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EFFECTS OF PHYSICO-CHEMICAL PARAMETERS ON ABUNDANCE AND BIOMASS OF PHYTOPLANKTON IN CHEBARA RESERVOIR-KENYA

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Abstract: *River impoundment creates reservoirs of varying sizes that supply water for multiple uses including electric power generation, domestic, agriculture or industry. However, damming of rivers creates an aquatic habitat of slow moving water of varying depths and altogether changing the biotic and physico-chemical status of a waterbody. Chebara reservoir was created to supply water to Eldoret Municipality. Chebara reservoir is located at 36 05 E and 0 22 S and situated within Elgeyo-Marakwet County. A study was conducted on the physico-chemical parameters and the abundance and biomass of phytoplankton in Chebara reservoir from December 2007 to April 2008. Stratified sampling was done every month at six stations distributed over the reservoir; one station at inlet, one station at the outlet, one stationat a minor inlet draining through human settlement, one at minor inletdrainingthrough farmland and one within the reservoir. Temperature, pH and ElectricalConductivity were measured in situusing JENWAY® 3405 Electrochemical Analyser. Secchi depth visibility was measured by vertically immersing a 25cm diameter Secchi disk to disappearance. Phytoplankton were collected using a 28 m diameter plankton net immersed vertically below the photic depth. Phytoplankton was identified and enumerated usingSedgwick—Rafter cell underan invertedo*r microscope, or Olympus® ModelCK2, atamagnificationofX400. *Primary production and biomass were determined by chemical analysis of chlorophyll-a concentration and biological oxygen demand (BOD). Nutrientconcentrations were measured spectrophotometrically, while alkalinity was measuredby acidimetric method. Phytoplankton abundance and biomass were related to the physico-chemical conditions of the reservoir. All statistical analyses were performed with STATIGRAPHIC 2.1 Plus and STATISTICA 6.0 procedures. There were no significant differences in the spatial or temporal physico-chemical parameters. The reservoir was homogenously oligotrophic and alkaline with only very slight variations. among dates and sampling* *stations. The productivity of Chebara reservoir was low (approximately 0.8 µgmillilitre*$^{-1}$*) as estimated by chlorophyll a, suggesting oligotrophy. The highest abundance was observed in March and at station 3,while the lowest abundance in April and at station 5. CCA results indicated strong relationships between the various phytoplankton genera and physical and chemical conditions, except for biological oxygen demand which had a weak effect. The study also indicates that phytoplankton growth in the reservoir is more likely to be limited by availability of P than N. The results obtained from this study can be useful for tracking the effects of changing activities in the drainage basin and the tributaries that contribute water directly to the reservoir. Calcium concentrations were consistently low, but the high abundance of pyraphytes in this reservoir could suggest a need to monitor management practices in the reservoir catchment that maintain calcium concentrations and populations of pyraphytes low in order to reduce the water treatment costs. This research further recommends that a research be carried out on macro invertebrates in order to accumulate sufficient knowledge which will be useful for watershed best management practices aimed at ensuring long term protection for water supply.*

***Keywords**: Physico-chemical Parameters; Abundance and Biomass; phytoplankton; Chebara reservoir*

INTRODUCTION

Aquatic algae are primary producers, hence form the base of the food web in aquatic systems (Agawin*et al*., 2000). Some of the algae are anchored to the substrates and are called benthic, but majority are free floating and are called the phytoplankton. The phytoplankton occur in streams, ponds, lakes and seas, mainly as single cells, filamentous forms or small aggregates of apparently independent cells. Thus, phytoplankton are generally beneficial in a water body, but some pose problems of economic importance. For example, cyanophytes cause poisoning of fish, livestock and humans. Pyrrophytes clog pipes making water treatment more expensive.

The phytoplankton are highly diverse and, because of their small size, respond rapidly to changing environmental factors. Therefore, phytoplankton arerecognised as valuable bioindicators of the state of a water body (Agawin*et al*., 2000; Walsh *etal.,*2003; Callieri, 2008). Phytoplankton occupy the base of food webs in aquatic systems, and can therefore be used to determinethe productivity(Hecky and Kling 1981; Mustapha, 2009; Park *et al*., 2003), energy flow of tropicalreservoir ecosystems (Simciv, 2005).The occurrence, diversity and primary production of phytoplankton communities result from the interactions among physical and chemical factors in a reservoir. Further, different algal species occupy unique ecological niches based on their environmental requirements and physiological adaptations. Thus, the presence of phytoplankton and their community composition are strong indicators of the trophic status of a water body (Reynolds, 1999), and offer useful tools for predicting and managing any perturbations in the reservoir or its catchment (Beyruth, 2000).

Algae in general exhibit shifts in the density and composition of their populations. Such shifts may be temporal or spatial, and follow the brisk changes in the water quality conditions. Algae, mainly the benthic forms, also represent one of the most direct indicators of, and exhibit profound responsesto, pollution in reservoirs (Soinnen&Niemela, 2001;Robin, 2005). The species composition and productivity of Phytoplankton are influenced by physical factors such as the quantity and quality of solar radiation, water temperature, and water chemistry, including pH, dissolved oxygen (DO) and mineral nutrient concentrations(Bell and Kalff, 2001; Pirlot*et al.*, 2005).Other factors such as wind, water inflow or outflow, and the stochiometry of a reservoir can have strong, but indirect local influence on algal assemblage and productivity (Chalar, 2006). The factors influencing seasonality and succession in plankton populations, their interactions with other organisms and the effects of human activities upon their habitat are of major ecological concerns (Carpenter *et al.,* 1989; Eloranta&Soininen, 2001; Soininen&Niemela, 2001).Changes in the water chemistry bring about chemical pollution (Burgis& Morris, 1987) which often results in marked changes in the populations of algae (Goldman & Horn, 1987).

Physical and chemical water quality monitoring often provides useful information at the time of the occurrence of an event, such as during the time of impoundment. Biological assessment, on the other hand, integrates independent and interactive effects of environmental (Sterner and Elser, 2002; A°gren, 2004) and the anthropogenic factors acting on the abiotic component; thus providing a robust indicator of changes in the characteristics of an aquatic environment (Li *et al*., 2001; Allan, 2004).

Algal growth is limited by the concentrations of phosphorus and nitrogen (Mueller &Helsel, 1999; Hakan et al., 2003). When large amounts of nutrients are available, excessive growths referred to as 'blooms' can occur, resulting in water quality problems (Burgis& Morris, 1987;

Soininen,2001). Some algal blooms release substances toxic to fish, birds, domestic animals and other alga, and often cause taste and odour problems in drinking water supplies. When nutrients are exhausted, the growth of algae and production of oxygen by photosynthesis decrease. Large populations of algae in a water body may cause, surface scum and anoxic conditions resulting from bacterial decomposition.

River impoundments, although beneficial, usually change lotic systems into lentic ones, with changes in the water quality, biotic assemblage and productivity. The velocity of the water decreases when it enters the reservoir, which leads to deposition of suspended matter (Scheffer, 1998). The water becomes clearer and growth of phytoplankton is enhanced (Bowling and Baker, 1996).

Small Water Bodies (SWBs) such as reservoirs are influenced by the physical, chemical and biological processes within the entire watershed (Huszar and Reynolds, 1997). Changes within the inflowing waters are likely to affect the physico-chemical status of the entire SWBs.This is because the water that gathers in the reservoirs more often depicts the cumulative effects of the water quality changes originating from the catchment areas (Scheffer, 1998; Sterner and Elser, 2002). For example, nutrients from agricultural land within the drainage basin and compounds introduced throughdirect precipitation and other human factors such as agriculture can influence the water chemistry and the aquatic biota, thereby affecting species assemblages and aquatic biodiversity (Blomqvist, 1994).

The use of aquatic organisms to assess the conditions of a water body is suitable since these organisms respond to varying degrees of perturbations of water's physical and chemical conditions. Macro-invertebrates have been used for a long time in carrying out such assessments (Urbanic, 2004; Bonada*et al.*, 2005). However, in extreme environmental conditions, the use of macro-invertebrates can be limited. Therefore, organisms that have shorter lifespan such as the algae can be used (Carpenter *et al.,* 1989; Angeler*et al.,* 2000). Although most aquatic biological monitoring systems and programmes have concentrated on the microinvertebrates and macroinvertebrates for assessment of water quality stress (Urbanic, 2004; Bonada*et al.*, 2005), there has also been some increasing interest in the use of phytoplankton as ecological indicators (Harris, 1996; Eloranta&Soininen, 2001).

Phytoplankton community composition and biomass of the Chebara reservoir have not been studied before. Therefore, it is not known what physico-chemical properties of the reservoir are pre-eminent in determining the phytoplankton assemblage and production. This study focused on such physic-chemical parameters as temperature, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Ph, total phosphorus in the reservoir were studie

METHODOLOGY

Climate, Geology and Hydrology

The study area has mean maximum temperature range of 18°C to 28°C, and minimumrange of 8°C to 12°C. The mean annual rainfall is 1,000 mm. Long rains occur between March and May, and short rains occur between September and October. Dry months occur between November and March (Land update, 2006).

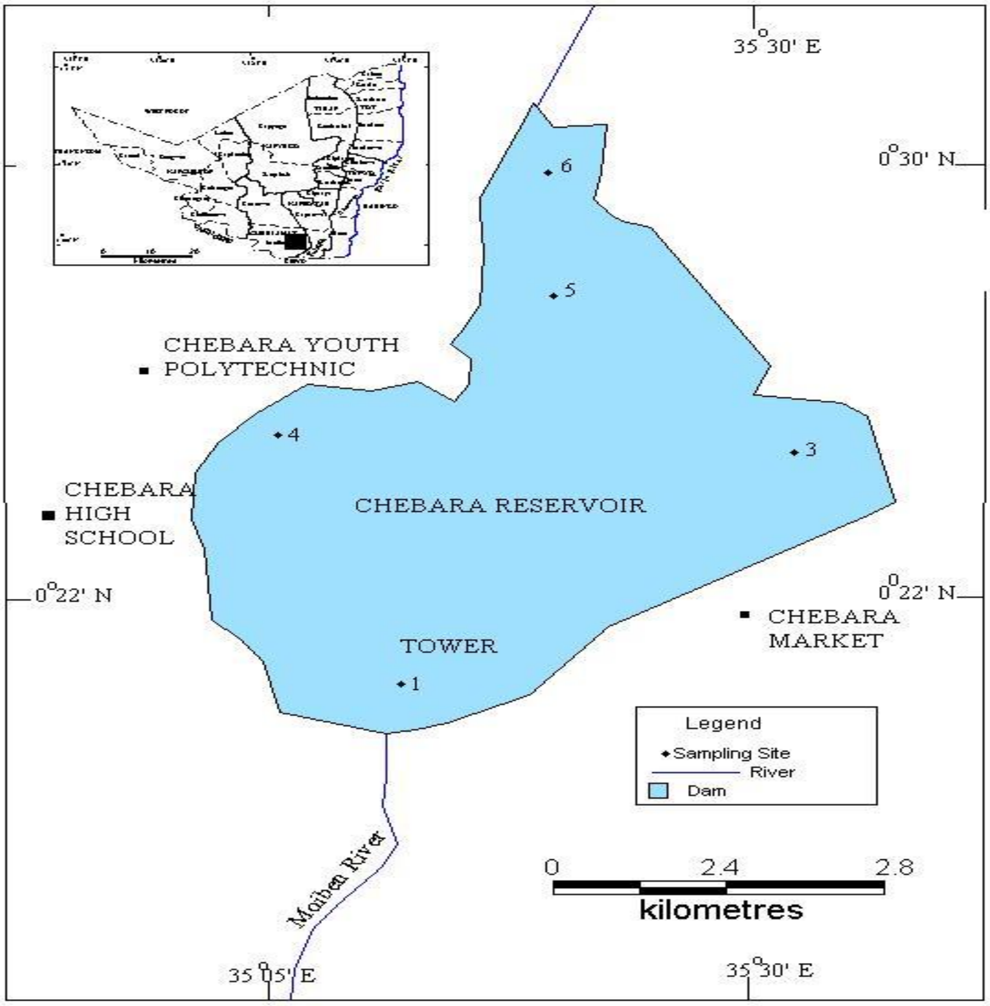

Figure 1: Location of Chebara Reservoir Showing Sampling Stations (Author, 2008)

Sampling

Water sampling was done once a month between December 2007 and May 2008 at each of the six sampling stations for both phytoplankton and physico-chemical properties. Stratified sampling was carried out during the study period at six stations (Fig 1). Stations 3 and 4 were situated at two minor inlets, and drain farmlands and human settlement respectively. These stations were thus chosen on the basis of possible impacts of farming and settlement on the physico-chemical characteristics of water in the reservoir.Sampling station 1was situated 10m away from the reservoir outlet in the open waters and was not frequented by water birds at the time of study. The water in this region is subject to turbulence as it moves out through the outlet. Turbulence and the wind action bring about mixing of the water in this area.Station 2was situated about 100 m east of the reservoir outlet. The area has dense vegetation in the littoral zone and is protected from wind action. The emergent vegetation was predominantly *Typha* spp. There was also a dense vegetation of both submerged and floating plants including *Elodea* and *Nymphaea* species. The waters here remained relatively calm during all the sampling sessions. Station 3, which is inlet of a minor stream, lies south of the reservoir and drains from farm land.Station 4 is also a minor inlet stream, lying to the south eastern side of the reservoir. The steam drains through human settlement which included Chebara Boys High School and Chebara Polytechnic. Station 4 has sparse terrestrial and aquatic vegetation, with the presence of waterfowl. This station was selected for in order to determine if there is a significant effect of settlement on the physico-chemical conditions of the reservoir. Station 5 was selected in the open waters, 300 metres inward and away from the main inlet. Water at this sampling station was very clear and devoid of vegetation. The area was open and subject to wind action.Station 6 is the main inlet of Moiben River which drains into the reservoir through a thick protected forest basically free from much human activity. The station had dense vegetation, which gave significant shading. Terrestrial plants include forest species that grew on land overlying the river mouth. The water was turbid and shallow and slow moving.

Phytoplankton Sample Collection and Analysis

Phytoplankton samples were collected using a plankton net of 28am mesh and 25 cm diameter. The net was immersed vertically below the photic depth of the water as determined using secchi disk (Wetzel 1999). The concentrated samples, measuring 50 millilitre each, were then put in plastic bottles (Wetzel 1999). The samples were then preserved in Lugol's iodine (APHA, 1998) and transported to the laboratory for algal species identification and enumeration. The samples were stored in the dark for four days before sedimentation. In the laboratory, the top 40ml of the sample was decanted to make a plankton concentrate of 10ml. 1 millilitre aliquot of the concentrated sample was pipetted into the Sedgwick-Rafter cell for identification and enumeration.Phytoplankton species identification was carried out using an inverted microscope (Olympus®Model CK2) at a magnification of X400. Identification was done to the genus level using different keys (Prescott, 1952; Lund, 1965; Vollenweider, 1969; Nygaard 1977; Cronberg, 1980; APHA, 2003).

Phytoplankton enumerationwas carried out using a Sedgwick-Rafter cell under an inverted microscope (Olympus® Model CK2) at a magnification of X400 (APHA, 1998). Phytoplankton were counted in at least ten cells of 1 mm x 1mm and numerical estimations of the phytoplankton abundance done using the drop method (Margalef, 1976). The relative abundance of the various taxa was then calculated according to Margalef (1976). Phytoplankton diversity indices were determined according to Shannon-Wiener (1949).

Primary production (PP) was measured using chlorophyll-*a* analysis. One litre of water sample from each station was filtered through Whatman filter paper no.44 using a filtration unit and a sunction pump. A pinch of magnesium carbonate ($MgCO_3$) was added to 10 milliliter of 90% acetone in a centrifuge tube (GEMS, 1992). The filter paper was then immersed in the $MgCO_3$–acetone mixture. The centrifuge tube was then covered using parafilm to exclude light, and then swirled to mix. The centrifugetube was then placed in a freezer for one hour, mixed further by swirling then centrifuged. The optical density of the supernatant was read in spectrophotometer Model 80-2088-84 100-120V/200-240V. Readings were made at absorbances of 664nm, 647nm and 630nm. Three readings were obtained for every sample station. Chlorophyll-a concentration (µg chl millilitre^{-1}) was calculated according to Strickland and Parsons (1968).

Water Sampling and Analysis

Water temperature (°C), electrical conductivity (EC) and pH were measured *in situ* at each of the sampling stations using JENWAY® 3405 Electrochemical Analyzer with probes for each of these variables. Replicates of three readings were recorded at each station once the probe was calibrated. Measurements were taken at a sensitivity of 0.01 for all parameters. Conductivity was measured to the nearest 1S m^{-1}.

Secchidepthvisibility was measured using a 25cm diameter Secchi disk. The secchi disk was first lowered and the depth at which the visibility disappeared recorded. The disk was again raised and the depth at which it reappeared was also recorded. Average of the two readings was then determined as the secchi depth to the nearest meters.

Chemical Analysis

Water samples for chemical analysis were collected in plastic bottles. All samples for nutrient analysis were collected just below the water surface.

Two aliquots of 500 millilitres were collected at each station. The bottles were capped immediately and stored in an ice-packed cool box to arrest any chemical changes. The samples were transported to the laboratory for analyses of chlorophyll-a (phytoplankton biomass), total alkalinity, nitrate nitrogen (NO_3^--N), ammonia-nitrogen (NH_4^+-N), total nitrogen and total reactive phosphorus. Analysis of nitrate- nitrogen samples was conducted using spectrophotometry at 543 nm absorbency (APHA, 1998).Soluble reactive phosphorus was determined using the Murphy and Riley (1962) method.

Ammonia concentration was measured colourimetrically as ammonium nitrogen (NH_4^+-N) at 665 nm absorbency (Boyd, 1990; APHA,1998).

Total alkalinity was determined by acidimetric method (APHA, 1998).

Concentrations of dissolved oxygen and Biological Oxygen Demand were determined by Winkler method (Strickland and Parsons, 1972). For BOD measurements, two BOD bottles were filled with water as in sampling for DO measurement.One bottle was fixed as for DO. The other bottle was wrapped using aluminium foil and transported in dark conditions. The wrapped bottles were incubated in the dark for five days, then Winkler measurements conducted .

Calcium concentration in the water samples was determined by flame photometric method.

RESULTS

Physico-chemical Characteristics of Water in Chebara Reservoir

The status of selected physico-chemical attributes of Chebara water are summarised in tables 1 and 2below.The study revealed that there was significant difference in nitrate concentration among sampling stations (Table 1) and dates (Table 2). Samples from stations 1, 2, 3,4 and 5 showed similar concentration of nitrate, with concentrations below 0.5 µgmillilitre^{-1}, but station 6 had higher concentrations. The mean concentrations of nitrate nitrogen at stations 1 and 6 were higher than the other stations,but all thestations had nitrate nitrogen concentrations above minimum reporting level (MRL) of0.05 µg millilitre^{-1}.

Table 1: Spatial Variation in Physico-Chemical Attributes in Chebara Reservoir over the Study Period between December 2007 and June 2008

Parameter	Sampling Stations						Sig.
	1	2	3	4	5	6	
NO_3^- (µg millilitre^{-1})	0.47±0.06	0.41±0.04	0.42±0.07	0.36±0.03	0.42±0.04	0.57±0.13	<0.0001
NH_4^+ (µg millilitre^{-1})	0.56±0.07	0.56±0.06	0.39±0.04	0.49±0.05	0.46±0.06	0.52±0.06	0.467
PO_4^{3-} (µg millilitre^{-1})	0.007±0.001*	0.008±0.001	0.007±0.001*	0.008±0.001	0.007±0.001*	0.01±0.003	<0.0001
pH	7.77±0.07	7.79±0.04	7.86±0.12	7.62±0.09	7.42±0.18	7.64±0.07	0.720
Electrical Conductivity (0.1 S m^{-1})	1.85±1.71	1.81±1.68	1.75±1.63	1.77±1.65	1.82±1.68	1.77±1.62	0.360
Secchi depth (m)	8.7±0.54	8.9±0.46	8.6±0.6	9±0.45	8.2±0.8	1.43±0.87	<0.0001
Temperature (ºC)	19.4±0.4	19.2±0.3	19.3±0.3	19.2±0.4	19.4±0.3	18.6±0.5	0.644
BOD (mg l^{-1})	4.62±0.32	3.36±0.29	3.81±0.11	5.83±0.24	0.89±0.31	2.51±1.36	0.260
DO (mg l^{-1})	6.42±0.66	4.92±0.86	5.44±1.48	6.11±0.9	6.3±0.73	6.02±0.86	0.905
Chl*a*	0.64±0.14	0.22±0.15	0.69±0.25	0.71±0.12	0.76±0.11	0.50±0.59	0.581
Ca	Trace	Trace	Trace	Trace	Trace	Trace	

Table 2: Temporal Variations in Physico-Chemical Attributes in Chebara Reservoir over the Study Period BetweenDecember 2007 and June 2008

Parameter	Sampling Dates					
	December	**February**	**March**	**April**	**June**	**Sig.**
NO_3 - (µg millilitre^{-1})	0.62±0.04	0.28±0.05	0.64±0.07	0.33±0.03	0.32±0.03	0.0001
NH_4 + (µg millilitre^{-1})	0.42±0.05*	0.42±0.04*	0.56±0.08	0.55±0.04	0.60±0.03	0.0001
PO_4^{3-} (µg millilitre^{-1})	0.007±0.001	0.0040±.004	0.006±0.006	0.008±0.001*	0.008±0.01*	0.0001
pH	7.93±0.2	7. 9±0.15	7.92±0.05	8.15±0.05	7.65±0.02	0.720
EC (0.1 S m^{-1})	0.14±0.008*	0.12±0.009	0.13±0.015	0.14±0.02*	0.16±0.009	1.000
Secchi depth (m)	8.4±0.I8	8.7±0.18	8.3±18	7.8±0. 5	7.3±0.6	0.0001
Temperature (ºC)	18.5±0.3	19.5±0.2	19.25±0.1	20±0.00*	20±0.00*	0.713
BOD (mg l^{-1})	3.4±0.22	3.68±0.05	3.4±0.33	4.46±0.05	4.58±0.32	0.260
DO (mg l^{-1})	7.53±0.13	4.29±0.093	5.01±0.1	5.82±0.13	5.84±0.1	0.905
Chl*a*	0.80±0.12	0.84±0.05	0.82±0.1	0.68±0.05	0.76±0.03	0.701
Ca	Trace	Trace	Trace	Trace	Trace	

There was significant difference in ammonium nitrogen concentration among sampling dates ($p< 0.001$) (Table 2) but not sampling stations ($p =0.467$) (Table 1). Highest mean concentrations of ammonium - nitrogen were recorded at stations 1 and 2 and the lowest at station 3. There was a wide range of ammonium concentrations at different stations, theleast being 0.39 µg millilitre^{-}1and the highest 0.56 µg millilitre^{-1}. There was nosignificant difference for ammonium - nitrogen concentrations in December 2007, February and March 2008. These months were dry seasons, and were different from the values obtained in rainy season (May and April).

The total reactive phosphorus concentration was significantly different for both the stations (Table1) and dates (Table 2). Mean total reactive phosphorus concentrations for most stations were equal to or below MRL. Stations 1, 2, 3, 4 and 5 did not show any significant difference. However, there were slight variations among stations; with a rangeof between 0.007 and 0.008 µg millilitre^{-1} (Table 1). Mean total reactive phosphorus concentration was highest at station 6 but lowest at stations 1, 3 and 5. The least phosphorus concentration was recorded in February (Table 2). Mean total reactive phosphorus concentration was generally lower than mean ammonium-nitrogen and nitrate-nitrogen concentrations.

Chebara water was generally alkaline, with the highest spatial pH value being 7.86 and the lowest being 7.42 (Table1). The highest temporal pH was 9.02 and the lowest 7. 65 (Table 2). There was no significant difference in electrical conductivity (EC) for all thestations ($p= 0.36$) and dates ($p =1.000$). The highest EC value was recorded (1.846 S m^{-1}) for stations 1, and the lowest (1.754 S m^{-1}) for station (Table 1).

Secchi depth was significantly different for stations (Table1), and for dates (Table 2). Stations 1,2,3,4 and 5 were similar ($p=1.000$), but significantly greater than secchi depth for station 6 (Table1). Secchi depth values for December, February, March, were similar and significantly greater than secchi depth for April and June.

There was no significant difference in water temperature ($p=0.644$) for all the stations (Table1) and dates (Table 2) ($p=0.715$). The highest water temperature was recorded in April and June, and the lowest in December. The lowest temperature was 18.6 ^{o} C at the station 6 and the highest was19.4ºC for stations 1 and 5.

There was no significant difference in biological oxygen demand (BOD) concentrations among the stations (*p*=0.260) and dates (*p*=0.260). The highest BOD concentrations were recorded at station 4 and the lowest at station 5 (Table 1). Station 6 also showed considerably low concentrations. The highest BOD concentrations were recorded in March and the lowest in April (Table 2).

Table1 and 2 also revealed that Dissolved oxygen (DO) concentrations were also similar among the stations (*p*=0.898 and dates (*p*=0.905). The highest DO level was recorded at station 1 and the lowest at station 2.

Calcium was found in traces in Chebara reservoir, thereby indicating very low ion concentrations.

Phytoplankton Abundance and Biomass

There was significant difference in both seasonal (Figure 2) but there was no significant difference in spatial (Figure 3) phytoplankton abundance (*p*= 0.700). Figure 2 indicates mean phytoplankton abundance for all the stations at each sampling date. The study revealed a twofold annual variation in phytoplankton biomass and abundance. The highest abundance was observed in March (Figure 2) and at station 3 (Figure 2), while the lowest abundance in April (Figure 2) and at station 5 (Figure 3).

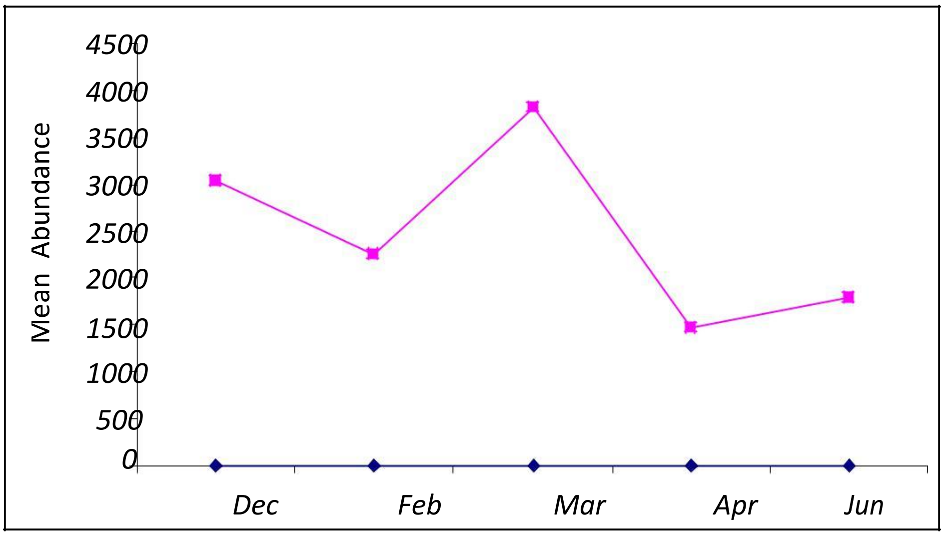

Figure 2: Temporal Variation in Phytoplankton Abundance in the SamplingPeriod (Author, 2008)

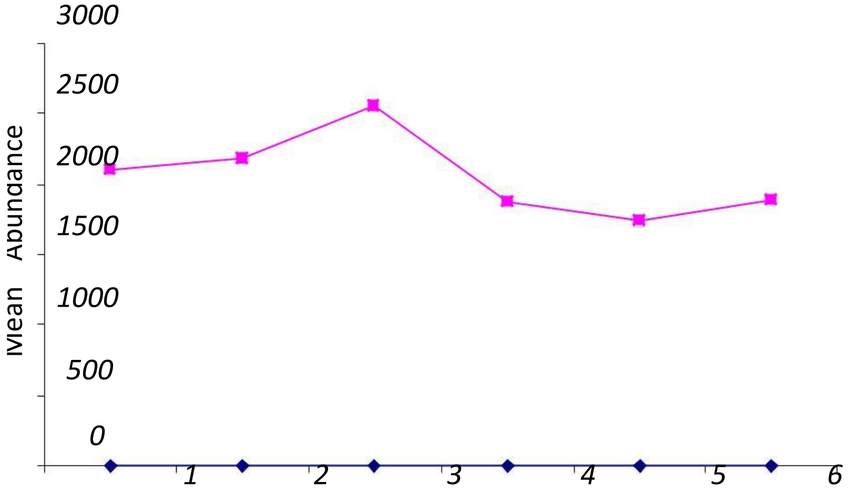

Figure 3: Spatial Variation in Mean Phytoplankton Abundance in Chebara Reservoir during the Study Period (Author, 2008)

Table 3: Species Composition in Chebara Reservoir during the sampling period between December 2007-June 2008

SIT			**1**					**2**					**3**					**4**					**5**					**6**		
DA	**a**	**B**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**	**a**	**b**	**c**	**d**	**e**
Microcystis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Dactylococc.	-	-	+	-	+	+	+	+	+	+	-	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+
Chroococcus	-	-	+	-	+	+	-	-	-	+	+	-	-	-	+	+	+	+	+	+	-	+	+	-	-	+	+	+	+	-
Oscillatoria	-	-	+	-	+	-	+	-	-	-	+	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	+	+	+
Gleocapsa	-	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	+	-	-
Aphanothece	-	-	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	-	-	+	+	-	-	
Merismoped.	-	+	+	+	+	-	+	+	+	+	-	+	+	+	-	-	+	+	-	-	+	+	-	-	-	+	+	+	+	-
Aphancapsa	+	+	+	+	-	-	+	+	-	-	-	-	+	+	-	+	-	+	-	-	-	+	+	+	-	+	+	-	-	-
Coelsphae.	+	+	+	-	-	+	+	+	-	-	+	-	+	-	-	+	+	-	-	+	-	-	+	-	-	-	+	+	+	-
Anabaenp.	+	+	+	+	-	-	-	-	+	+	+	-	-	+	-	-	-	-	-	+	-	-	+	-	-	+	+	+	+	-
Synedra	-	+	+	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-
Navicula	-	+	+	+	+	+	+	+	-	+	-	-	+	-	+	-	+	+	-	+	-	+	+	+	+	+	-	+	+	+
Melosira	-	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	-	-	+	-	+	-	+	+	+	+	+	+	+
Pinnularia	-	-	-	+	+	-	+	+	+	+	-	+	+	-	+	-	+	-	+	-	+	-	+	+	+	+	+	+	+	+
Eunotia	-	+	+	+	-	+	-	-	-	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	-	-	-	-	-	-
Niztchia	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	-	+	-	+	+	+	-	-	+	+	-	-	-	-
Ankistrodes.	+	+	+	+	+	+	-	-	-	+	+	-	-	-	+	+	+	-	-	-	+	-	-	-	-	+	-	-	-	+
Stigeoclo.	-	-	+	+	+	-	-	-	+	-	-	+	+	-	+	-	-	-	-	+	-	-	+	+	+	-	-	+	-	-

Stichococcus	-	-	+	+	+	-	-	+	-	+	-	+	+	-	+	-	-	-	-	+	+	-	+	+	+	-	-	+	-	-
Volvox	+	+	+	-	-	-	+	+	-	-	+	-	+	-	-	+	-	-	-	+	-	-	+	-	-	+	-	+	-	+
Chlamyd.	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gleocystis	-	+	+	+	-	-	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	+
Cosmarium	-	-	+	+	+	-	+	+	+	-	-	+	-	-	+	+	-	+	+	+	-	+	+	+	-	-	-	-	+	-
Zygnemopsis	-	+	+	+	-	-	+	+	+	+	+	-	+	-	+	-	+	-	-	-	+	+	+	+	+	+	+	-	+	-
Nephrocytium	-	+	+	-	-	+	+	+	+	-	+	+	-	+	-	+	-	+	-	-	-	+	-	+	-	-	-	+	-	-
Dinobryon	-	+	+	-	-	+	+	+	-	+	-	+	-	+	+	+	+	+	+	+	-	+	+	+	-	-	-	+	+	-
Trachemonas	-	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+	+	+	-	-	+	-	+	+	-	+	+	-	+	+
Ceratium	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Peridium	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Straustrum	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

KEY:

SIT- sampling site **a**-14/12/2007 **c**-28/03/2008 **e**-07/06/2008

DAT-sampling date **b**-28/02/2008 **d**-20/04/2008

Dactylococc.-Dactylococcopsis;

Merismoped.-Merismopedia;

Coelsphae.-Coelsphaerium;

Anabaenp.-Anabaenopsis;

Ankistrodes.-Ankistrodesmus

Concentration of chlorophyll-*a* was similar for all the stations and dates (p=0.581). The highest concentration was at station 5 and the lowest at station 2 during all the sampling dates (Figure 3). Low concentrations of chlorophyll-*a* in station 2 corresponded with low Biological Oxygen Demand concentrations.

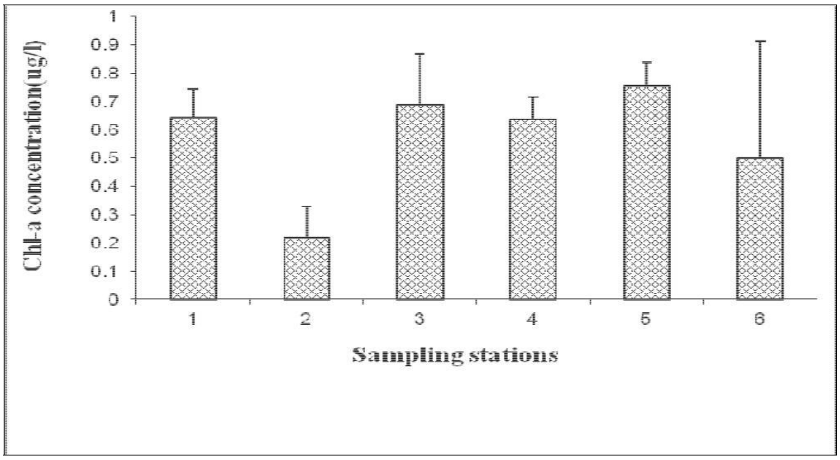

Figure 3: Mean Spatial Chlorophyll-*a* Concentration (µg L^{-1}) in Chebara Reservoir during the Sampling Period (Author, 2008)

Abundance was higher in December, March and February in that order. This corresponded with dry seasons during which light intensity and transparency are high, and possibly with high flushing rates (Floder and Burns, 2005). During the dry period, the water level of the reservoir seems to be a key factor controlling the access of the phytoplankton to the nutrients stored in the sediments (Chalar, 2006).

Phytoplankton biomass was low at stations 2 and 6 (Figure 3). Both stations were shaded by dense vegetation in the littoral zone and protected from wind action. In water columns with low transparency, light limitation forces competition and maintains phytoplankton diversity under natural regimes of light flactuations (Huisman*et al,* 1999a, Floder and Burns, 2005). In stable aquatic ecosystem, species with the lowest critical light intensity will exclude all others (Floder and Burns, 2005). Under high flushing rates as in station 6 (Figure 2), in-lake processes are weak, and the biomass is maintained low but dominated by species adapted to permanent water mixing, high turbidity and low retention time (Reynolds, 1993).

Relationships between Phytoplankton and Physico-chemical Parameters

To reduce the number of genera used in the ordinations and avoid overcrowding the plots, genera whose contribution to the total abundance was less than 0.4 % within the group were eliminated. This reduced the number of genera from 123 to 32 with a combined abundance of 84.07 % (Table 5). To reduce the numbers further, the remaining 32 genera were subjected to pair-wise multiple correlation to eliminate redundant ones. Genera whose Pearson Product Moment was more than 0.85 were considered redundant. Only one genus from among the redundant groups was selected for ordination analysis with physicochemical parameters.

For the genera with more than 0.4% contribution to the total abundance (Table 7) the following redundant groups were identified: *Microcystis*, *Pinnularia*; *Chroococcus*, *Stigeoclanium*; *Dactylococcopsis*, *Schitococcus*and*Chlamydomonas*; *Merismopedia*and*Coelosphaerum*; *Aphanocapsa*and*Oscillatoria*; *Eunotia*and*Melosira*; *Chlamydomonas*, *Schitococcus*, *Niztchia*and*Dinobryon*; *Volvox*, *Melosira*and*Ankistrodesmus*; *Gleocystis*and*Straustrum*; *Cosmarium*, *Peridinium*, *Ceratium*, *Eunotia*, *Navicula*, *Trachelomonas*,*Synedra*and*Pinnularia*. Genera that were not redundant were included in theordinations, and included *Aphanothece*, *Anabaenopsis*, *Scenedesmus*, *Zygenemopsis*,*Trachaelomonas*and*Nephrocytium*. From among the redundant groups, those included inthe ordinations were *Microcystis*, *Chroococcus*, *Dactylococcopsis*, *Merismopedia*,*Oscillatoria*,*Dinobryon*,*Melosira*,*Straustrum*,*Ceratium*,*Navicula*and*Synedra*. A total 18 genera with higher relative abundance and representing 58.5% of total phytoplankton abundance was used in the ordinations.

Table 5: Taxa with relative abundance > 0.4% identified in Chebaara Reservoir during the sampling period between December 2007-June 2008

Division	Genera	Within Group Relative Abundance
Cyanophyceae	*Microcystis*	8.60
	Dactylococcopsis	6.71
	Chroococcus	3.92
	Oscillatoria	1.59
	Gleocapsa	1.46
	Aphanothece	1.24
	Merismopedia	1.21
	Aphanocapsa	1.03
	Coelosphaerum	0.55
	Anabaenopsis	0.45
Bacillariophyceae	*Synedra*	2.39
	Navicula	1.81
	Melosira	1.51
	Pinnularia	0.90
	Eunotia	0.57
	Niztchia	0.46
Chlorophyceae	*Ankistrodesmus*	1.41
	Stigeoclonium	0.92
	Schitococcus	0.88
	Volvox	0.85
	Chlamydomonas	0.84
	Gleocystis	0.70
	Cosmarium	0.69
	Scenedesmus	0.67
	Zygnemopsis	0.67
	Nephrocytium	0.45
Crysophyceae	*Dinobryon*	5.85
Euglenophyceae	*Trachelomonas*	1.41
Pyraphyceae	*Ceratium*	15.32
	Peridinium	14.39
	Straustrum	1.33

Ordination results (Fig5) indicated that increased PO_4^{2-}, NO_3^-N and NH_4^+-N but reduced BODconcentration and secchi depth led to marked increase in *Ceratium* species, *Scenedesmus* species, *Mensmopedia*, *Nephrocytium*, *Anabenopsis* at station 6 and increase in *Straustrum*at station 4, but led to reduced abundance of*Chroococcus*,*Zygnemopsis*, *Dactylococcopsis*species, Dinobryon at stations 2 and 3. Increased PO_4^{2-}, NO_3^--N, NH_4^+-N, pH, DO, and led to marked decrease in abundance of *Synedra*, and *Dinobryon*, but increased abundance of *Trachelomonas*, *Navicula*, *Oscillatoria*.

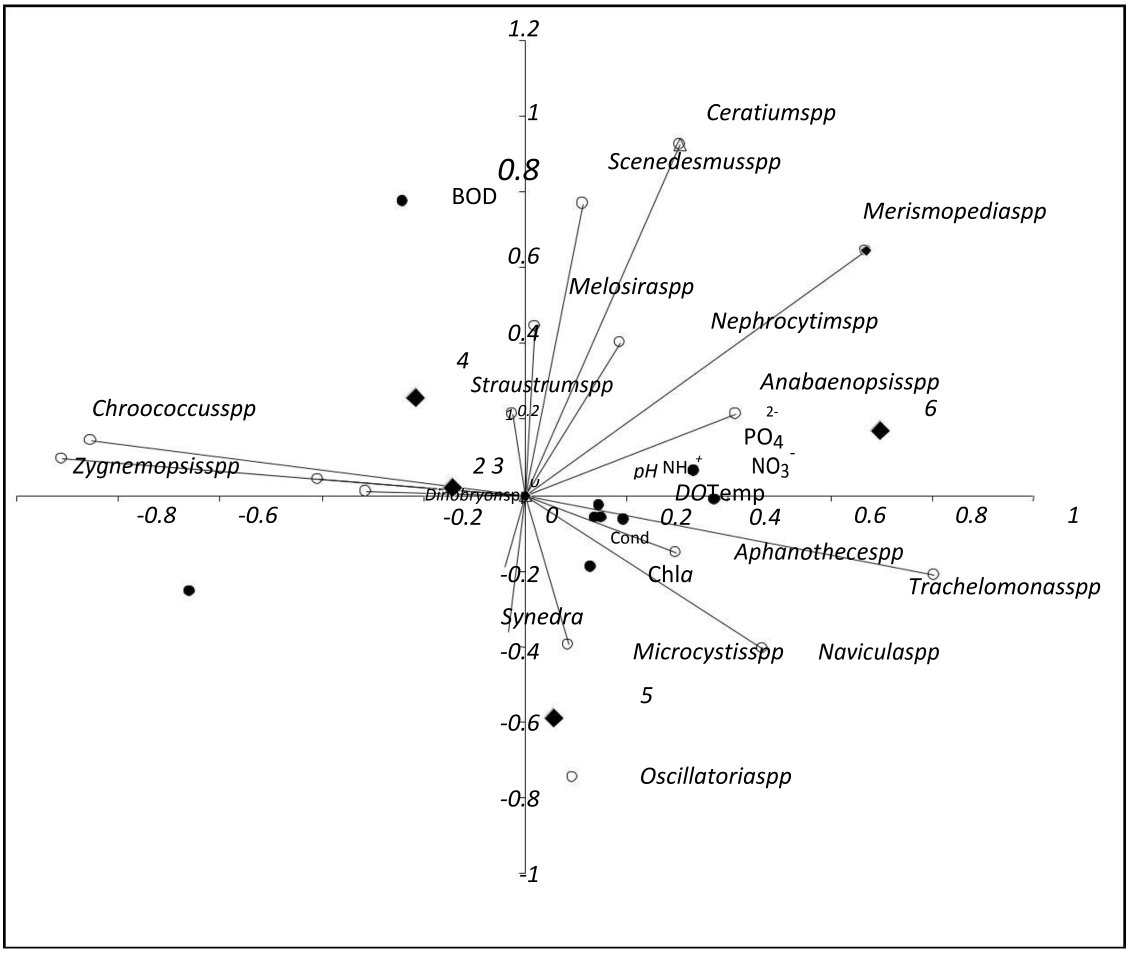

Figure 4:Biplot ordination for phytoplankton and physico-chemical factors at in Chebara Reservoir (Chl-a= Chlorophyll a; DO = dissolved oxygen;NH4+ = Ammonium; Temp = temperature; NO3-= Nitrates and BOD =Biological oxygen demand) (Author, 2008)

Increased PO_4^{2-}, $NO_3^-$and NH_4^+ but reduced BOD concentrations and secchi depth led to marked decrease in *Chroococcus*, *Zygnemopsis*, *Dactylococcopsis*, *Dinobryon* and *Synedra*. Increase in BOD favoured*Straurostrum*, *Dactylococcopsis*, *Chroococcus*and*Zygnemopsis*, but decrease in*Aphanothece*, *Trachelomonas*, *Microcystis*, *Navicula*and*Oscillatoria*. Increased PO_4^{2-}, NO_3^--N, NH_3-N, pH, temperature and conductivity led to marked decrease in *Aphanothece*, *Trachelomonas*, *Navicula* and, *Oscillatoria*, but decrease in population of *Chroococcus*, *Zygnemopsis*, *Dactylococcopsis*. High turbidity favoured growth of *Dinobryon* and *Synedra*, but led to decreased populations of *Ceratium*, *Scenedesmus*, *Merismopedia*, *Nephrocytium*and*Anabaenopsis*.

The correlation of various phytoplankton genera with various physico-chemical parameters of the reservoir is shown in Table 6 below. Most phytoplankton including *MicrocystisDactylococcopsis*, *Chroococcus*, *Oscillatoria*, *Aphanothece*, *Merismopedia*, *Anabaenopsis*, *Synedra*, *Navicula*, *Melosira*, *Scenedesmus*, *Zygnemopsis*, *Nephrocytium*, *Dinobryon*, *Trachelomonas*and*Ceratium*showed weak negative correlation with nitrate, ammonia, soluble reactive phosphorus, pH, conductivity, secchi depth, temperatureBOD and DO. Only *Straustrum* showed positive correlation with all the physico-chemical factors. *Microcystis* exhibited negative correlation with nitrate, ammonium, total phosphorus, pH, conductivity, secchi depth, temperature BOD and DO. However, agenerally weak negative correlation was observed.

Table 6: Spearman Rank Correlations between Phytoplankton and Various Physico-Chemical Parameters Investigated in the Sampling Period

Taxa	NO_3-N	NH_3-N	PO_4	pH	Conductivity	Secchi depth	Temperature	BOD	DO
Microcystis	-0.23	-0.64	0.12	-0.77	-0.23	-0.26	-0.09	-0.37	0.14
Dactylococcopsis	-0.73	-0.23	0.09	0.43	-0.49	0.43	-0.27	0.03	-0.83
Chroococcus	-0.12	0.20	-0.62	0.66	0.20	0.49	0.53	0.60	0.09
Spirulina	0.06	-0.35	0.37	0.54	-0.93	-0.09	-0.62	0.26	-0.60
Oscillatoria	0.06	-0.41	-0.68	0.14	0.17	-0.37	0.62	-0.60	-0.09
Aphanothece	-0.13	0.44	0.56	-0.32	0.28	-0.06	-0.40	-0.58	-0.32
Merismopedia	0.28	-0.16	0.55	-0.03	-0.62	-0.17	-0.63	0.32	-0.03
Anabaenopsis	0.70	-0.46	-0.25	0.31	-0.41	-0.66	0.09	-0.09	0.09
Synedra	-0.23	-0.93	-0.28	-0.37	-0.41	-0.31	0.18	-0.37	-0.03
Navicula	0.35	0.23	0.22	-0.60	0.52	-0.54	0.00	-0.83	0.20
Melosira	0.06	-0.35	0.37	0.54	-0.93	-0.09	-0.62	0.26	-0.60
Scenedesmus	-0.06	0.44	0.69	-0.29	-0.06	0.35	-0.58	0.52	0.17
Zygnemopsis	-0.52	0.58	-0.15	0.43	0.35	0.83	0.18	0.54	-0.14
Nephrocytium	0.58	0.76	0.10	0.53	0.36	-0.09	-0.05	0.09	0.00
Dinobryon	0.20	0.06	-0.28	0.94	-0.20	-0.09	0.09	-0.03	-0.54
Trachelomonas	0.38	0.28	0.55	-0.55	0.28	-0.55	-0.36	-0.75	0.03
Ceratium	0.06	0.46	0.93	-0.03	-0.29	0.14	-0.88	0.26	-0.26
Straustrum	0.23	0.986	0.28	0.08	0.64	0.25	-0.08	0.2	0.2

DISCUSSION

Based on results of correlations, nitrate-nitrogen, soluble reactive phosphorus, ammonium-nitrogen, pH, dissolved, BOD and conductivity all played a role in determining the community structure and composition of phytoplankton community in Chebara reservoir. High diversity of phytoplankton in Chebara reservoir positively correlates with availability of nutrients, high secchi depth and open nature of the reservoir which exposes it high irradiances. Phytoplankton abundance was greatest in March which was the beginning of long rains. The highest values of biomass were recorded at the end of the dry season and during the transition period which corresponds to the period when mineral nutrients are flushed from the catchment into the reservoir. Thomas, *et al*., (2000) reported that phytoplankton abundance and productivity in tropical reservoirs is usually rain induced .The rain water drains from land deposits nutrients, suspended solids and algal cells (or resting/reproductive stages) into the water body, or in some cases may brings nutrient dilution effect (Phlips, *et al*., 1997; Kalff, 2002).

Many genera of cyanophytes and chlorophytes occurred in patches and at low densities. Hutchinson (1961) noted the paradox of phytoplankton in which 10-50 species appear to coexist within apparently uniform water body. Studies suggest that several species can coexist in equilibrium, even with very slight spatial and temporal nutrient variations, provided that each species is limited by a different factor or resource (Hutchinson *et al*. 1970; Platt & Denham (1980).

The dominance of diatoms is typical of tropical rivers (Wood and Talling, 1988; Alfred-Ockiya and Otobo, 1990). Diatoms were most abundant in wet season and at station 6 which was close to the inlet of the main river. During wet season mixing of water and wash outs may occur during which time diatoms receive shortly pulsed external sources of silica. These nutrients have been known to be limiting to phytoplankton growth (Harris& Baxter, 1996). Station six also showed high turbidity, resulting in low light intensities in water. Diatoms have high sedimentation rates and are physiologically situated to grow under deep and mixed waters which also have low light conditions (Harris and Baxter, 1996) where silica is available. Therefore greater frequencies of diatoms respond to increased flows, as in the inlet and outlet regions (Krammer and Lange-Bertalot, 1991). Significant abundance of diatoms was also observed at station 1 in which the water column was deep and clear

(Harris and Baxter, 1996). Station 6, being located in riverine zone of the reservoir, was showed higher inputs of nutrients coming from rocks and sediments. The dominance of *Melosira* and *Synedra* was probably due to high pulses of silica and sulphate especially abundant during the rains. Other diatoms such as *Navicula*, *Synedra*, Nitzchia,*Eunotia*and*Pinnularia*were observed to occur at low densities. Ofthe diatoms listed, *Pinnularia* and *Eunotia* showed the least abundance are associated with low water pH, and their limited occurrence may be linked to high pH (Krammer and Lange-Bertalot, 1991). Both *Synedra* and *Melosira* species are associated with waters containing high concentrations of DO, low concentrations of BOD and lowconcentrations NH_4^+, $PO_4^{2-}$and nitrates (Krammer and Lange-Bertalot, 1991; Alfred-Ockiya and Otobo, 1990). *Navicula* and *Niztchia species* flourish in alkaline waters having low DO, and high BOD but are also tolerant to eutrophication (Steinberg and Schieffele, 1988). However, since diatoms are basically benthic, they showed generally low abundance in the plankton.

The occurrence of nitrates and phosphates may have caused the abundance of chlorophytes and cyanophytes. These nutrients have been known to be limiting to phytoplankton growth (Talling and Lemoalle, 1998). In waters with high nutrient status, cyanophytes can proliferate and form blooms (Reynolds, 1984). But low populations of cyanophytes were observed due to low nutrient status of the reservoir. *Microcystis* was the most abundant of all cyanophytes, being favoured by relatively strong build up of ammonium and phosphates but low concentrations of NO_3^-. Other cyanophytes that occurred in low concentrations of NH_4^+ include *Chroococus* and *Aphanothece*(Blomquist *et al*, 1994; Reynolds, 2006). A high abundance of cyanophytes was observed during the dry season. However, chlorophytes showed higher species diversity and higher spatial distribution. Dry seasons were also characterized by relatively high concentrations of NH_4^+ but low concentrations of phosphates. Studies have revealed that in reservoir discharges with low N:P, nitrogen becomes limiting, providing a competitive advantage for N-fixing forms of cyanophytes over chlorophytes (Webster *et al.*, 1996). *Microcystis*can also flourish in low nitrogen supply (Reynolds, 1999). This wasdemonstrated by the high relative abundance of members of cyanophytes over the chlorophytesin the reservoir. Only few desmids were identified in the reservoir. Desmids prefer brackish and highly saline conditions (Opute, 2000) as opposed to Chebara reservoir whose water was fresh and oligotrophic.

Chebara reservoir has a mean water depth of 45 meters and clear, and may have favouredcyanophytes at stations 1, 2 and 3. Depth of water determines the extent of light penetration and mixing of water mass and consequently survival and growth of phytoplankton. Many cyanophytesposses buoyancy mechanisms and are able to control their vertical position in the water column (Harper, 1992; Vanni, 1999).

Scenedesmus and *Ankistrodesmus* multiply in high concentrations of organic nitrogen (NH_4^+), but low concentrations of NO_3^- and are capable of converting nitrate into NH_4^+ (Opute, 2000). Highest mean concentrations of ammonium nitrogen were recorded in stations 1 and 2 and the lowest at station 3. Relatively high mean concentrations of ammonium nitrogen were also recorded at stations 4 and 5. *Ankistrodesmus* showed highest abundance at stations 1 and 6 while, *Scenedensmus*showed highest abundance at station 4, and patchiness in station 1 (Table 3). Station 6 the highest PO_4^{2-} level, and never favoured these algae (Table 3).

Both station 2 and 6 had a lot of vegetation. Chrolococcales such as *Scenedesmus*, *Chlorella*, *Oocystis* and *Tetraedron* were in greatest abundance in these stations. These phytoplankton may be epipelic or epiphytic and flourish in neutral waters that are rich in organic phosphorus and nitrogen (Scheffer, 1998; Simciv, 2005). The same environments also favour the growth of cyanophytes such as *Microsystis*, *Aphanizomenon*, *Anabaena* and *Gleotrichia*, *Chroococcus*and*Coelosphaerum*which are known to pref were er anoxic conditions with high NH_4^+concentration. Pyraphytes such as *Straustrum* were also observed at these stations.

Spatial variability is a structural character of an ecosystem and allows for complex population interactions involving energy transfer, competition, predation, nutrient depletion, death /sinking and niche formation (Reynolds, 2006). It is therefore expected that less disturbed stations exhibit higher species diversity, with evenly distributed taxa (Kling *et al*., 2001; Jones *et al*., 2001, Death, 2004).

Although there was observed seasonal variation, it is noteworthy that most phytoplankton genera showed similar growth patterns throughout the study period. In general diatoms dominated the colder nutrient- rich waters such as at station 6, chlorophytes were more abundant in warmer oligotrophic waters and dinoflagellates appeared to grow in intermediate environmental conditions. Perodicity was clear, with peaks followed by lows. Many algal cells can sink, permanently from the water column. At the bottom they utilize all oxygen and since they do not receive sufficient light for photosynthesis, the cells die. Death and decay cause oxygen depletion bringing about anaerobic conditions in the hypolimnion. Detritus in the hypolimnion is dense with rich supply of nutrients but beyond reach by phytoplankton. The phytoplankton then receives limited nutrients and their growth rate is reduced, till mixing occurs, or water levels reduce as in dry seasons (Chalar, 2002).

The productivity of Chebara reservoir was low as estimated by chlorophyll-*a*, suggesting oligotrophy. Low concentrations of chlorophyll-*a* at station 2 corresponded with low BOD concentrations, indicating relatively low primary productivity at this station. This could be attributed to the shading effect of terrestrial and some aquatic vegetation that was in both stations. Depth of water is an important diving force in nutrient dynamics of a reservoir. Shallow lakes and reservoirs are generally more productive (Thomas, 2000). In some shallow lakes, resuspension events are correlated with increases in phytoplankton biomass as estimated by chlorophyll-*a* (Schelske*et al*., 1995; Hamilton and Mitchell, 1997; Ogilvie and Mitchell, 1998). Mixing can result from the entrainment of meroplankton into the water column (Schelske*et a*l., 1995), and nutrients deposited in the lower regions of the lake are brought up to the photic zone, being available for phytoplankton growth On the contrary, deep lakes tend to be oligotrophic (Kotut*et al*., 1998). The water volumes are high, mixing is limited if not rare and thermal stratification normally occurs. This leads to algal growth confined only within the epilimnion. The hypolimnion remains rich in nutrients, but beyond reach of phytoplankton. Chebara reservoir is also characterised by narrow littoral and sublitoral zones, but an extensive profundal zone. This reservoir generally supports a lot of green algae and diatoms, supports a lot of green algae and diatoms, but with marked patchiness.There was negative correlation between transparency and most of phytoplankton. Increased transparencies favoured*Dactylococcopsis*, *Chroococcus*, *Scenedesmus*, *Zygnemopsis*, *Ceratium*and*Straustrum*. . Higher transparency may have allowed for grazing (Reynolds, 2006). In dry season, phytoplankton proliferate and competition for nutrients may ensue (Grover and Chrzanowski, 2004) Genera with low adaptability to utilise nutrients even at low concentrations become reduced.

Physico-chemical Parameters in Chebara Reservoir

The physical and chemical conditions of the Chebara reservoir show homogeneity on spatial and temporal scales. According to Scheffer (1998) these conditions often interact to determine the productivity nature and make up the assemblage of the autotrophic organisms. Chebara water showed oligotrophy in relation to phytoplankton assemblage and abundance.

Temperature of a water body influences the occurrences, and intensities of occurrence, of other parameters such as DO, conductivity and total alkalinity (Kalf, 2002). Temperatures were generally medium, a high of 20°C and low of 18 ºC and similar for all the stations and times of sampling. Temperatures of this reservoir are falls within the same range asthose recorded in many East African lakes that include Lake Victoria (Lunganyia*et al*, 2000), Lake Tanganyika (Kimereri*et al*., 2005), Lake Turkana (Burgis and Morris, 1987) and Lake Naivasha (Kitaka,1991), Turkwell Gorge (Kotut, 1998). The low temperatures of 18 ºC recorded are due to the location of the reservoir in a forest causing low insulation, its situation in high altitude where atmospheric temperatures low. Presence of outlet leads to water losing heat as it flows out of the reservoir. Temperature of a water body also influences the occurrences, and intensities of occurrence, of other parameters such as DO, conductivity and total alkalinity (Kalff, 2002).

The pH of the reservoir is neutral to slightly alkaline. This value is falls within the same range as the pH of deep tropical lakes such as Lake Victoria (Lunganyia*et al*., 2000) and Lake Tanganyika (Kimirei*et al*., 2005). According to Kalff (2000), spatial variations of pH within the same water body can be attributed to the combined effects of both phytoplankton population and nutrient condition. In shallow alkaline nutrient-rich water bodies, high phytoplankton population with subsequent high biomass allows the removal of large quantities of CO_2 and HCO_3^- in the daytime (Lewis, 2006). Significant shifts inpH could be caused by variations in water volumes that influence the extent of dilution of dissolved chemicals (Reynolds, 1998; Kalff, 2002; Lewis, 2006). Most lakes are basic (alkaline) when they are first formed but become more acidic with time due to the build-up of organic materials (Menden-Deuer and Lessard, 2000). As organic substances decay, carbon dioxide (CO_2) forms and combines with water to produce a weak carbonic acid.

The minor inlet river at station 3, which drains through open agricultural and settlement land, showed the highest pH. This variation could be attributed to changes in thechemical composition of water within the catchment area. Forests acts as filters and purifiers and as such could alter or correct the pH of waters that drain through them (Angeler*et al*., 2000).

This could explain the relatively low pH values recorded at stations 5 and 6. Station six also recorded the lowest abundance of cyanophytes. According to Harris and Baxter (1996), the abundance of cyanophytes becomes reduced at low pH levels. This could explain the observation made in Chebara reservoir.

Conductivity was low and fairly uniform for all the sampling stations, suggesting that the reservoir draws from smaller catchment and short water retention time. This finding concurs with findings from African lakes (Burgis and Morris, 1987). Variations in conductivity may be brought about by precipitation and discharge of water into a reservoir (Kalff, 2002). This is because the water discharged from a drainage basin often reflects the activities being carried out in the basin and its intrinsic characteristics. Harris (1986) also observed that larger catchments usually yield larger conductivity and alkalinity values as compared to smaller catchments. This is mainly because large catchments have many different land features, are exposed to evapo-transpiration over a long time, often drain across intensely disturbed land surfaces and posses greater contact between run-off and rock surfaces (George and Hewitt, 2006).

The spatial and temporal variation in nutrient was minimal within the reservoir. Soluble reactive phosphorus status of phosphorous was heterogeneous, concentrations being similar and slightly higher for April and June, but lower for February and March. Mean concentration of soluble reactive phosphorus an indicator mainly of living and non-livingP, decreased from a high of 0.01 µg millilitre^{-1}(station 6) to a low of 0.007 µg millilitre^{-1}(station 1, 3 and 5). These results strongly suggest that external loading by incoming water as observed at station 6 also contributed to phosphorus of this reservoir (Sanchez-Carrilo*et al*., 2000a). High soluble reactive phosphorus concentrations at station 6 with a corresponding small secchi depth suggested that there was greater contact, and therefore a frequent exchange of phosphorus between water and sediment. Nitrate- nitrogen and ammonia-nitrogen concentrations were greater than concentrations of soluble reactive phosphorus, indicating that phosphorus was limiting in the entire reservoir. This study confirmsprevious studies that P is limiting in tropical waters (Reynolds, 1999; Sanchez-Carrilo*et al*., 2000; Reynolds, 2001). Phosphorus in deep aquatic ecosystems is adsorbed on sediments, on solids suspended in water or in insoluble salts. Thus in deep waters reservoir, phosphorus can only be available if mixing occurs. However, it has been established that a great proportion of phosphorus in East African fresh waters comes from atmosphere rather than from sediments (Cole et al., 1990; Schindler et al. 2008).

Higher DO concentrations at station 1 compared to stations 3, 4 and 6 (main inlet) is likely to result from the effect of mixing at stations 1, 3 and 6, and possibly from atmospheric inputs. High DO at station 4 corresponds to high productivity at station 4 (Table 2) (Death, 2004). Station 1 is open waters at the reservoir's outlet and higher DO concentrations at this station could possibly be from atmospheric inputs into the turbulent water as it flows through the outlet, and the high primary productivity that leads to liberation of oxygen. The highest BOD concentrations were recorded at station 4 and the lowest at station 5. This may be explained by biochemical utilization of DO along the river channels at sample stations 3, and 4. Station 3, which drains open agricultural andsettlement lands, had low DO. Death (2004) reported that catchments with high human activity tend to increase BOD caused by respiring soil flora and fauna and by marked inputs of phosphates and nitrates in run-off from farm fields (George and Hewitt, 2006).grazing by zooplankton, and depletion of nutrients leading to reduced densities at different stations. (Harris*,* 1996)

Trophic state indices based on phytoplankton chlorophyll-*a* concentrations, secchi depth and phosphorus concentrations indicate that the reservoir is oligotrophic. It also indicates that phytoplankton growth in the reservoir is more likely to be limited by availability of P than N. Thus, small increases of phosphorus in the reservoir could stimulate phytoplankton to produce even blooms, whereas increases in N may not. Nuisance conditions associated with phytoplankton diversity and productivity were absent probably due to the reservoir's oligotrophic status.

The results indicated low BOD concentrations, suggesting oligotrophic fresh water bodies that support many species of chlorophyceae and fresh water diatoms (Krienitz*etal*., 1998; Kimirei *et al*., 2005). The results also indicated that P is probably the limitingfactor in phytoplankton growth in the reservoir. The results of this study correspond with results obtained earlier in fresh waters by Ryther and Danstan, 1971. In their study, they concluded that lower concentrations of P in fresh waters inhibited growth of phytoplankton.

Mean concentration of phosphorus, an indicator mainly of living and non-living P, decreased from a high of 0.01 µg millilitre^{-1} (station 6) to a low of 0.007 µg millilitre^{-1}(stations 1,3 and

5). This pattern is probably due to sedimentation of organic and inorganic particles in the three stations. These stations are sheltered from strong winds.

Spearman rank correlations results suggested such factors as temperature, nutrient dynamics, sechi depth, pH, conductivity BOD and DO as some of the factors possibly contributing to phytoplankton depletion in dry seasons. Different correlations existed between the phytoplankton and the physico-chemical parameters of the reservoir. Temporal negative correlations with temperature and transparency for most genera were an indication that the phytoplankton and leading to their reduced occurrence. Higher transparency may have allowed for grazing (Reynolds, 2006). In dry season, phytoplankton proliferate and competition for nutrients may ensue (Grover and Chrzanowski, 2004) Genera with low adaptability to utilise nutrients even at low concentrations become reduced.

CONCLUSION

Trophic state indices based on median phytoplankton chlorophyll-a concentrations, median secchi disk transparencies and median TP concentrations indicate thatChebara reservoir is a moderately warm, oligotrophic and low in N and P. The results indicated that low BOD levels observed indicate high water quality characteristics of oligotrophic fresh water bodies which support high species diversity of chlorophyceae and fresh water diatoms. Based on results of correlations, NO_3, TP, NH_3-N, pH, DO, BOD and conductivity all played a role in determining the and composition of phytoplankton community in Chebaara reservoir. The study also indicates that phytoplankton growth in the reservoir is more likely to be limited by availability of P than N. Thus, small increases of p in the reservoir could stimulate phytoplankton to produce even blooms, whereas increases in N may not. This study provides information on the phytoplankton community composition as influenced by environmental parameters, and can form a basis for further research on the reservoir.

RECOMMENDATIONS

It is important to note that for effective water quality monitoring of Chebara reservoir, the tributaries that contribute water directly to the reservoir should be selected as monitoring stations. For this reason stations 3 and 4 were selected. This site is at the points where the tributaries empty their water into the reservoir. This study provides information on the phytoplankton community composition as influenced by environmental parameters, and can form a basis for further research on the reservoir. The results obtained here also form a benchmark for management of reservoir catchment.

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