich inland water resources, consisting of both natural water bodies such as rivers and lakes and man-made lakes (reservoirs), which may provide admirable opportunities for comparative limnology owing to the considerable variations in their morphometric, physical and chemical features. Ethiopian fresh waters are also very productive at the primary (algae), secondary (zooplankton) and tertiary (fish and other aquatic vertebrates) levels and are consequently used as habitats for a variety of organisms. However, in industrial areas and urban centers, there is pollution of these water bodies associated with high levels of domestic and industrial wastes originating from human activities. In spite of the fact that freshwater bodies are very limited and sensitive resources that need proper care and management, they are probably the most abused of natural resources.

Accelerated eutrophication of lakes, rivers and reservoirs due to human activities has become a concern in Ethiopia as it has always been throughout the world. In Ethiopia, several reservoirs have been built, the most important ones being those which are used principally for the generation of hydroelectric power and as water supply sources. These reservoirs are facing pollution problem owing to their establishment in the proximity of fast-growing towns, industrial operations, or agricultural lands on which fertilizers are applied. Geffersa Reservoir, which constitutes a large proportion of the supply source of drinking and household water to the city of Addis Ababa and Burayyu town, is no exception. During periods of precipitation, runoff occurring down the surrounding steep slopes presumably brings silt, nutrients and other chemicals into it. The brownish colour of the reservoir water seems to be a reflection of the introduction of large quantities of particulate and dissolved substances through runoff. Although algal growth that reached bloom level, similar to those frequently observed in Koka (Adane Sirage, 2006) and Legedadi (Melaku Mesfin and Amha Belay, 1989; AAWSA, 2000-2002: Hadgembes Tesfaye, 2007) Reservoirs has not been reported so far, there is still potential threat to public health associated with the introduction of nutrients that stimulate algal growth, eventually leading to the development of nuisance/toxic algal blooms and contamination with chemicals hazardous to public health.

The protection of public health necessitates the generation of phyisco-chemical and biological qualities of a body of water used for human consumption, which may be of some help in the development of strategies geared towards the protection of our water resources and human welfare. There have, however, been no assessment and monitoring programs aimed at generating long-term and dependable data on the physical, chemical and microbiological quality of our reservoirs including Geffersa. It is, therefore, imperative to investigate the physicochemical water quality of the reservoir and the taxonomic composition and biomass of the phytoplankton community it supports as phytoplankton is the first community of organisms affected both quantitatively and qualitatively by external loading of materials

(Anna-Lissa and Galina, 1999) and which are consequently used as bioindicators of environmental pollution (Danielson, 1998; Apfelbeck, 1999).

Temporal variability in the structure and function of phytoplankton community is of fundamental importance to the metabolism of an aquatic system (Calijuri *et al.,* 2002). The changes in species composition, standing crop and photosynthetic production of phytoplankton are brought about by several biotic and abiotic factors including water column mixing/stratification, underwater light, temperature, nutrients, toxic substances, heterotrophic microorganisms, pathogenic agents, parasites and herbivores (Reynolds, 1987). Aquatic environments are subject to high temporal variability, with frequent reorganization of the relative abundance and species composition of phytoplankton as a result of the interactions between physical, chemical and biological variables (Reynolds, 1990). Phytoplankton studies on some of Africa's large and better studied lakes have shown some qualitative changes that are the result of several years of cultural eutrophication (Hecky, 1993). In Reservoirs, there are additional factors owing to the hydrodynamic differences arising from the location, morphometry and the main function of a given system. The hydrological cycle, which determines precipitation, governs dam operation and theoretical water retention times in the system, generating 'pulses' of material and nutrients in suspension, material cycling and biomass losses (Calijuri, 1999). According to Calijuri's (2002) study on the eutrophic Barra Bonita Reservoir, the main external factors that regulate the reservoir are rainfall, wind, flushing rate and theoretical water retention time. The study of changes in phytoplankton biomass, species composition and primary production in water bodies is, therefore, fundamental to the understanding of both water quality and fisheries (Taylor *et al.,* 2002).

Zooplankton can also affect the relative abundance of phytoplankton species, both by direct grazing (top-down) and by nutrient recycling (bottom-up) processes. Zooplankton interacts with phytoplankton at several levels. Haney (1987) has shown these levels of interactions, particularly with cyanobacteria, which affect the structure of phytoplankton and contribute to the reduction of the negative effect of algal blooms. Removal by grazers is one way of reducing the negative effect of cyanobacterial blooms (Reeders and BijdeVaate, 1990). The first order interaction is through direct grazing and fertilization of the system through nutrient release, which was also shown by Carney and Elser (1990). Second order effects are indirect effects and include the influence of selective grazing on competition between species of cyanobacteria and non-cyanobacteria species. Bendorff (1988) proposed integration of two strategies to have a better water quality and lower cost /benefit ratio in the management of water resources. These are: 1) strategy of reducing the external load of nutrients, toxic substances, organic matter or acid precipitation 2) The strategy of controlling internal ecological processes. If one considers the second solution, it is clear that zooplankton grazing is one of the internal dynamics regulating water clarity.

Grazing refers to the predator-prey interactions in water where algae, bacteria, detritus and protozoans are the prey organisms. The importance of grazing by herbivorous zooplankton on the development of phytoplankton populations became recognized in the 1970s and demonstration that grazing was directly involved in the clear water phase provided available field support for this concept (Lampert, 1978). The clear water phase describes the very regular occurrence of a minimum density of phytoplankton in the middle of the growth period, most frequently in meso-and eutrophic lakes.

When grazing by zooplankton is intense, the phytoplankton biomass and productivity can be reduced and clear water phase can be produced (Lampert *et al.*, 1986). Grazing has been found to be the most important source of mortality for phytoplankton, which brings about seasonal changes in the abundance of phytoplankton (Reynolds, 1984). Zooplankton possesses complex grazing behavior, and rates of particle capture may vary with size, shape, taste or surface charge of phytoplankton (Leman, 1988). Thus, grazing not only causes mortality but may also alter the size or species composition of the phytoplankton. The two major components of mesozooplakton, Cladocera and Copepoda contribute significantly to grazing pressure on phytoplankton. Strong top-down effects on phytoplankton have been reported for cladoceran-dominated zooplankton in some lakes (Sommer, 1986) and for copepod-dominated zooplankton in the sea (Bautista *et al.,* 1992). However, the relative significance of predatory control can vary along a nutrient gradient (Jeppesen, *et al.,* 1998).

A large number of studies have been made on the community structure and primary production of phytoplankton in various East African Lakes including those found in Ethiopia (Talling and Lemoalle, 1998). In Ethiopia, several reservoirs have been built, the most important ones being those which are used principally for the generation of hydroelectric power. However, very limited attention has been given to Ethiopian reservoirs. The few studies which were conducted on the phytoplankton of Ethiopian reservoirs have not been systematic. The studies made on the species composition of phytoplankton in Ethiopian reservoirs are those of Melaku Mesfin *et al.,* (1988) and Elizabeth Kebede and Willen (1996) on Koka Reservoir, whose investigations involved the analysis of single samples. The only systematic long-term studies made on the phytoplankton of reservoirs in Ethiopia are those of Melaku Mesfin and Amha Belay (1989) and Adane Sirage (2006) on Legedadi Reservoir and Hadgembes Tesfay (2007) on Koka reservoir. Nothing has been done on this and other related aspects in Geffersa reservoir. It is, therefore, imperative to investigate the physicochemical quality of Geffersa reservoir and the taxonomic composition, abundance and biomass of the phytoplankton community it supports in relation to the taxonomic composition and abundance of zooplankton as phytoplankton composition and its temporal variability are good bioindicators of environmental changes (Danielson, 1998).

2. OBJECTIVES

2.1. General objective

- To assess the physico-chemical and microbiological quality of the water in Geffersa Reservoir with emphasis on the temporal dynamics of the bioindicators-phytoplankton.

2.2. Specific objectives

- To assess the physico-chemical quality of the water in Geffersa Reservoir and evaluate its compliance with acceptable standards.
- To relate the temporal dynamics of phytoplankton and physico-chemical water quality with a view to establish causal relationships among them.
- To determine if there is any likelihood of threat to public health from potentially harmful/toxic cyanobacteria.
- To investigate the impact of zooplankton on phytoplankton abundance and species composition.

2. DESCRIPTION OF THE STUDY AREA

Geffersa Reservoir (Fig. 1) is one of the major water supply sources used for drinking and other domestic purposes by people of the city of Addis Ababa and Burayu town. It is located at approximately 18 km west of Addis Ababa at an altitude of 2580 m above sea level and lying between 8^0 56' and 9^0 05' latitude North and between 38^0 43' and 38^0 50' longitude. Geffersa reservoir has two dams (the main and secondary dam) built on the course of Geffersa stream, which is a tributary of Akaki river. The main and secondary dam have usable raw water storage capacity of approximately 6 500 000 and 1 500 000 m^3 respectively with a total catchment area of about 57 km^2. The main supply of water for the reservoir is Geffersa River that comes from the north west of the reservoir originating from Walmera Woreda. Geffersa Reservoir has irregular shape and is shallow. This Reservoir, with a maximum depth of 20 m and with nearly complete exposure to wind action is expected to be a frequently mixing body of water.

The main dam, which has a height of 20, was built in 1964 E.C. No systematic and long-term studies have so far been made on physico-chemical water quality, phytoplankton, zooplankton and pisci-fauna. However, some physical and chemical parameters were measured for single samples of raw and treated waters of Geffersa Reservoir in 1982 and are given in Table 1.

The reservoir area is highly covered with green vegetation which extends from Entoto mountain to Menagesha forest. The vegetation found in the reservoir area includes indigenous trees of J*uniperus procera,Podocarpus falcatus and exotic tree Eucalyptus globulus* trees.

The reservoir area supports some endemic birds of Ethiopia including Blue-wing Goose, Black-headed Siskin, Wattle Ibis, White-collared pigeon and Abyssinian long claw. The reservoir also supports species of fish including the common carp (*Clarias gariepinus* Burchell) which was introduced from Sebata fisheries research center.

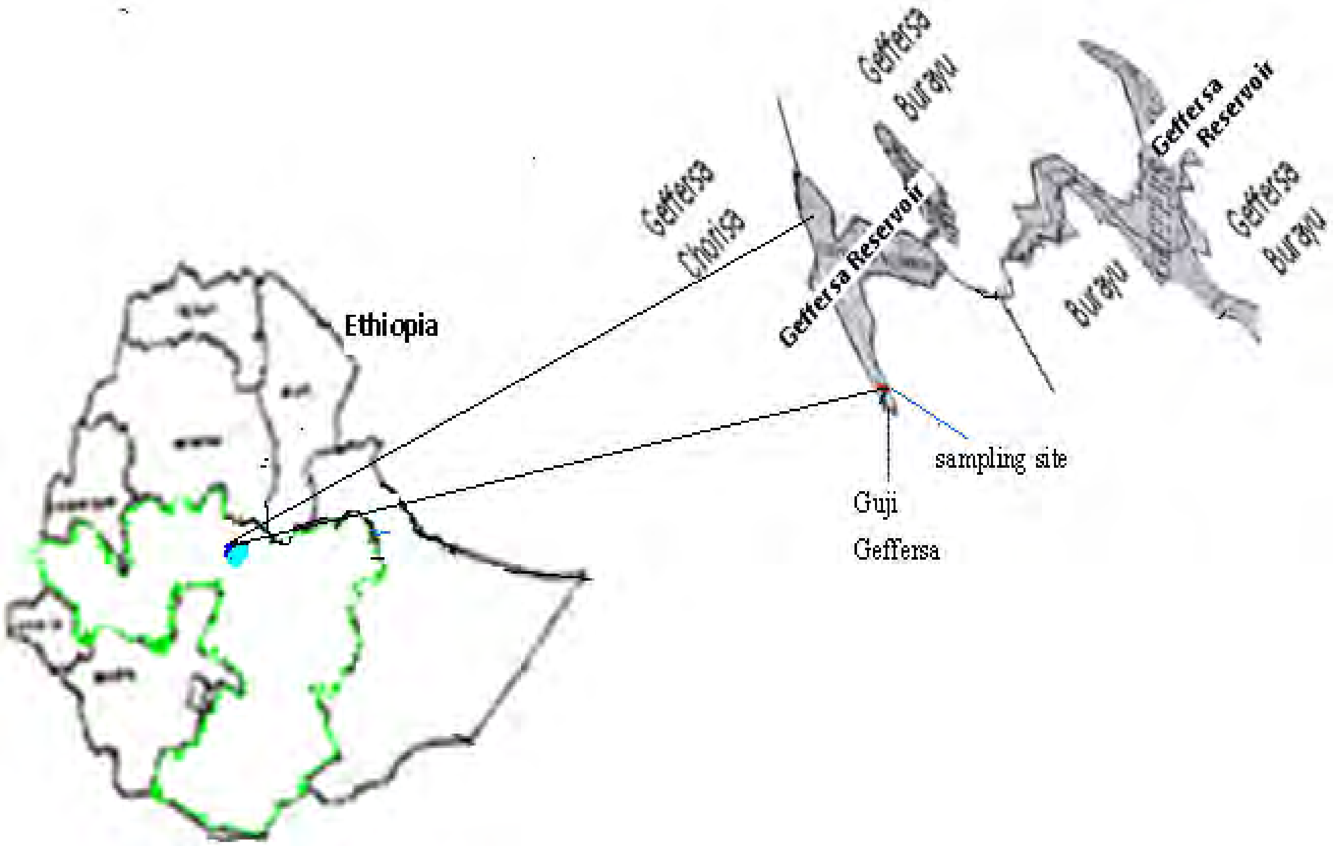

Fig.1. Map showing the location of Geffersa Reservoir (AAWSA, 1993)

Table 1. Some physicochemical features of Geffersa Reservoir measured in February, 1982. Units are in mg L^{-1} unless otherwise indicated. (Source: AAWSA, 1993).

Parameter	Values recorded for		
	Raw water	Treated water	Remarks
Temperature (°C)	18	19	
Turbidity (FTU)	45	0	Value in second Column questionable
Color (Pt-Co Units)	100	5	
Suspender matter$^{)}$	25	0	Value in second Column questionable
Total Alkalinity (mg $CaCO_3$ L^{-1})	30	15	
Chloride (mg Cl^-)	5	5	
Fluoride (F^-)	0.6	0.5	
Nitrite-nitrogen (NO_2-N)	0.01	0.01	
Nitrate-nitrogen (NO_3-N)	4	0	
Ammonia + + Ammonium-nitrogen (NH_3 + NH_4^+-N)	0.5	0.1	
Total Hardness as $CaCO_3$	30	35	
Calcium (Ca^{++})	8	10	
Magnesium (Mg++)	2.4	2.4	
Iron (Fe)	0.7	0.0	
Manganese (Mn)	0.6	0.6	
Copper (Cu)	0	0	
Chromium (Cr^{+6})	0	0	
Silica (SiO_2)	ND	ND	

ND-Not Determined

3. MATERIALS AND METHODS

4.1 Sampling protocol

To study the temporal dynamics of physico-chemical and microbiological quality of water in Geffersa Reservoir, a reconnaissance survey was conducted and one sampling station was selected 20 m away from the main dam to detect the variation of physico-chemical and biological quality of the Reservoir temporally. Water samples were collected bi-weekly from a selected station (maximum depth= 9 m) with a bottle sampler (Kemmerer) from 0, 1 and 2m depths. The collected samples were mixed in equal proportions to produce composite samples, which were used for chemical analyses, identification of species of phytoplankton and estimation of their abundance and biomass.

4.2 Measurements of physic-chemical parameters in the field

In the field, some physical and chemical parameters were measured on each sampling day shortly before the collection of water samples. Water transparency was determined using a standard Secchi disc of 20cm diameter quartered alternately black and white. pH was measured in situ by a portable digital pH meter (Jenway 3200). Turbidity was measured by a turbidity meter (Hanna LP 2000).

4.3 Chemical Analyses in Laboratory

Collected water samples were used for the estimation of the following chemical parameters: Nutrients were analyzed following the standard methods described APHA *et al.* (1999) and Wetzel and Likens (2000) using samples previously filtered through Whatman GF/F glass fibre filters.

The following nutrients were measured using a HACH KIT portable spectrophotometer (DR 2100) at low range. Orthophosphate (PO4-P) was determined by the Ascorbic Acid method while soluble reactive silica (SiO_2)

was determined by the Molybdosilicate method. Nitrate-nitrogen (NO_3-N) was determined by the Cadmium reduction method while Ammonia + Ammonium-Nitrogen (NH_3 + NH_4^+-N) was analyzed by the Phenate Method. Conductivity, TDS and Salinity were measured with S-C-T meter (YSI model 63).

4.4. Identification of species of phytoplankton and Determination of their Abundance

Aliquots of collected samples were also preserved with Lugol's iodine and used to identify species of phytoplankton and determine their abundance. The phytoplankton samples were examined with an inverted microscope (Nikon) and species of phytoplankton were enumerated at a magnification of x150 in random grids (squares). and their identification to genus or species level was made using concentrated samples on the basis of various taxonomic literatures available on phytoplankton (Whitford and Schumacher, 1973; Durand and Leveque, 1980; Gasse, 1986). 50 ml of composite samples was sedimented in a graduated measuring cylinder overnight. The supernatant water was removed by a syringe leaving 10 ml of the sample in the graduated cylinder. From the concentrated sample, 1 ml sub-sample was taken with an automatic pipette and transferred to a Sedgewick-Rafter cell. Of which 1 ml sub-sample was pipetted into a Sedgwick-Rafter cell and algal units (unicells, filaments and colonies) within 20 grids were counted randomly.

To facilitate comparison of total abundance of phytoplankton observed at different times of the year, number of cells in 5 to 50 filaments and colonies were counted and mean cell number per colony or filament of a taxon was determined and employed to estimate the total number of cells of a filamentous or colonial alga encountered in the phytoplankton samples (i.e. no. of filaments or colonies microcysits No. of cells per colony or filament).

Cell number of phytoplankton in the collected samples was calculated according to Hotzel and Croome (1999). The counts of phytoplankton species were added together to give total abundance of phytoplankton.

4.5 Estimation of phytoplankton biomass as Chl a concentration

Phytoplankton biomass was estimated as chlorophyll a concentration spectrophotometrically from 90% acetone extracts of the particulate material retained on Whatman glass fiber filters (GF/F). The filters were manually ground in a small volume (5-8 ml) of 90% acetone, placed in a parafilm-covered tube and pigments of cells retained on filter papers extracted in acetone in cool, dark conditions after homogenization and centrifuged at 3000 rpm for ten minutes. The absorbance of the pigment extract was measured at 665 and 750nm against a blank by a visible spectrophotometer (Pye Unicam, SP6-350 model). Chl a (µg L^{-1}) was calculated using the formula of Talling and Driver (2000).

4.6. Estimation of abundance and biomass of Zooplankton

Zooplankton samples were collected by were collected by towing upward from 3m depth using No. 25 (67 µm mesh) plankton net with a mouth diameter of 31 cm. 100 ml sample was concentrated and preserved with 4 % formalin solution in glass bottles. 20-25 ml sub-samples were removed for counting using a pipette with wide mouth and poured into a grided petri-dish. Three grids were counted for each sample after allowing the sample to settle and checking the uniform distribution throughout the grids and then extrapolation was made. Counting was done under a stereoscope microscope (magnification of 50 X). Zooplankton species were identified using identification keys in Defaye (1988), Dussart and Fernando (1988) and Fernando (2002. The different zooplankton groups were counted and their counts were summed to give total zooplankton abundance. The calculation was done using the formula in Lind (1979) and Wetzel and likens (2000).

4.7. Meteorological Data

The temporal variations in meteorological variables (monthly rainfall and mean monthly maximum and minimum air temperature) obtained from AAWSA Meteorological Services of Geffersa station is shown in Fig. 2.

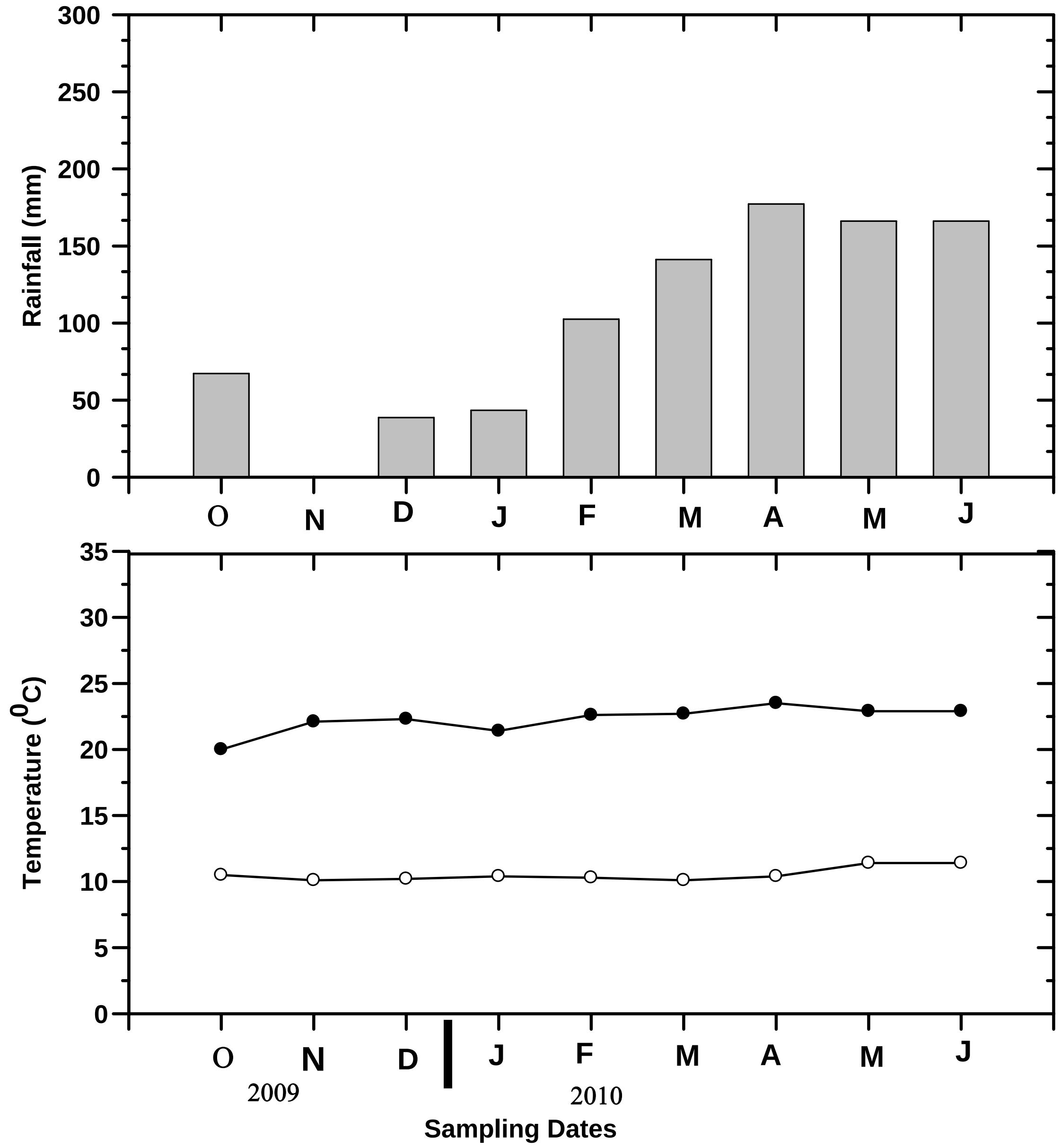

Fig. 2.Temporlal variations in monthly rainfall, mean monthly maximum (closed circle) and minimum (open circle) air temperature in the study region.

The mean monthly minimum air temperature varied from 10.1 °C in the month of October, 2009 and March, 2010 to 11.4 °C in the month of May, 2010, while the mean monthly maximum air temperature ranged from its lowest value of 20°c in October 2009 to its highest value of 23 °C in April, 2010.

The mean monthly rainfall of the reservoir region varied from a minimum of 0.5 mm in November, 2009 to a maximum of 14.8 in April 2010. The monthly rainfall increased consistently from December to April before it declined to its level in May and June. Throughout this thesis, the periods extending from November to February and March to May will be referred to as the dry and minor rainy periods respectively.

Description of symbols used in the text

AAWSA	Addis Ababa water and sewerage authority
Zsd	secchi depth (m)
Zeu	Depth of euphotic zone (m)
Kd	mean vertical extinction coefficient (ln units m^{-1})
Chl a	Chl a, in mgm3 or μl^{-1}
NTU	Nephelometric turbidity unit
FTU	Formanzin turbidity unity

5. RESULTS AND DISCUSSION

5.1 Physico-chemical Features

5.1.1. Physical parameters

The temporal variations in optical characteristics of Geffersa reservoir during the study period are shown in Fig. 3 and Appendix 1. Water transparency (vertical visibility) varied from a minimum of 0.20 m in May, 2010 of the minor rainy season to a maximum of 0.66 m in October, 2009. It declined almost consistently from its highest peak in October, 2009 to the seasonal minimum in May, 2010 with few small temporary increases in between. However, there was relatively small difference secch depth value between October and November as 0.66m and 0.65 m respectively. The maximum Secchi depth values were recorded in the post-rainy period (Octber to December, 2009) with the lowest turbidity values recorded during the entire study period, at the time when relatively small quantities of particulate materials were in suspension as a result of sedimentation. The correlation between Secchi depth and turbidity was negative but strong (r=1.0). The correlation between secchi depth and phytoplankton biomass measured as Chl a was also negative but modest ($r=0.659$, $r^2=0.43$ at $p=0.0040$) and the variation in phytoplankton biomass seems to account for about 43 percent of the variation in secchi depth suggesting the greater importance of abiogenic turbidity to the underwater climate in Geffersa Reservoir.

The temporal variations seen in the transparency of Geffersa Reservoir seem to be related to changes in the extent of resuspension of inorganic particles resulting from wind-driven mixing, variation in phytoplankton biomass and external loading of particulate materials.

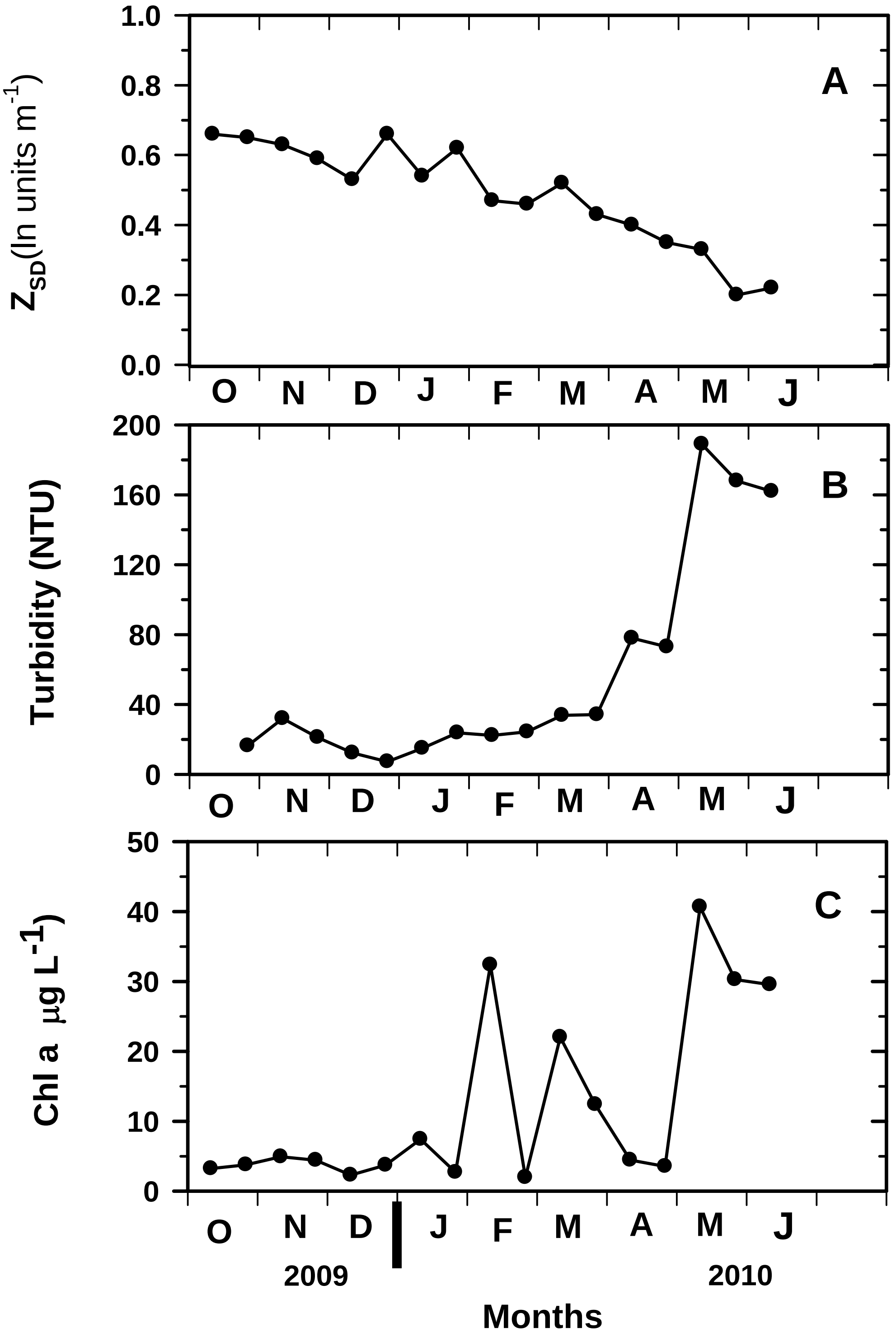

Fig. 3.Temporal variations in (A). Secchi depth ($Z_{SD,}$) (B).Turbidity (NTU) and (C). Chl a in Geffersa Reservoir during the period.

The large quantities of soil particles which are brought from agricultural lands and accumulate in the secondary dams during summer may drastically affect the transparency of the water in the main dam, during the minor rainy period, from which samples were collected. Despite its nearly complete exposure to wind action, Geffersa Reservoir exhibited secchi depths which are not as low as those of the other reservoirs, Legedadi (Adane Sirage, 2006) and Koka (Hadgembes, 2007), which is probably attributable to its greater maximum depth of 20 m.
The high Secchi depth values of Geffersa reservoir are higher than those of other lakes and Reservoirs of Ethiopia including Legedadi (0.082-0.11m; Adane, 2006) and Koka (0.28m, Elizabeth Kebede, 1996.0.28m, Hadgembes Tesfay, 2007) Reservoirs and Lakes Ziway (0.35), Langano (25-35; Tudorancea *et al.,* 1989) and Chamo (0.21-0.375m, Eyasu Shumbulo, 2004), in which attenuation of underwater light is primarily due to silt and clay, which are known to form a stable colloidal suspension in Lake Langano (Wood *et al.,* 1978; Amha Belay and Wood, 1984; Elizabeth Kebede, 1996) and algal biomass (Oglesby and Schaffner,1975). High Secchi depth values of the Reservoir reflect high water clarity, and are observed when the concentration of suspended particles and runoff decline.

Using Secchi depth as a tool one can evaluate the light climate of aquatic ecosystems and compare their optical conditions at different times of the year. Vertical coefficients for total underwater light (mean vertical extinction coefficient, K_d) can be estimated from Secchi depths using the widely used equation, which was proposed by Holmes (1970) as a better estimator of the vertical extinction coefficient of total underwater light of turbid waters (Appendix 1). The values of K_d, calculated according to Holmes (1970, see Appendix 1), ranged from a minimum of 2.18 to a maximum of 7.2 corresponding to euphotic depths (Z_{eu}), approximated as $Zeu = 4.6/ Kd$ equation given above assumes that light reduction conforms, approximately, (Kalff, 2002) of 0.7 to 2.31. The calculation of euphotic depth using the to a single average vertical extinction coefficient, K_d. Euphotic depths (the depth at which 1% of the surface irradiance is detected, Kirk, 1994) estimated using vertical extinction coefficients calculated from Secchi depths seem to indicate that the vertical extent of the euphotic zone in Geffersa Reservoir was often shallower than 2.5 m.

The Reservoir exhibited fluctuations in turbidity from 7.2 to 189 NTU, with the minimum and maximum levels occurring in December, 2009 and May, 2020 corresponding to the dry and rainy periods. The fluctuation in turbidity exhibited a pattern of temporal variations, which was more or less similar to that of phytoplankton biomass measured as Chl a and the modest positive correlation ($r= 0.649$, $r^2= 0.415$ at $p= 0.0070$) between the two parameters corroborating this fact. The high turbidity values of Geffersa Reservoir are much lower than the highest turbidity values that raw water can have (<1 to 1000 NTU; WHO, 1996).

5.1.2. Chemical features

5.1.2.1. Conductivity, TDS and pH

Fig. 4 illustrates the temporal variations in collective chemical parameters (conductivity, TDS and pH) measured for samples from Geffersa Reservoir. TDS of Geffersa varied a minimum value of 32 mg L^{-1} in November, 2009 to a maximum value of 47 mg L^{-1} in October, 2009. TDS increased almost consistently after its abrupt decline from its peak in October, 2009 to its seasonal minimum in November, 2009.

The TDS values for Geffersa are similar to those reported for Legedadi Reservoir near the dam (37-67 mg L^{-1}) by Adane Sirage, (2006) while they were mostly considerably smaller than those recorded for the same reservoir (62 to 77mg L^{-1}) by Lehmusluoto (1999). As TDS comprises metals, minerals, inorganic salts and dissolved matter, its measurements can be used as an indicator of the general quality of water (USA, Environmental quality center, 2003). TDS is regulated because of its aesthetic value rather than health hazards although it is a secondary drinking water standard (not directly related to health hazard). For aesthetic reasons, a limit of 500 mg L^{-1} has been established as part of secondary drinking standards (Environmental Quality Center, USA, 2003).

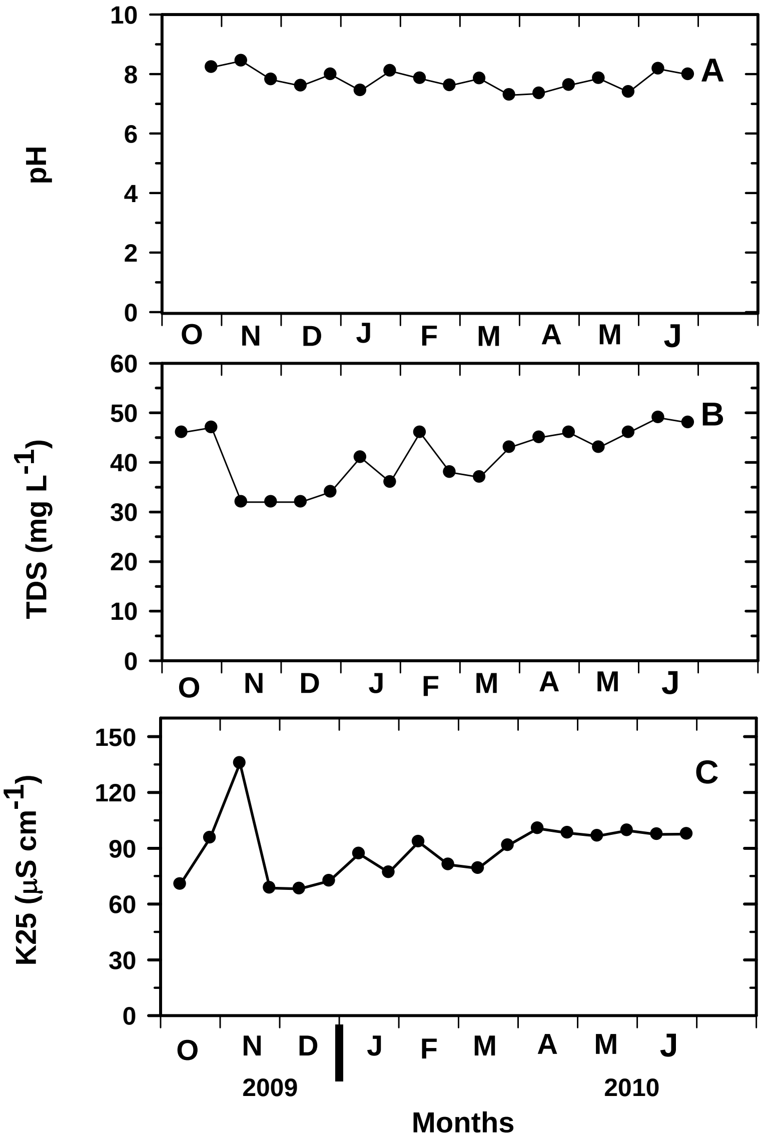

Fig.4.Temporal variations in (A). pH, (B).Total Dissolved Solids(TDS) C). Specific conductance (K_{25})in Geffersa Reservoir during the study period.

Water containing below 1000 mg L^- TDS is usually acceptable while that with extremely low concentrations may be unacceptable to consumers owing to its flat insipid taste and corrosiveness to water supply systems (WHO, 1996).

Electrical Conductivity (K_{25}, in µS cm^{-1}) of Geffersa Reservoir measured for composite samples varied from a minimum of 72.4 in late December, to a maximum of 136.56 in early November, 2009, with its maximum value being within the range that drinking water should have (25-250; WHO, 1996). The high conductivity value of the dry period is probably related to evaporative concentration of ions. The correlation between TDS and K_{25} values of Geffersa reservoir was positive but low ($r=0.2695$, $r^2=0.0726$ at $p=0.2784$).

Electrical conductivity values of Gefersa Reservoir, other Reservoirs in Ethiopia and drinking water supply reservoirs in South Africa are given in Table 2 for comparison. Although the conductivity values of Geffersa Reservoir are broadly similar to those previously reported for Legedadi Reservoir by Adane Sirage (2006), they are much lower than those recorded for southern Africa reservoirs by Walmsley and Butty (1980) and Ashton, (1981). The differences in the conductivities of these Reservoirs depend largely on that of inflowing rivers; turnover rates and the soil of their catchment areas (Payne, 1986).

The relationship between TDS and conductivity is a function of the type and nature of the dissolved cations and anions in the water and possible nature of any suspended materials.

The pH of Geffersa Reservoir ranged from a minimum of 7.29 in April, 2010 to a maximum of 8.44 in October, 2010. The maximum pH value recorded for Geffersa Reservoir in the present study is close to those reported for Koka

Reservoir (8.66) by Hadgembes Tesfay (2007) and Lake Kuriftu (7.9 – 8.4; Brook Lemma *et al.,* (2001).

Table 2. Reported conductivity values of Geffersa and other Reservoirs.

Reservoir	Conductivity (µS cm-1)	References
Bloemhof	360	Walmsley and Butty, (1980)
Bospoort	390	
Bridledrift	399	
Vonbach	207	Department of south African Water Affairs, (1985)
Rietllei	407	Ashton, (1981)
Prince Edward	15	Watts, (1982)
Alexander	29	Thornton, (1987)
Pumbi	31	
Gwenoro	98	
John Mack	120	
Koka	200-380	Melaku Mesfin *et al.,* (1988)
Legedadi	63-131	Adane Sirage, (2006)
Geffersa	**68.1-135.5**	**Present study**

5. 1.2.2. Inorganic nutrients

The temporal variations in the concentration of inorganic nutrients in relation to phytoplankton biomass in Geffersa Reservoir are shown in Fig. 5. The concentrations of Nitrate (NO_3-N) varied from a minimum of 10.0 µg L^{-1} in May, 2010 to a maximum of 300µg L^{-1} in November, 2009. NO_3-N concentrations increased from early October, 2009 to the maximum peak in late November, 2009, before it consistently declined to concentrations below 50 µg L^{-1} of the period extending from March to June, 2010. The low levels of NO_3 during the minor rainy period corresponded to algal biomass measured as Chl a, which was generally at relatively high levels attained after the seasonal minimum in late January while the high nitrate concentration in November, 2009 was probably related to precipitation and **i**ntroduction of excreta such as animal dung and urine from domestic animals which live around the Reservoir and River.

As the present results indicate, nitrate concentrations in Gaffersa Reservoir are much lower than the highest desirable level for drinking water (Wilson, 1979) and concentration levels recorded for Legedadi Reservoir (240 to 1850 µg L^{-1}, Adane Sirage, 2006), (1200 µg L^{-1}, Melaku Mesfin and Amha Belay, 1989), (800-1200 µg L^{-1}, AAWSA, 1994).

The observations made on the concentrations of nitrate-nitrogen in other African and Sri Lankan reservoirs constructed to serve as drinking water supply sources (see Table 3) are indicative of the fact that nitrate levels are generally remarkably high in reservoirs, contrary to what is observed in natural tropical lakes (see Talling and Talling, 1965; Wood and Talling, 1988; Elizabeth Kebede, 1996).

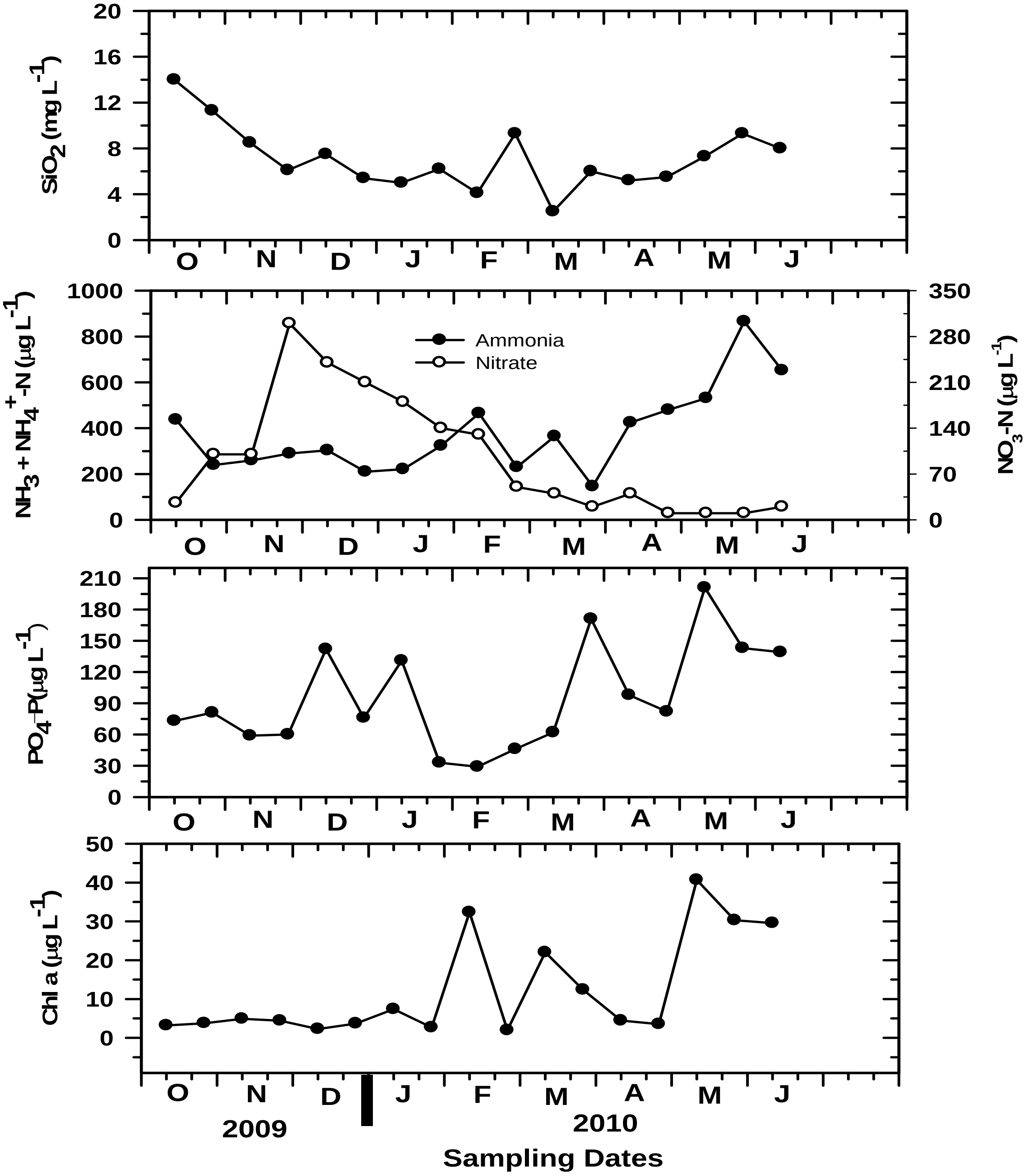

Fig. 5. Temporal variations in $PO_{4-}P$, $NO_{3-}N$, $NH_3 + NH_4^{+}$–N and SiO_2 in relation to Chl a in Geffersa Reservoir.

The observed high nitrate levels in Geffersa Reservoir seem to be the result of inputs from the surrounding agricultural lands on which fertilizers are commonly applied to boost crop yield. During periods of high rainfall, nutrients may be washed into the reservoir through runoff and may also be introduced through Geffersa River from agricultural lands of Walmara woreda. Concentrations of $NO_3 + NO_2$-N of the present study are indicative of human- induced environmental degradation to which the water quality of the reservoir is subjected.

Table 3. Concentration of nitrate-nitrogen in Geffersa Reservoir and other reservoirs of Africa.

Reservoir	Location	NO_3-N (µg L^{-1})	References
Legedadi	Ethiopia	240-1185	Adane Sirage (2006)
Geffersa	This study	10-300	Original
Alexandria	South Africa	550	Thornton (1987)
Prince Edward		390	Walmsey and Thornton (1984)
Henley Dam		770	Walmsey and Butty 1980)
Midmar		140	Twinch and breen (1984)
Robertson (Darwendale)		30	Thornton (1987)
Albert Falls		30	Breen(1983)
Parakrama Samudra		350-1080	Gunatilake 1983)
Awaba reservoir	Nigeria	0-400	Aweto (2003)

Ammonia + ammonium-nitrogen (NH_3 + NH_4^+-N) concentration, hereafter referred to as ammonia, varied irregularly from a minimum of 146 µg L^{-1} in late March, 2009 to a maximum of 866 µg L^{-1} in late May, 2010 with generally low levels during the dry and minor rainy period. There was generally correspondence between levels of ammonia and Chl a biomass of phytoplankton with one of the large peaks in ammonia concentration corresponding to a large peak of phytoplankton biomass, which occurred in February, 2010. The positive and moderate correlation between ammonia evels and phytoplankton biomass ($r = 0.662$, $r^2 = 0.44$ at $p=0.0045$) corroborates the general correspondence between the two parameters observed in their temporal variations.

The observed high concentrations of ammonia are intriguing considering the shallowness and nearly complete exposure of the Reservoir to wind action, which is, therefore, presumably frequently mixed and well-oxygenated. The concentration of ammonia in well-oxygenated waters is usually low relative to those of other nutrients (McCarthy, 1980) due to its prompt oxidation and rapid and preferential uptake by phytoplankton (Eppley *et al.* 1969; Liao and Lean, 1978). While acknowledging the difficulty in making generalizations, the fact that the concentration of ammonium-nitrogen in well-oxygenated waters is usually low relative to those of other nutrients (McCarthy, 1980) due to its prompt oxidation and rapid and preferential uptake by phytoplankton (Eppley *et al.* 1969; Liao and Lean, 1978) can not be overlooked. The only water bodies with such incredibly high levels of ammonia are the polymictic shallow lake Chamo (Eyasu Shumbulo. 2004) and Lake Hayq (Baxter and Goloistch, 1970). The presence of unusually high levels of ammonia in Geffersa Reservoir probably reflects the significance of microbial regeneration and zooplankton excretion. Regeneration of nutrients through zooplankton excretion in lakes may make significant contribution to ambient nutrient concentration as has been shown for the shallow tropical lake, Lake George by Ganf and Viner (1973) and Ganf and Blažka (1974).

Soluble Reactive Phosphate (SRP) concentrations recorded during the study period ranged from 29 to 201 µg L^{-1} with its lowest seasonal concentration coinciding with the second largest phytoplankton biomass measured in February. The maximum concentration of SRP, which was observed in May, 2010, however, corresponded to the largest phytoplankton biomass of the entire study period. The correlation between phosphate and Chl a (r= 0.435, r^2=0.289 at p= 0.0806) and that between nitrate and Chl a (r=-0.4093, r^2= 0.1675 at p= 0.1028) are not very different possibly due to the occurrence at unusually high levels of both nutrients thereby precluding nutrient-limitation of algal growth.

The remarkably high concentration of SRP seem to be associated with the intensive human activities carried out in the catchments area such as agricultural activities involving the use of inorganic fertilizers particularly, Diammonium phosphate (DAP), settlements, animal rearing and livestock waste from barnyard pastures, feedlots, range lands and nutrient-rich organic matter originating from manure application practices are all washed away during runoff and may disposed directly into the reservoir water as has been suggested for Legedadi reservoir by Adane Sirage (2006). On other hand, increments in SRP level may associate aquatic animal excreta like zooplankton. Although the nutrient-contribution of excreta of aquatic animals has not been studied in any detail in African aquatic ecosystems (Thornton et al., 1986), the regeneration of phosphorus by zooplankton can be high enough to raise the ambient concentration to a level capable of supporting algal growth (Morris,1980).

The concentration of molybdate-reactive silica (SiO_2) varied from a minimum of 2.5 mg L^{-1} in early April, 2010 to a maximum of 13.4 mg L^{-1} in October, 2009. Some of the levels of silica observed in Geffersa Reservoir were unusually low as silica levels in Ethiopian lakes are almost always much higher the largest concentration observed in this study (Tudorancea *et al.,* 2002). The comparatively low silica levels in Geffersa Reservoir may be attributed to the quantitative importance of diatoms. No apparent quantitative relationship between the concentrations of reactive silica and phytoplankton biomass was observed ($r=-0.1878$, $r^2=0.0353$ at $p=0.4704$)

5.2. Biological Features

5.2.1. Species composition and abundance of phytoplankton

During the study period, a total of 46 species of phytoplankton belonging to six algal classes were identified (see Table 4.) in composite samples collected from Geffersa reservoir. The identified taxa belonged to the algal classes Chlorophyceae (Green algae) with 20 species, Bacillariophyceae (diatoms) with 11, Cyanophyceae (blue-green algae) with 6, Cryptophyceae with 3, Dinophyceae with 3 and Euglenophyceae with 3 species.

The species diversity of phytoplankton was found to be high in comparison with those of the other Ethiopian Reservoirs, Koka Reservoir 36 (Hadgembes Tesfay, 2007) and Legadadi (35) (Adane Sirage, 2006).

The temporal variations in the relative importance of the major algal groups to the abundance of the phytoplankton assemblage in Geffersa Reservoir and the temporal changes in the abundance of the major species of phytoplankton are shown in Figs. 6 and 7 respectively.

Temporal changes in the quantitative importance of the different taxonomic groups to the abundance of phytoplankton in the Reservoir were observed. Because of the seasonality of water-input from feeder rivers and run-off, there is higher frequency of fluctuation in the underwater light climate and levels of nutrients in such turbid waters as Geffersa Reservoir (Grobbelar, 1989; Dokulil, 1994) resulting in short-term changes in biological variables.

Vincent *et al.,* (1986) have also singled out that flood-related changes in nutrient supply and abiotic turbidity are factors of overriding importance in shallow well -mixed water bodies such as Geffersa Reservoir.

Table. 4. List of species of phytoplankton identified from Geffersa reservoir during the study period.

Chlorophyceae	**Bacilarophyceae**
Ankistrodesmus nannoselene Skuja *Carteria radiosa* Huber. Past *Clostrium Diana* Ehr. *Coelastrium microporum* Nage *Cosmarium contractum* Kirch *Crucigenia fenestratea* (schmid.)schmid *Crucigenia rectangularis* Nagel *Crucigenia tetrapedia* (kirchner) *Dispora crucigeniodes* *Excentrospharea viridis* L. Moorgewasser *Kirchnerialla lunaris* (Kirch). Moe *Oocysts rhompodea* *Opephora swartizii* (Kirch). Moe *Palmellococcus minutus* (Kutz.) *Scenedesmus obliquus* (L. Turp.) Kutz *Tetrachlorella altanans* Korshikov *Tetraustrum triangulare* *Ulothrix tenerrima* Kutz. *Volvox dissipaturix* Utex *Zoochlorella conductrix* Brandt	*Amphora ovalis* (kutz.) kutz. *Cyclotella comensis* (Grun.) *Cyclotella glomereta* Bach *Cyclotella melosiroides* (kirchn.) Lemm. *Cyclotella menhinana* kutz. *cyclotella stelligera* cleve and Grun. *Fragillaria capucina* desm. *Fragillaria crotonensis* kitt. *Melosira agasszii* (Ostenf.) Simonsen *Nitzschia cloterium* W.Sm. *Rhopalodia gibberulla* (Ehr) O. Mull.
	Cyanophyceae
	Anabaena cf. affinis Lemm. *Cylindrospermosiscurvispora*(M.Watan.) *cylindrospermopsis spp.* *Microcystis aeruginosa* (Kutz.) Kutz. *Microcystis panniformis* Jari Kom. *Mycrocysts reinboldii* (Reinbold.)
Dinophyceae	***Cryptophyceae***
Peridinium bipes Stein *Peridinium cinctum* (O.F. Mull) Ehr. *Peridinium pusillum* Penard	*Cyptomoas cf. borealis* Skuja *Cryptomonas marssonii* (mars.) Skuja *Cryptomonas ovate* Ehr.
Euglenophyceae *Phacus longicauda* (V. Stein) *Phacus tortus (lemm.)* Skuja. *Lepocinclis striata* (Hubner) Skuja	

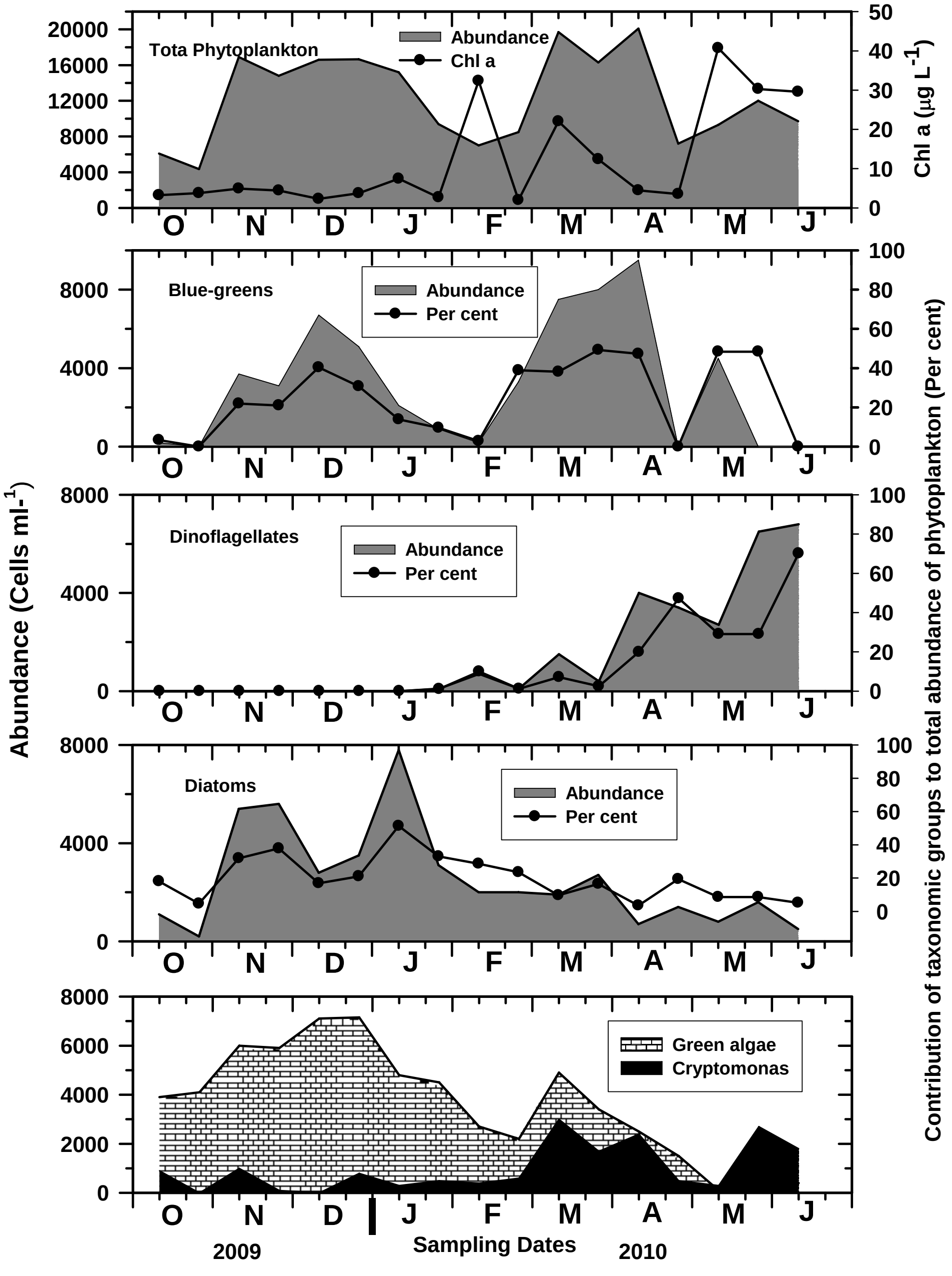

Fig. 6. Temporal variations in the abundance and percentage contributions of algal groups to total abundance of phytoplankton in relation to total Chl a biomass of phytoplankton.

The most abundant and species-rich algal group was the green algae, with contributions ranging from 1 to 95 % and with most values above 25%. The green algae were most abundant during the dry period (November_Janaury) and were constituted primarily by species of the genera *Ankistrodesmus, Cosmarium, Closterium, Crucigenia* and *Kirchneriella,* with *Crucigenia* being the most species-rich green algal genus. The second most abundant algal group was the blue-green algae, which was dominated by two species of *Microcystis, M. aeruginosa* and *M. panniformis.* The abundance of blue-green algae peaked in December, 2009 and April, 2010 of the dry and minor rainy periods respectively, coincident with peaks of total phytoplankton abundance. The third most important algal group was diatoms, which was also species-rich. Peaks of abundance of diatoms occurred in November, 2009 and December, 2010, concurrently with those of total phytoplankton abundance. Diatoms were dominated by a species of the filamentous genus *Melosira, M. agassii,* followed by *Fragilaria capucina* and *Rhopalodia gibberulla* among the flagellate groups, dinoflagellates were the most important, with *Peridinium cinctum* and *P. bipes* becoming quantitatively important during the minor rainy period (March-May). Among the cryptomonads, *Cryptomonas marsonii* and *C. ovata* were found in large numbers among the phytoplankton during the months of the minor rainy period.

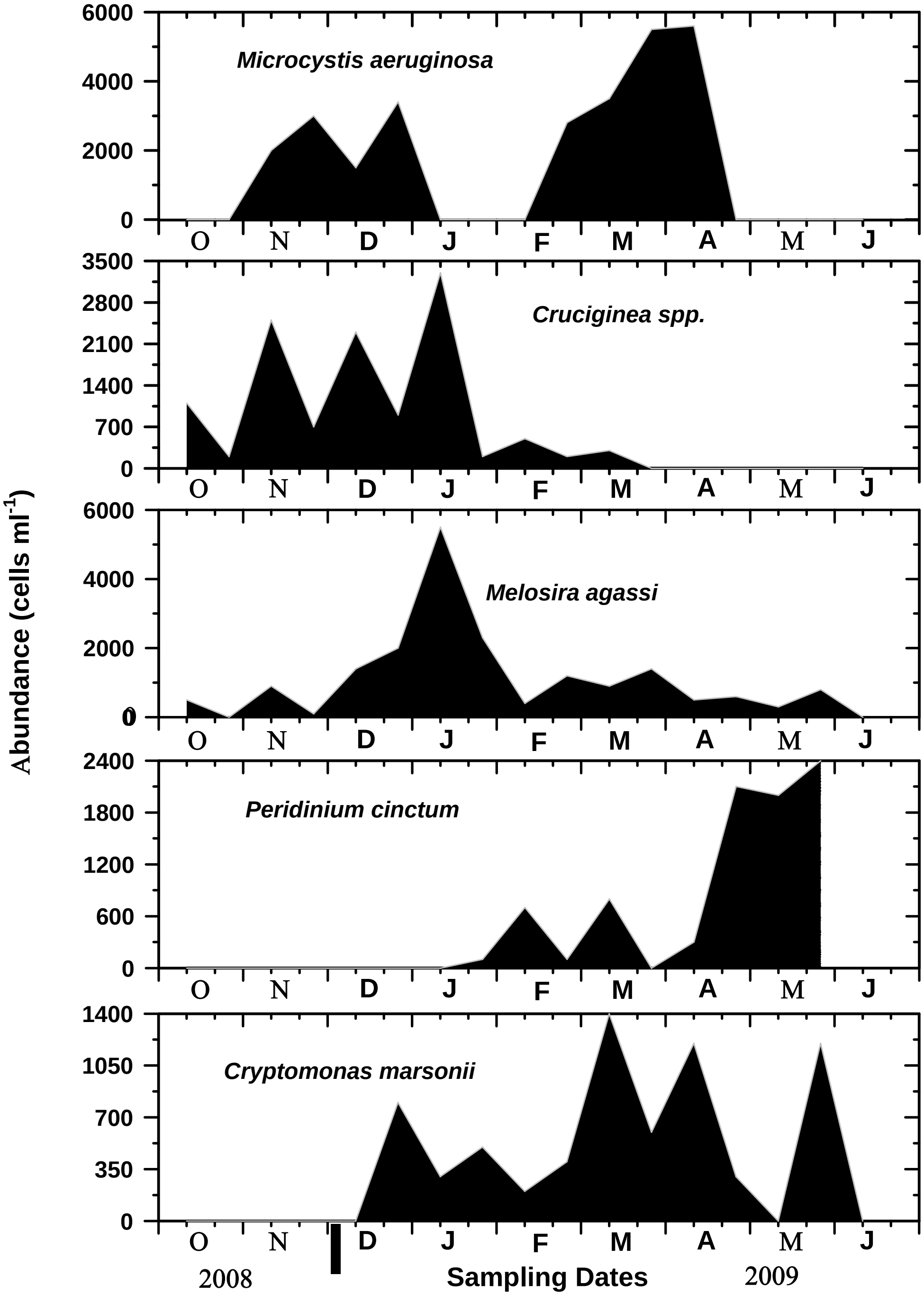

Fig. 7.Temporal variaitons in the abundance of major species of phytoplankton in Geffersa Reservoir.

The abundance of green and blue-green algae in freshwaters of Ethiopia is not uncommon. The study by Girma Tilahun (2006) has shown the predominance of blue-green algae in terms of number of species and fresh weight biomass Lakes Awassa, Chamo and Ziway. Green algae were also reported to be quantitatively important for most of the year in Lakes Awassa and Chamo (Girma Tilahun, 2006). Green algae seem to be favored by nutrient-rich, fairly turbulent low-salinity waters (Graham and Wilcox, 2000). The predominance of green algae in freshwaters is the result of their structural and physiological adaptations that include their generally small size, deformed shapes (e.g. in desmids) and formation of mucilaginous colonies which reduce loss due to sedimentation and/or grazing by zooplantkton (Graham and Wilcox, 2000). Blue-green algae, particularly *Microcystis* species, are known for their year-round quantitative importance in many water bodies of Ethiopia including Lakes Hora (Abebaw Wondie, 2006), Kuriftu (Zelalem Desalegne, 2007), Chamo (Eyasu Shumbulo, 2004; Girma Tilahun, 2006) and the reservoirs Koka (Hadgembes Tesfay, 2007) and Legedadi (Adane Sirage, 2006) with frequent blooms in the latter three bodies of water.

Blue-green dominance is a common phenomenon in lakes and reservoirs and was reported for several reservoirs in Africa (Thornton, 1987). Although the relative importance of environmental factors vary considerably among different species of blue-green algae (Reynolds, 1984), their dominance is initiated and enhanced by one or several environmental factors such as light, temperature, water column mixing/stratification and availability of nutrients in the open water. The high quantitative importance of blue-greens in Geffersa reservoir seems to be associated with low light conditions (Smith, 1986), high phosphate levels and their ability to minimize grazing (Hanley, 1987) and/or buoyancy regulation (Reynolds, 1987).

Although the nutrient levels of Geffersa Reservoir seem to have been at favorably high levels for both diatoms and dinoflagellates throughout the study period, these two algal groups attained and maintained high population densities during the dry and minor rainy periods respectively, which were presumably different in physical regimes.

Diatoms, owing to their dense siliceous cellular envelope and lack of organelles of motility and the consequent inability to regulate their vertical position in lakes and reservoirs, are favored by turbulent water column conditions (Willen, 1991), while dinoflagellates prefer clam water column conditions, as they can always replenish their cells by nutrients obtained from deep parcels of water owing to their ability to migrate vertically, and because turbulence impedes cell division and disrupts cells (Fogg, 1991). The noticeably low levels of abundance of dinoflagellates despite the high levels of nutrients during the period extending from November, 2009 to January, 2010 seem to be associated with increased wind-induced turbulence, a physical condition that favors diatoms.

5.2.2. Phytoplankton biomass

Phytoplankton biomass estimated as chlorophyll a exhibited temporal variations in Geffersa reservoir over the study period (see Figs. 5, 6 and 8). Chl a biomass averaged 12.41 µg L^{-1} and varied from a minimum of 2.29 µg L^{-1} in December, 2009 to a maximum of 40.67 µg L^{-1} in May, 2010. The high phytoplankton biomass values of the present study in Geffersa Reservoir are comparable to those of Legedadi Resevoir (22.19 to 39.45 mg $m^{-}3$, Adane Sirage, 2006).

Phytoplankton biomass remained below 10 µg L^{-1} during the period extending from October, 2009 to January, 2010 despite the high levels of abundance of phytoplankton before it peaked in February and May, 2010, with the former one coinciding with the low abundance of all taxonomic groups of phytoplankton and zooplankton, seasonal minimum concentration of phosphate and low levels of nitrate and silicate. The largest peak of phytoplankton biomass, which occurred during the minor rainy period in May, coincided with moderate abundance of blue-greens and dinoflagellates and increased concentrations of nutrients, particularly of phosphate. Phytoplankton biomass values of Geffersa and other reservoirs are given in Table 5. The reported Chl a values of the Reservoirs seem to indicate that phytoplankton biomass is generally low in Reservoirs which may be attributed to their turbid water column conditions and short residence time of phytoplankton. .

Table.5. Phytoplankton biomass as chlorophyll a reported for various Reservoirs

Reservoir	**Chlorophyll a (μg L^{-1})**	**References**	**location**
Badagiriya	21	Silva *et al.,(*2002)	Sri Lanka
Kaudulla	45		
Nuwarawewa	104		
P Samudra	35		
Udawalawe	11		
Chandricawewa	5		
Tissawewa	6	Amaasinghe and Vijverberg,(2002)	
Turkwel George	15-70	Kotut *et al.,* 1998	Kenya
Spioenkop	4.6-36.8	Hart,1999	South Africa
Wuras	30-31	Grobbelar, 1985	
Hazelmere	6	Thornton, 1986	
Mcillwaine	12	Thornton, 1987	
Harbeespoort	52	Robets and zohary, 1986	
Dalrymple	3.4	Faithful and Griffith, 2000	Australia
Maroon	13.1	Hunt *et al.,* 2003	
Xolotlan	65	Erikson, 1998	Nicaragua
Huguanojo	2.4	Laiz *et al.,* 1994	Cuba
Tuinicu	16		
Lebrinje	22		
Zaza	10		
Legadadi	29.92-39.45	Adane Sirage, 2006	Ethiopia
Koka		Hadgembes Tesfay	
Geffersa	**2.29-40.67**	**Original data**	

5.2.3. Taxonomic Composition and abundance of Zooplankton

During the study period, a total of 25 species, with 15 species of rotifers, 8 species of copepods and 2 species of cladocerans (See Table 6) were identified. The mean percentage contributions of the three zooplankton groups to the total abundance of zooplankton are shown in Fig. 9. Rotifers accounted for 66.82 per cent of total zooplankton abundance while the contributions from copepods and cladocerans were 24.51% and 8.67% of the total abundance of the zooplankton respectively on annual basis. Rotifers were, therefore, not only the most species-rich zooplankton group, they were also the most abundant of all zooplankton groups with pattern of variations similar to that of total zooplankton abundance (see Fig. 8) suggesting that seasonal dynamics of the zooplankton assemblage in Geffersa Reservoir is largely a function of the temporal dynamics of rotifers.

Table. 6 List of zooplankton taxa identified over the study period in Geffersa Reservoir .

Rotifers	**Copepods**	**Cladocera**
Brachionus falkatus *Brachionus angularis* *Brachionus mirus* *Keratella tecta* *Keratella tropica* *Keratella cochlearis* *Keratella Americana* *Horaella brehmi* *Horaella thomsoni* *Polyathra vulgaris* *Trichocerca puilla* *Trichocerca similis* *Trichocerca similis grands* *Trichocerca flagellata* *Testudinella*	*Nauplia (calanoida)* *Nauplia(cyclopoida)meta Cyclops* *Adult calanioda* *Macrocylops albidus* *Thermocyclops* *Tropocyclops prasinus* *Cyclopoid (eucyclops agiloides)* *Metaboeckella dilatata.*	*Cerio Daphnia spp.* *Moina cf. buckella*

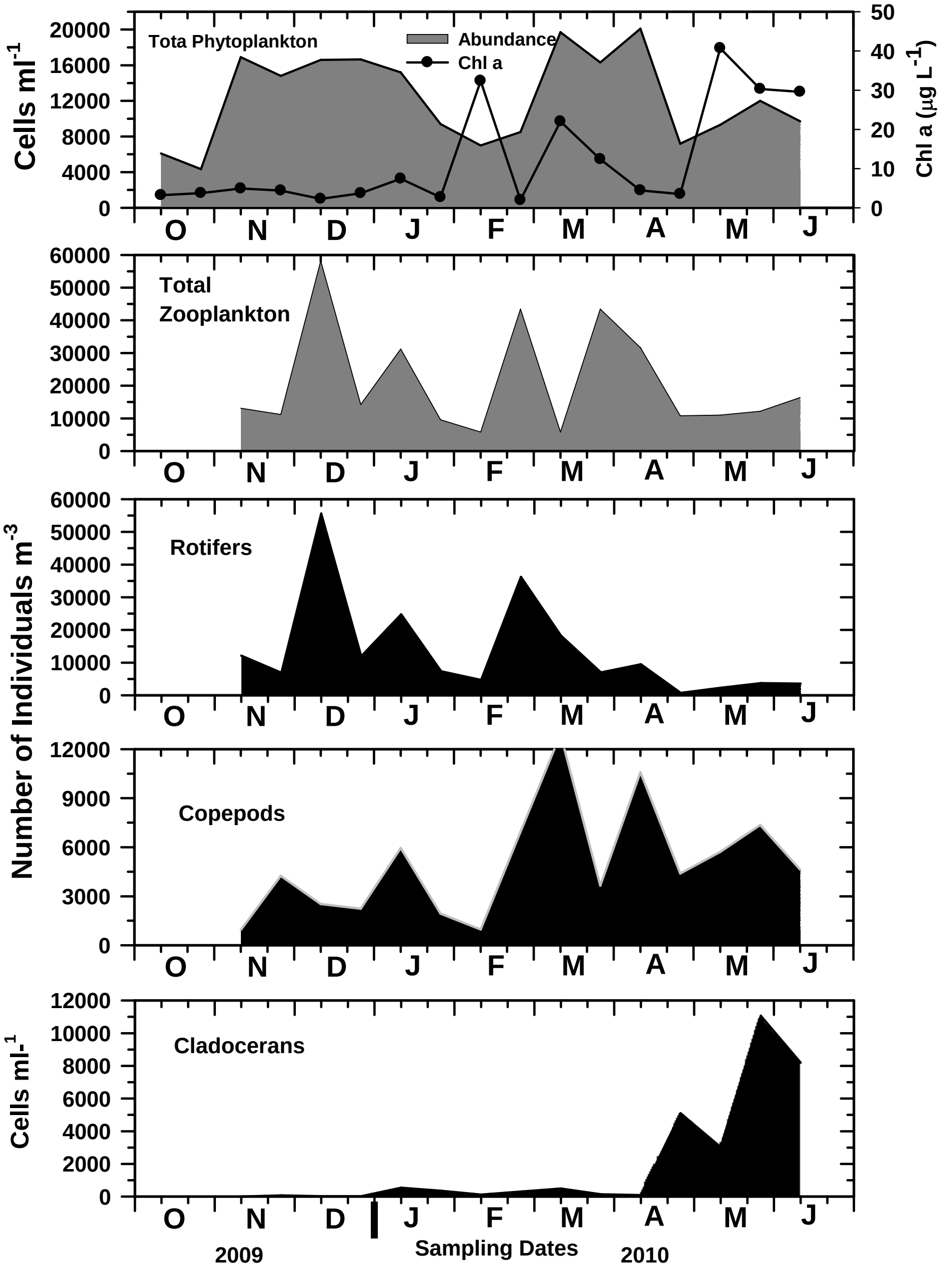

Fig. 8 Temporal variations in the abundance of zooplankton groups in relation to total abundance of zooplankotn and phytoplankton and total Chl a biomass of phytoplankton.

The high population density of the rotifers could be attributed to their parthenogenetic reproductive patterns and short generation time under favorable conditions and their ability to feed on different food type (Wetzel, 2001). The dominance of rotifers in tropical waters is also ascribed to their preference for warm waters as highlighted by (Sharma, 2000). Peaks of rotifer abundance coincided with peaks of abundance of blue-green algae, diatoms and green algae.

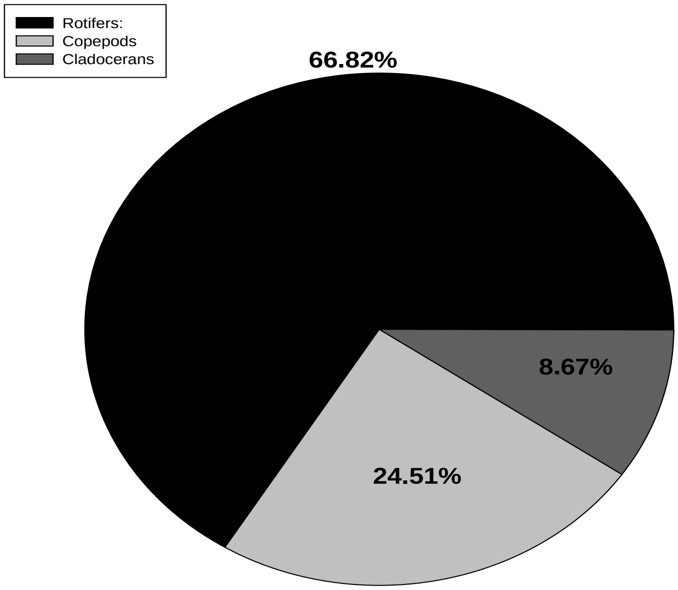

Fig. 9. Mean percentage contributions of rotifers, copepods and cladocerans to total zooplankton abundance in Geffersa resevoir.

The generally high rotifer numbers during the dry period may be associated with increases in the density of such edible phytoplankton as green algae and diatoms. The major species of rotifers w*hich* were responsible for the dominance of the group included *Keratella spp. including K. tropica and K. chochlearis var. tecta and Horaella brehmi, Polyathra vulgaris and Trichocerca pusilla.*

Copepods and cladocerans also exhibited temporal variations in their abundance, which were more marked for the latter. The zooplankton community of a water body is shaped by the relative importance of resource and predator control (Wetzel, 2001). Although changes in available food sources and predation pressure are known to induce responses by zooplankton reflecting their ‘sandwiched role’ in aquatic foodwebs (Gliwicz, 2002), the two forces operate on different time scales with the effect of predation being immediate. The peaks of abundance of copepods in March and April, 2010 were observed at the times of blue-green algal peak abundance while those of cladocerans in May and June, 2010 occurred concurrently with peaks of dinoflagellate abundance. The peak of abundance of copepods at the time of large peak of blue-green abundance could be related to the presence of diatoms and green algae, which were also abundant. Despite disparity in opinions on the nutritive value of diatoms, there are many field observations supporting that diatoms are excellent food for the growth of herbivorous zooplankton (Porter, 1977). The low density of cladocerans during the period of cyanobacterial abundance may be partly related to their inability to effectively graze upon blue-greens (Sharma, 2000). Although lack of small algal particles in blue-green algal-rich phytoplankton community was regarded as the factor restricting cladocerans in Lake George, Uganda (Porter, 1977). Increased grazing pressure seems to be the reason for the low abundance of cladocerans during the dry period since algae that are edible to filter-feeding cladocerans --diatoms and green algae-were also abundant. The increase in density of cladocerans during the wet months of May and June might be associated with the increase in some edible phytoplankton forms at the time of presumably low predation pressure.

6. CONCLUSIONS AND RECOMMENDATIONS

Geffersa Reservoir is a shallow, frequently mixing and turbid water body with high levels of nutrients which have presumably originated from surrounding agricultural lands on which fertilizers are applied. The reservoir supports moderate level of phytoplankton biomass constituted largely by green algae, blue-green algae and diatoms that exhibit marked temporal variations that seem to be associated with hydrographic and hydrological conditions of the reservoir.

TDS, pH, turbidity and concentrations of inorganic nutrients are currently within the permissible range of limits. With time all the measured physico-chemical and biological parameters may change drastically and pose threats to public health. The more worrying aspect of Geffersa reservoir is that, with increased turbidity, the major blue-green species of the genera *Microcystis* and *Cylinderospermopsis,* which are now at relatively low levels of abundance, may develop into nuisance and toxic algal blooms.

Based on the results obtained during the study period, the following recommendation are made.

- As public education is the first line of defence against water quality problems, farmers should be educated to reduce runoff from their private properties as runoff that comes from private holdings picks up fertilizers and toxic chemicals on its way to the reservior or and any other body of water.

- Enclosing the reserviour to prevent pollution with wastes from liivestock is advisable as domestic animals freqently visit the reservir to drink water and graze on grasses growning on the reservor’s shores.

- Planting a buffer strip of plants with well-studied and good filtering capacity and minimal litter (e.g. grasses) is recommended to minimize the risk of nutrient enrichment and high turbidity from siltation.

- Investigations that invovle determinations of residues of the most commonly used pesticides in the reservoir are recommended as the use of pesticides has recently become widespread in this country.

- Monitoring of levels of abundance of the potentially toxic phytoplankton taxa is recommended to avoid unexpected and disasterous consequences of algal blooms.

7. REFERENCES

AAWSA (Addis Ababa Water and Sewerage Authority) (1993). Geffersa water treatment plant operation and maintenance manual, Ltd. Addis Ababa, Ethiopia.

Abebaw Wondie (2006) Temporal dynamics of biomass and primary production of phytoplankton in relation to some physicochemical factors in lake Hora-Arsedi, Ethiopia. M. Sc. Thesis, Addis Ababa University, Addis Ababa: 85pp.

Abrams, P. A. (1993). Effect of increased productivity on the abundance of trophic levels. *AmericanNaturalist* **14:** 351-371.

Adane Sirage. (2006). *Water quality and Phytoplankton Dynamics in Legedadi Reservoir.*M.Sc thesis Addis Ababa University, Addis Ababa 109 pp.

Addis Ababa Water and Sewerage Authority (AAWSA) (1994). The study of problem analysis of means to conrol water quality deterioration of Legadadi Reservoir. Final report, vol.I; Main report and vol.II: figures and annexis.

Addis Ababa water and Sewerage Authority (AAWSA) (2000-2002). Chemical analysis reports for Legedadi Reservoirs. Unpublished data.

Amarasingahe, P, B. and Vijverbrgr, J. (200). Primary production in tropical reservoir in SriLank. *hydrobiologia*, **487**: 85-93.

Amha Belay and Wood, R. B (1982). Limnological aspects of on algal bloom on Lake Chamo in GamoGofa Administration Region of Ethiopia in 1978. *SINET: Ethiop.J.Sci.***5:** 1-19.

Anna-lissa, H. and Galina, L., (1999). Effects of nutrient load on species composition and productivity of phytoplankton in Lake Ladoga. *Boreal Env. Res.* **4**: 215-227.

Ashton, P. J. (1981). Nitrogen fixation and the nitrogen budget of eutropic impoundment. *Water res.* **15**: 823-833.

Bautista, B. and Harris, R. P. (1992). Copepod gut contents, ingestion rates and grazing impacts on phytoplankton in relation to size `structure of zooplankton and phytoplankton during spring blooms. *Mar. Ecol. Prog. Ser.* **82**: 41-50.

Baxter, R. M. and Golobistch, D. L. (1970). A note on the limnology of Lake Hayq, Ethiopia. *Limnol.Oceanogr.* **15:** 144-149.

Bell, S. G. and Codd, G. A. (1994). Cyanobacterial toxins and human health. *Rev.Med. Microbiol.* **5**: 256-264.

Bendorf (1988). Objectives and unsolved problems in ecotechnology: A preface. *Limnologica* **19**: 5-8.

Berglind, L. H., Holtan, H., and Skulberg, O. M., (1983). Case studies on off-flavours of some Norwegian lakes. *Wat. Sci. Technol.,* **15:** 199-209

Bernardi, R. D, and Guissani, G. (1990). Are blue-green algae a suitable food for zooplankton? An overview. *Hydrobiologia*, **201**: 29-41.

Brook Lemma, (1994). Changes in the Limnological Behavior of a tropical African Explosion Crater Lake: L. Hora- Kilole, *Ethiopia. Limnologica* **21:** 57-70.

Bosque-Hamilton, E. K., Nana-Amankwaa, E. and Karikari, A. Y. (2004). A preliminary comparative limnological assessment of three coastal water supply reservoirs in Ghana. *J. Ghana Sci. Ass.* **6**: 128–138.

Calijuri, M. C., Deberdt, G. L. B. and Minoti, R. (1999). A produtividade primária pelophytoplankton na Represa de Salto Grande (Americana—SP). In Henry, R. (ed.), Ecologia de Reservatórios: Estrutura, Função e Aspectos Sociais. Pp. 109–148.

Calijuri, M. C., Dos Santos, A. C. and Jati, S. (2002). Temporal changes in the phytoplankton community structure in a tropical and eutrophic Reservoir (Barra Bonita, S. P. Brazil). Cambridge University Press, Cambridge. *Journal of Plankton Research.* **24**: 617-634.

Carmichael, W. W. (1988). Naming of cyclic hepatotoxic toxins of cynabacteria.

Taxicon. **26**: 971-972.

Carney, H. J. and Elser, J. J (1990). Strength of zooplankton –phytoplankton coupling in relation to lake trophic state. **In**: Large Lakes: Ecological structures and functions, pp. 615-631, (Tizler M. M. and Serruya C.eds), Springer-Verlag, New York.

Cederlof, U., Rydberg, Mgendi, M., and Mwaipopo, O., (1998).Tidal exchanged in warm tropical Lagoon. chwaka Bay, Zanzibar Ambio **24**: 458-464.

Danielson, T. J. (1998). Indicators for monitoring and assessing biological integrity of inland wetlands: a review of the technical literature (1989-1996).U.S. Environmental Protection Agency, Washington, D.C., EPA-43- R-98-002.

DeBernardi, R. and Giussani, G. (1990). Are blue - green algae suitable foods for zooplankton? An overview, *Hydrobiologia.* **200:** 29-41.

Defaye, D. (1988) Contribution a laconnaissance des crustaces copepods d'Ethiopiae. *Hydrobilogi*a. **164**: 103-147.

Demeke Kifle. (1985). Variation in phytoplankton primary production in relation to light and nutrients in Lake Awassa. M. Sc. Thesis, Addis Ababa University, Addis Ababa: 108 pp.

Deparment of water Affairs (1985). Some aspects of the physical and chemical limnology of the waters of the eastern National water carrier: the impoundments and Okavango River. Report No.85/7, water quality division, department of water affairs, wind hoek.

Durand, J. R. and Leveque, C. (1980). Flore Faune aquatiques de L'Afrique sahelo-Soudanienne, O. R. S. T. M., Paris.

Dussart, B. H and Fernando, G. H. (1988). Sur quelques Mesocyclop (Crustacea, Copepoda). *Hydrobilogia.* **157**: 241-264.

Dokulil, M.T. (1994). Environmental control of phytopalankton productivity in turbulent syatems. *Hydrobiologia***, 289:** 65-72.

Edmondson, W. T and Winberg, G. G. (1971). *A manual on methods for the assessment of secondary productivity in freshwaters*. I.B.P. Handbook. No.7

Elizabeth Kebede (1996). Phytoplankton in an alkalinity-salinity series of lakes in the Ethiopian Rift Valley. PhD Thesis, Uppsala University, Uppsala, Sweden.

Elizabeth Kebede and Willén, E. (1998). Phytoplankton in a salinity-alkalinity series of lakes in the Ethiopian Rift Valley. *Algologicalstudies*, **89**: 63-96.

Environmental quality Center, USA, (2003). Total dissolved solids in drinking water quality.*URL:http://www.water research net/total dissolved solids.htm.*

Erikson, R., (1998). Optimal condition for primary production in polymictic Tropical lakes. *Hydrobiologia.**382**:1-16.*

Eppley, R.W. (1972). Temperature and phytoplankton growth in the sea. fisheries Bulletin. **70**: 1063-1085.

Eyasu Shumbulo (2004). Temporal and spatial variations in biomass and photosynthetic production in Lake Chamo, Ethiopia. M.Sc. Thesis, Addis Ababa University.

Faithful, J.W. and Griffiths, D.J. (2000). Turbid flow through a tropical reservoir (lake Darymple, Queens land, Australia

Falkowski, P. G. and Raven, J. A. (1997). *Aquatic photosynthesis.* Blackwell Sciences, Oxford, 375 pp.

Fernando, C. H. (2002). Zooplankton, fish, and fisheries in tropical freshwaters. *Hydrobiologia*. **272**:105-123.

Fritz, L. Quilliamm, A., Wright, J. L., Beadle, A. M. and Work, T. M. (1992). An outbreak of domoic acid poisoning attributed the pennate diatom *Pseudonitzschia australis. J. Phycol.*, **28**: 439-442.

Fogg, G. E. (1978). The comparative physiology and biochemistry of green algae. *Bactriol. Rev*. **20:** 148-168.

Ganf, G. G. and Viner, A. B. (1973). Ecological Stability in a Shallow equatorial lake (Lake George, Uganda). *Proc. Roy. Soc.* **184**: 321-346.

Gasse, F. (1986). East African diatoms: Taxonomy and ecological distribution.Gebruder Burntraeger, Berlin. Stuttgart, 201pp.

Girum Tamire. (2006). Zooplankton Community Grazing Rates in Lake Kuriftu. M.Sc. thesis Addis Ababa University, Addis Ababa, 72 PP.

Girma Tilahun. (2006). Temporal Dynamics of the Species Composition, Abundance and Size-Fractionated Biomass and primary production of Phytoplankton in Lakes Ziway, Awassa and Chamo (Ethiopia). PhD. Thesis, Addis Ababa University, Addis Ababa. 201pp.

Gliwicz, Z. M. (1977). Food size selection and seasonal succession of filter feeding zooplankton in eutrophic lakes. *Ekol. Pol,* **25**:179-225.

Graham, L. and Wilcox, L., (2000). Algae. Upper Saddle River: Prentice, Hall, 640 pp.

Green, J. (1986). Zooplankton associations in some Ethiopian crater lakes. *Freshwater Biology* **16**:495-499.

Gorham, P. R. and Carmichael, W. W. (1979). Phycotoxins from blue green algae. *Pure Appl. Chem*. **52:** 165-174.

Grobbelar, J. U. (1989). Phytoplankton productivity in a shallow turbid impoundment,Wuras dam. Verh. *Int. ver. Theor. Angew. Limnol.*, **22**:1594-1601.

Hadgembes Tesfay (2007). Spatio-Temporal Variations of the Biomass and Primary Production of Phytoplankton in Koka Reservoir, MSC thesis Addis Ababa University, 85pp.

Hanley, J. F. (1987). Field studies on zooplankton-cyanobacteria interactions. New Z. *J. Mar. Feshwat. Res.* **21**: 467-475.

Hecky, R. E. (1993). The eutrophication of Lake Victoria. *Verh. Int. Verein.Limnol.* **25**: 39-48.

Hunt, R. J., Matveev, V., Jones, G. J. and Warburton, K. (2003). Structuring of cynobacteria community by pelagic fish in subtropical reservoirs:

expermantal evidence from Australia. Fresh water biology, **48**: 1482-1495.

Holmes, R. W. (1970). The Secchi disc in turbid coastal waters. *Limnol. Oceanogr.* **15**: 688-694.

Hotzel, G. and Croome, R. (1999). A phytoplankton counting methods manual for Australian freshwaters. Land and Water Resource Research Development Corporation Canberra, 51pp.

Jeppesen, E., Olrik, K. and Kristensen, P. (1994). Impact of nutrients and physicalfactors on the shift fromcynobacterial to chlorophyte dominance in shallow Danish lakes.*Can.J.Fish.aquat.Sci.* **51**:1692-1699

Kalff, J. (2002). *Limnology: Inland water Ecosystems*. Prentice-Hall, Inc, NJ 592pp.

Krik, J. T. O. (1994).Light and Photosynthesis in Aquatic Ecosystems, 2nd edn. Cambridge University Press, New York, 509pp.

Kotut, K., Kientitz, L. and Muthuri, F. (1998). Temporal changes in phytoplankton structure and composition at Turkwell GeorgeReservoir, Kenya. Hydrobiologia, **368**: 41-59**.**

Lampert, W. (1978). Further studies on the inhibitory effects of the cyanobacterium *Mircocystis aeruginosa* on the filtering rate of zooplankton. *Arch. Hydrobiol.*, **95**: 207-228.

Lampert, W., Fleckner, W. Rai, H. and Taylor, B. E. (1986). Phytoplankton control by grazing zooplankton in a study on the spring clear–water phase. *Limnol.Oceanogr***.** **31**: 478-490.

Lehmusluoto, P. (1999). Water for Addis Ababa, capital of Ethiopia, legadadi reservoir. Information given for the review of Ethiopian limnology in developing countries. Vol.2

Leman, J. T. (1988). Selective herbivores and its role in the evolution of phytoplankton growth strategies. **In:** *Growth and Reproductive*

Strategies of Fresh water Phytoplankton, pp.369-386, (C.D. Sandgren, ed). Cambridge University Press. Cambridge.

Lind, T. O. (1979). *Handbook of common methods in Limnology*, 2nd ed. The C. V. Mosby Company. 199 pp.

MacCarthy, J. J. (1980). The physiological ecology of phytoplankton. **In**: *Studies in Ecology* .Vol.7, pp. 191-234 (Morris, ed.). Blackwell.

Melack, J. M. and Kilham, P. (1974). Photosynthetic rates of phytoplankton in east African alkaline saline lakes. *Limonol. Oceanogr.* **19**: 743-755.

Melaku Mesfin and Amha Belay (1989). A study of seasonal variation of phytoplankton in relation to water quality in Legedadi Reservoir. *Int. J. Ecol. Environ. Sci.***15**:1-16.

Melaku Mesfin, Tudorancea, C. and Baxter, R. M. (1988). some limnological investigations on two Ethiopian hydeoelectrical reservoirs: Koka Shewa administrative district and Fincha (wollega administrative District). *Hydrobiologia,* **157**: 47-55.

Michael, J. V. (2002). Spatial and Seasonal Variation in nutrient excretion by benthic invertebrates in eutrophic reservoir. *Freshwate Biol.* **47**:1107-1121.

Millard, E. S., Myles, D. D., Johansson, O. E. and Ralph, K. M. (1996). Seasonal phosphorus deficiency of Lake Ontario phytoplankton at two index stations: light versus phosphorus limitation of growth. *Can. J. Fish. Aquat. Sci.*, **53:**1112–1124.

Morris, I. (1980). The physiological ecology of phytoplankton. *Blackwell ScientificPublications.* 625 pp.

Oglesby and Schaffner, (1975). The response of lakes to phosphorus. **In**: nitrogen and phosphorus food production, waste, the environment, K.S. porter. 23-57pp.

Payne, A.I (1986). Ecolgy of tropical lakes and Reservoir.Wiley, 301pp.

Perl, T. M., Bedard, L., Hockin, J. C., Todd, E. C. and Remis, R. S. (1990). An outbreak of toxic encephalopathy caused by eating mussels contaminated by domoic acid. New England, *J. Med.* **322**: 1775-1780.

Porter, K. G. (1972). A method for the *in situ* study of zooplankton grazing effects on algal species composition and standing crop. *Limno. Oceanogr.* **17**: 913-917.

Reeders, H. H. and Bijde Vaate A. (1990). Zebra mussels (*Dreissena polymorpha*): a new perspective for water quality management, *Hydrobiologia.* **200**: 437-450.

Reynolds, C. S. (1987). *The ecology of fresh water phytoplankton.* Cambridge University Press, Cambridge.

Reynolds, C. S. (1990). Temporal scales of variability in pelagic environments and the response of phytoplankton. *Freshwat. Biol.* **23**: 25-5.

Reynolds, C. S. (1994). The long, the short and the stalled: on the attributes of phytoplankton selected by physical mixing in lakes and rivers. *Hydrobiologi.* 89: 9-21.

Sharma, B. k. (2000). Rotifers from some tropical lakes of Assam (N.E. Indian). *Tropical Ecol.* **41**: 175-181.

Suess, M. J. (1981). Health Aspects of Eutrophication. *Wat. Qual. Bull.***6:** 63-65.

Silva, E. L. Amarasinghe, U.S., De Silva, S.S, Nissanka, C. and chiemer, F. (2002). Some aspects of photosynthetic characteristics in a set from72 perennial irrigation reservoirs located in the river basins in Sri Lanka. *Hydrobiologia* **485:**19-33.

Smetacek, V., Bathman, U., Nöthig, E. and Scharek, R. (1991).Coastal eutrophication: Causes and consequences. **In:** *Ocean Margin Processes in Global Change*, pp. 251–279 (Mantoura, R. F., Martin, J. M.an Wollast, R., eds). John Wiley, New York.

Smith, V.H. (1986). Light and nutrient effects on the relative biomass of blue-green algae in Lake Phytoplankton. *Can. J. Fish. Aquat. Sci.*, **43**:148-153.

Stengel, E., AND Soeder, C. J. (1975). Massive cultivation of microalgae: *Results and prospect.* **72:** 1573-5117.

Sommer, V. (1986). The paradox of the plankton: fluctuations of phosphorus availability maintain diversity of phytoplankton inflow through culture. *Limnol. Oceanogr.* **29**: 633-636.

Talling, J. F. and Driver, D. (2000). Some problems in estimation of Terrestrial algae. The British Physiological Society, Cambridge Taxonomic analysis of the genus *Anabaenopsis. Arch.Hydrobiol* . **51**: 3-24.

Talling, J. F. and Lemoalle, J. (1998). *Ecological dynamics of tropical inland waters.* Cambridge University Press, Cambridge.

Taylor, W. D., Elizabeth kebede and Zenabu Gebre-Mariam (2002). Primary and Secondary production in the pelagic zone of Ethiopia Rift Valley lakes. **In**: Ethiopia Rift Valley lakes,Tudorancea,C and Taylor, W.D(eds.), Backhages publishens, Leiden, The Netherlands, Pp 95-108.

Twinch, A. J. and Breen, C. M. (1986). A study of phosphorous partitioning and exchange in a South African impoundment .*Water Res.*, **18:775**-782

Tudorancea C., Baxter, R. M. and Fernando, C. H. (2002). A comparative limnological study of zoo benthos association in lakes of the Ethiopian rift Valley. *rchiv fur Hydrbiologie.*, **83**: 121-174.

Thornton, J. A. (1987). A review of some unique aspects of the limnology of shallow southern African-made lakes. *Geo. Journal*, **143**: 339-352.

Thornton, J. A. (1986). Nutrients in African lakes Ecosystem: Do we know all? *J. limno. Soc. Sth. Afr.***12**: 6-21.

Walmsley, R. D. and Butty, M. (1990). Limnology of some selected South African impoundments. Water research commission, Pretoria.

Walmsley, R. D and Thornton, J. A. (1984). Evaluation of OELD-type phosphorus eutrophication Models for the predicting the trophic status of southern African man-made lakes. *S. Afri. Sci.* **80***: 257-259.*

Watts, C. J. (1982). An examination of phytoplankton nutrient limitation in MCIlwaine and the Hunayani River system. **In**: Thornton, J. A. (ed), Lake MCIlwaine, Monogr.

Wetzel, R.G. and Likens,G.E. (2000). Limnological analyses. 2nd ed. Springer-Verlag, Inc. Newyork, 391pp.

Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems.3rd* edition, Academic Press, New York.

Whitford, L. A. and Schumacher, G. J. (1973). A manual of freshwater algae. Sparks Press Raleigh, N.C.

Willen, E. (1991). Planktonic diatoms – An ecological balance review. *Algological Studies* **62**: 69-106. Stuttgart.

WHO (1996). Guidelines for drinking water quality .2nd edition,volume 2.WHO Geneva. Wilson,E.M.(1979). Reserviors (2nd ed). Brian-Henderson shellers.

Vincent, W. F., Wurtsbaugh,W., Neale, P. J. and Richerson, P. J. (1986). Polymixs and algal production in a tropical lake: latitudinal effects on the seasonality of photosynthesis. *Freshw. Biol.***16**: 781-803.

Vollenwieder, R. A. (1991). "Eutrophication- A global problem*". Water Qual. Bull.* **6:** 59-89.

Zelalem Dessalegn, (2007).Temporal dynamics of biomass and primary production of phytoplankton in relation to some physicochemical factors in lake Kuriftu, Ethiopia. M.Sc. thesis Addis Ababa University, Addis Ababa, 89 pp.

8. APPENDICES

Appendix 1: Measurements of Secchi depths (Z_{SD}) and estimates of mean vertical extinction coefficients (K_d,) and Euphotic depths (Z_{eu}) of the Gaffersa reservoir

Date	Z_{SD} (m)	K_d (units m)	Z_{eu} (m)	Turbidity(NTU)
10/2/2002	0.66	2.18	2.31	-
25/2/2002	0.65	2.22	2.28	16.36
10/3/2002	0.63	2.29	2.21	31.93
25/3/2002	0.59	2.44	2.07	21.11
10/4/2002	0.53	2.71	1.86	12.3
25/4/2002	0.66	2.18	2.31	7.23
10/5/2002	0.54	2.66	1.89	15.00
25/5/2002	0.62	2.32	2.17	23.76
10/6/2002	0.47	3.06	1.66	22.22
25/6/2002	0.46	3.13	1.61	24.40
10/7/2002	0.52	2.76	1.82	33.79
25/7/2002	0.43	3.35	1.56	34.19
10/8/2002	0.40	3.6	1.40	78
25/8/2002	0.35	4.11	1.23	73
10/9/2002	0.33	4.36	1.16	189
25/9/2002	0.20	7.2	0.70	168
10/10/2002	0.22	6.55	0.77	162

Appendix 2: Results of the statistical analyses of the relationship among physicochemical and biological parameters.

Chl a	parameters	r	r^2	p
	$N0_2$	-0.0807	0.0065399	0.7576
	NO_3	-0.40929	0.167518	0.1028
	PO_4	0.435463	0.189625	0.081
	Sio_2	-0.10144	0.01029007	0.470
	pH	-0.26752	0.0715669	0.299231
	NH_3	0.662729	0.4392027	0.9546
	Turbidity	0.7435	0.74357	0.000624
	Z_{SD}	-0.65899	0.434267	0.004013
	TDS	0.346288	0.119915	0.0325

Appendix 3: Formulae used to determine various parameters:

1). For Zooplankton abundance: **(Edmondson and Winberg, 1971; Green, 1986)**

$$V_{net}\ (m^3) = \pi\ r^2\ d$$

$$\text{No.}\ /m^3 = \frac{C \times TG \times F}{CG \times V_{net}}$$

Where, C= count of zooplankton,

TG= total grid (15),

F= factor of sub-sample,

CG= counted grids,

V_{net}= Volume of net

r= radius of the net,

d = the length of the course of the net through the water column (depth of sampling), π = 3.14.

2). Phytoplankton Abundance (Hotzel and Croome, 1999).

$$\text{No. of cells (or algal units) ml}^{-1} = \frac{N \times 10^3\ \text{mm}^3}{A \times D \times F \times 0.2}$$

Where N = number of cells or units counted

A = area of field (square)(1mm^2)

D = depth of field (square) (Sedgwick-Rafter chamber depth-1mm)

F = number of fields (squares) counted

0.2= Concentration factor or factor of sub-sample, (10/50 ml)

3). Chl a biomass of Phytoplankton (Talling and Driver, 1963)

$$\text{Chl a } (\mu g\ L^{-1}) = \frac{13.9\ (E_{665} - E_{750})\ V_e}{V_s \times Z}$$

where, E665 = extinction at 665 nm

E750 = extinction at 750 nm

Ve = volume of extract (in ml)

Vs = volume of sample filtered (in Litres)

Z = path length of the cuvette (Spectrophotometric cell) (in cm).

DECLARATION

I declare that the thesis is based on my original work and has not been presented for a degree in any other University. All sources of materials used for this thesis have been fully acknowledged.

Name: Nigatu Ebisa
Place: Addis Ababa University
Signature__________________
Date________________________

This work has been presented with my approval as supervisor.
Advisor, Dr. Demeke Kifle
Signature _________________________
Date of submission___________________