Variation of water quality and phytoplankton along different zones of Aswan High Dam Reservoir

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ABSTRACT

This study was carried out at Aswan High Dam Reservoir and focused on the spatial variation of water quality parameters and phytoplankton composition. Water samples were collected from eighteen sampling stations, where six stations for each of the different zones were selected to represent the lacustrine, transition and riverine zones of the reservoir during 2007 and 2008.

The results of the environmental factors showed wide variations in their concentrations along the different zones of the reservoir.

In this study, chlorophyll *a* concentration was lower in the lacustrine zone than in the riverine, although turbidity and secchi depth values were all optimal for light availability. This result was influenced by higher abundances in the reservoir phytoplankton assemblages where riverine conditions predominate, by species tolerant to turbulent conditions and typical high mineral turbidity. Calculation of the trophic state index showed that riverine and transition zones are classified as eutrophic, while lacustrine zone is mesotrophic. Phytoplankton composition recorded thirty nine species belonging to Chlorophyceae (19 species), Cyanophyceae (10 species), Bacillariophyceae (7 species), and rare groups including Dinophyceae (2 species) and Eugelnophceae (1 species). Cyanophyceae were the most encountered group in the lacustrine and transition zones, while Bacillariophyceae were most encountered group in the riverine zone. This is due to that Cyanophyceae prefer the steady, transparent and low nutrients water (lacustrine), while Bacillariophyceae prefer flowing, turbid and nutrient-rich water (riverine).

Statistical analysis showed that certain environmental factors do affect the phytoplankton growth. The results of the one-way ANOVA revealed that the different environmental factors (DO, water temperature, secchi depth, water velocity, turbidity, nitrate, phosphorus, magnesium, total dissolved solids, and trophic state index) and biotic factors (such as chlorophyll *a* and phytoplankton groups) were significantly different at the three zones of Aswan High Dam Reservoir ($p<0.05$). This result supports the speculation of variation in water quality and phytoplankton along the different zones of the reservoir.

Keywords: water quality, phytoplankton, lacustrine, transition, riverine

INTRODUCTION

Reservoirs are designed and operated to control the flow of rivers to achieve flood control, water storage, power generation, irrigation, navigation and other beneficial uses. They are considered as hybrid systems between rivers and lakes (Collier *et al*., 1998), because they exhibit a progressive transformation from lotic systems (riverine) to lentic or lake systems (lacustrine). Aswan High Dam Reservoir which was formed in the 1960s by the construction of the High Dam in order to control the annual floods of the Nile River is considered the strategic water bank for Egypt. It extends for about 350 km along Egyptian land, and 150 km in the Sudan with storage capacity of 162 billion cubic meters between levels of 83 to 182 meters above sea level.

Building the High Dam across the Nile River, and impounding water behind it, caused profound changes in the limnological regime of the waterbody. These included chemical and physical changes, that in turn affected the flora and fauna of the regulated waterbody (Reynolds, 1997). There are considerable increases or decreases in the values of many physico-chemical and biological parameters (*e.g*., minerals, composition and number of planktonic organisms), which is in contrast to undisturbed reservoir zones (Stanford and Ward, 2001).

Reservoirs exhibit a large degree of spatial heterogeneity in phytoplankton productivity and biomass as a result of longitudinal gradients in basin morphology, water residence time, flow velocity, suspended solids, and availability of light and nutrients. A typical reservoir commonly has three distinguishable zones along its longitudinal axis (Kimmel *et al*., 1990 and Wetzel, 1990).

1. The riverine zone which is characterized by higher flow, shorter water residence time, and higher levels of available nutrients, suspended solids, and light extinction relative to downstream portions. Abiogenic turbidity will often limit light penetration, thereby limiting the thickness of the photic layer. A real primary productivity is often light limited.
2. The transition zone, characterized by high phytoplankton productivity and biomass. This occurs in conjunction with increasing breadth of the basin, decreasing flow velocity, increased water residence time, sedimentation of silt and clay particles from near-surface waters, and increased light penetration. The transition zone can be considered as the most fertile region of a reservoir, because both light and nutrients are available for algal photosynthesis.
3. The lacustrine zone which occurs nearest the dam and usually has the longest water residence time. It also exhibits lower concentrations of dissolved nutrients and suspended abiogenic particles, higher water transparency, and a deeper photic layer. However, the volumetric phytoplankton productivity of the photic zone is reduced, often by nutrient limitation, during most of the growing season, and is supported mostly by *in situ* nutrient cycling rather than by advected nutrients.

Each of these zones has distinct biotic, physical, and chemical characteristics.

The main goals of this study were to describe changes in the general character of water quality and phytoplankton in the Aswan High Dam Reservoir, and to study the effect of physico-chemical parameters on phytoplankton density along the different zones of the reservoirs.

METHODOLOGY

In order to study physical, chemical and biological longitudinal gradients in the Aswan High Dam Reservoir, eighteen sampling stations were established from the river inflow to the dam, where six stations were selected to represent the riverine (from station 1 to station 6), transition (from station 7 to station 12) and lacustrine (from station 13 to station 18) zones (Table 1 & Figure 1). At every station, integrated water samples were collected from the euphotic zones for physical, chemical and biological analysis.

Table 1: Sampling stations and site name along the different zones of the reservoir.

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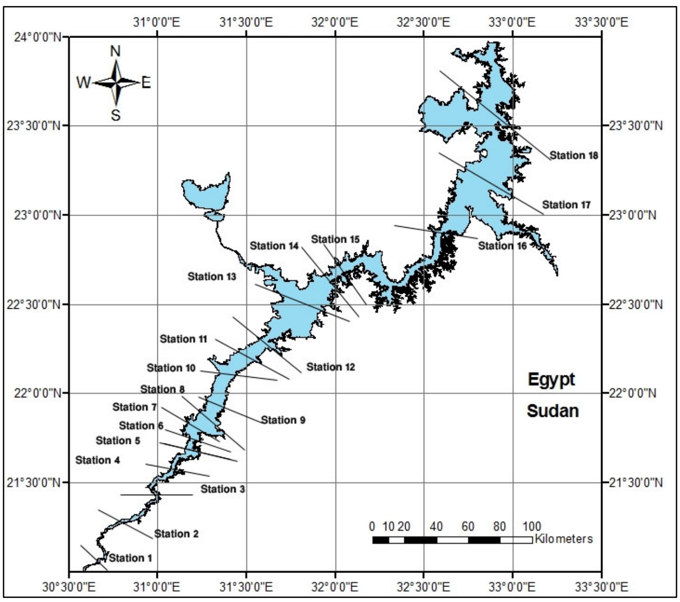

Fig. 1: Sampling stations along the Aswan High Dam Reservoir.

Environmental factors

The following limnological variables were determined twice in winter (once during 2007 and the other during 2008) at all stations: water temperature (ºC, by digital thermometer), turbidity (NTU, HacH 2100 portable turbidimeter), water transparency (m-by secchi disk with 30 cm diameter), flow velocity (ms^{-1} by current meter-Valeport BFM 108 MK11), pH (portable pH meter- WTW), dissolved oxygen (mg l^{-1}, by portable oxygen meter WTW Oxi 197), total dissolved solids (TDS) (mg l^{-1}- gravimetric method based on evaporation), nitrate (mg l^{-1}, nitrate selective electrode method using Orion 940), total phosphorus (mg l^{-1}- stannous chloride method) and magnesium hardness (mg l^{-1}- EDTA titrimetric method).

Biotic factors

Chlorophyll *a* (Chl.-*a*) was extracted in 90% hot methanol and measured colorimetrically at the different wave lengths using spectrophotometer - HacH 2400 and applying trichromatic equation as reported in SCOR/UNESCO, (1991).

A trophic state index (TSI) was used to assess the trophic state of the reservoirs zones (Carlson's, 1977). TSI values range from 0 to 100. TSI in this study was calculated independently from Secchi depth in meter and chlorophyll *a* as μgl^{-1}. The average value of TSI classified the reservoir to Oligotrophic (<40), Mesotrophic (40-50), Eutrophic (50-70) or Hypertrophic (>70).

Phytoplankton samples were obtained by vertical net hauls, using conical plankton net of 20µ mesh size, 30 cm mouth diameter and 80 cm length from the euphotic zone at each site. The collected samples were kept in glass bottles, and preserved with drops of Lugol's Iodine solution. The standing stock of phytoplankton organisms was calculated as follow:

$$\text{Number of organisms } m^{-3} = \frac{N \times D}{Sb \times \pi \times r^2 \times C}$$

where, N: the mean total number of phytoplankton in the samples, D: the volume of the concentrated sample (100-150 ml), Sb: the sub sample volume (1-3 ml), π: the constant factor = 3.14, r: the plankton net radius (0.15 m), C: water column depth (m).

Most phytoplankton species were identified to species and genera with an optical microscope. Abundance of phytoplankton cells was observed with an inverted microscope. All these analyses were performed according to APHA *et al*. (1992).

Statistical analysis

Correlation matrix and one way analysis of variance were applied on the data using Minitab 12 for windows.

RESULTS

Environmental factors

The average values of environmental factors affecting the phytoplankton growth in the different zones of the reservoir are presented in Table (2) and Figure (2).

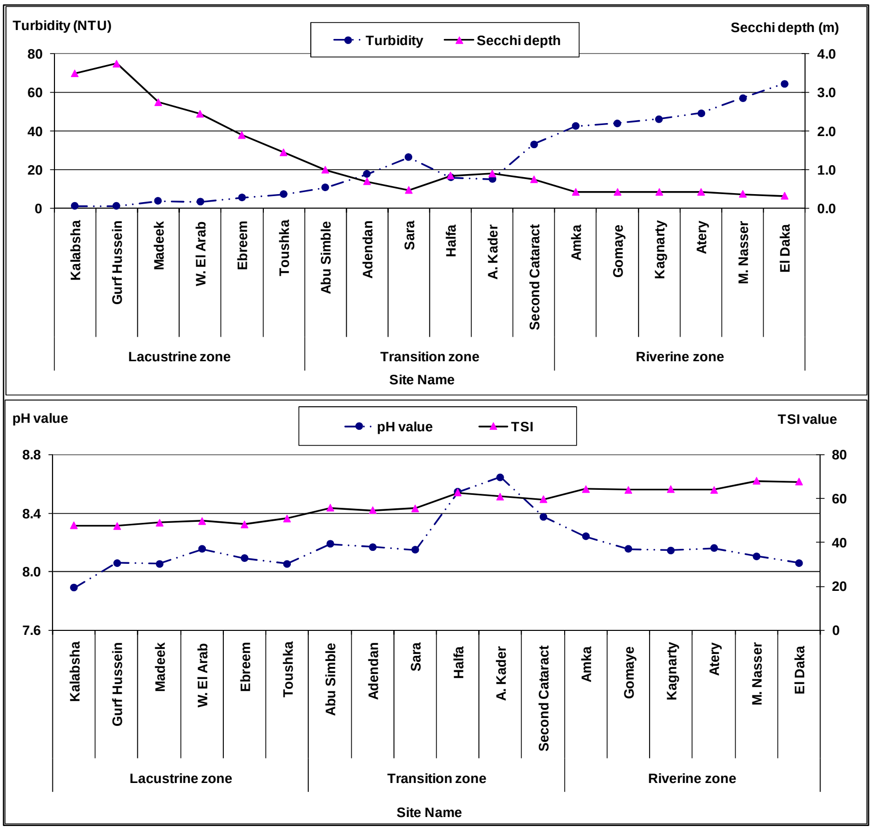

Fig. 2: Variation of the average water quality factors along the different zones of the Aswan High Dam Reservoir.

Riverine zone extends from the inflow (El Daka at km 488) to (Amka at km 364) includes six stations. Water temperature values were found in the range 18.25-19.55 ºC (mean 18.91±0.44). Water turbidity were found in the range 42.6-64.5 NTU (mean 50.68±8.5213) and secchi disk depths were found in the range 0.33-0.43 meters (mean 0.41±0.047). Water velocity ranged from 0.12-0.26 ms^{-1} (mean 0.193±0.054). pH values were found in the range of 8.06-8.24 (mean 8.15±0.06), representing alkaline system. Dissolved oxygen concentration was found in the range of 8.64-9.16 mg l^{-1} (mean 8.89±0.22). Total dissolved solids were found in the range134-135 mg l^{-1} (mean 134.8±0.61), indicating low concentrations of current conducting compounds or other analogous material. Nitrate concentrations were found in the range 0.88-1.36 mg l^{-1} (mean 1.01±0.18), while total phosphorus (TP) were found in the range 0.24-0.38 mgl^{-1} (mean 0.33±0.050). Magnesium concentration ranged between 7.92-8.4 mgl^{-1} (mean 8.16±0.215). Chlorophyll *a* value was found in the range 12.65-23.9 mgl^{-1} with mean 15.92±4.4461. Trophic state index ranged between 63.90 and 67.93 (mean 65.37±1.90), classifying the segment as eutrophic, indicative of excessive primary productivity and nutrient conditions.

The transition zone extends from Second Cataract (km 357) to Abu Simble (km 281) including six stations.

Water temperature was found in the range 18.5-21.2 ºC (mean 20.12±0.98). Water turbidity was found in the range 10.95-33.23 NTU (mean 20.00±8.28) and secchi disk depth was found in the range 0.48-1.00 (mean 0.78±0.18). Water velocity was found in the range 0.071-0.130 ms^{-1} (mean 0.104±0.020). pH values was found in the range of 8.15-8.65 (mean 8.35±0.21), representing alkaline system. Dissolved oxygen was found in the range of 8.84-9.54 mg l^{-1} (mean 9.12±0.28). Total dissolved solids ranged from 134-144 (mean 138.17±3.44), indicating low concentrations of current conducting compounds or other analogous material. Nitrate was found in the range 0.87-1.58 mg l^{-1} (mean 1.06±0.30), while total phosphorus (TP) was found in the range 0.28-0.42 mg l^{-1} (mean 0.33±0.05). Magnesium concentration ranged between 8.16-10.08 mg/l (mean 9.12±0.816). Chlorophyll *a* value among the stations was found in the range 2.75-27.5 mg l^{-1} (mean 12.68±9.8). Trophic state index was found in the range 54.66-62.71 (mean 58.24±3.33), classifying this segment as eutrophic, indicative of excessive primary productivity and nutrient conditions.

The lacustrine zone extends from Toushka (km 247) to the Dam including six stations.

Water temperature was found in the range 21.85-23.3 ºC with mean 22.41±0.52. Water turbidity was found in the range 1.34-7.54 NTU (mean 3.84±2.43) and secchi disk depth was found in the range 1.45-3.75 meters (mean 2.63±0.89). Water velocity was found in the range 0.07-0.13 ms^{-1} (mean 0.08±0.014). pH values were found in the range of 7.89-8.09 (mean 8.05±0.32), representing a slightly alkaline system. Dissolved oxygen was found in the range of 8.21-8.82 mg l^{-1} (mean 8.55±0.27). Total dissolved solids ranged from 146-164 mg l^{-1} (mean 151.5±6.72), indicating moderate concentrations of current conducting compounds or other analogous material (salts) in this segment.

Nitrate concentration was found in the range 0.32-0.93 mg l^{-1} (mean 0.69±0.24), while the average total phosphorus (TP) was found in the range 0.12-0.27 mg l^{-1} (mean 0.19±0.06). Magnesium concentration ranged between 10.32-11.28 mg/l (mean 10.76±0.353).

Chlorophyll *a* value was found in the range 5.5-11.0 mg l^{-1} (mean 8.54±2.76). Trophic state index was found in the range 47.51-50.97 (mean

48.91±1.32), classifying the segment as mesotrophic, indicative of moderate primary productivity and nutrient conditions.

Table 2: Variation of the average water quality factors along the different zones of the Aswan High Dam Reservoir.

Station	Site Name	Temp. (ºC)	Velocity (m/s)	DO (mg/l)	NO_3 (mg/l)	Total-P (mg/l)	TDS (mg/l)	Mg (mg/l)	Chl *a* (mg/l)
	Riverine Zone:								
1	El Daka	19.55	0.260	9.16	1.36	0.32	135	7.92	18.40
2	Malikel Nasser	18.90	0.230	8.71	0.99	0.38	135	8.40	23.90
3	Atery	19.05	0.220	8.64	0.88	0.36	134	8.16	12.65
4	Kagnarty	18.65	0.190	8.73	0.92	0.24	134	8.40	13.55
5	Gomy	18.25	0.140	8.99	0.95	0.33	136	7.92	12.90
6	Amka	19.05	0.120	9.11	0.95	0.37	135	8.16	14.10
	Transition Zone:								
7	Second Cataract	20.60	0.130	9.36	0.88	0.28	136	8.40	12.30
8	Abdel Kader	19.85	0.110	9.54	1.58	0.29	137	8.88	21.00
9	Halfa Doghaim	18.50	0.110	9.11	1.28	0.30	137	8.16	27.50
10	Sara	19.70	0.071	9.01	0.87	0.42	138	9.12	2.75
11	Adendan	20.85	0.106	8.84	0.88	0.37	140	10.08	4.00
12	Abu Simble	21.20	0.094	8.84	0.88	0.32	144	10.08	8.50
	Lacustrine Zone:								
13	Toushka	21.85	0.100	8.73	0.93	0.27	146	10.56	5.50
14	Abreem	22.65	0.080	8.78	0.88	0.24	147	10.56	4.75
15	Wadi Al-Arab	23.30	0.070	8.82	0.79	0.16	149	10.32	9.50
16	El Madeek	22.15	0.070	8.24	0.73	0.14	151	10.80	9.50
17	Gurf Hussein	22.45	0	8.34	0.47	0.12	161	11.28	11.00
18	Kalabsha	22.40	0	8.21	0.32	0.18	164	11.04	10.50

Phytoplankton composition

Thirty nine species belonging to three main groups in addition to some rare groups were recorded in this study. Chlorophyceae was the most diversified group (19 species), followed by Cyanophyceae (10 species), Bacillariophyceae (7 species) and two rare groups which include Dinophyceae (2 species) and Eugelnophceae (1 species). The different groups were abundant in the reservoir zones with different ratios as shown in Table (3) & (4).

Table 3: The average numbers and percentages of the different phytoplankton groups along the different zones of the Aswan High Dam Reservoir.

Phytoplankton group	Riverine		Transition		Lacustrine	
	$cell*10^4l^{-1}$	%	$cell*10^4l^{-1}$	%	$cell*10^4l^{-1}$	%
Bacillariophyceae (Bacil)	77817.5	85.95	36099	40.24	394	17.02
Chlorophyceae (Chloro)	5253	5.8	2258.5	2.52	379.5	16.39
Cyanophyceae (Cyano)	5946	6.57	50610.5	56.42	1523.5	65.81
Rare groups	1522.5	1.68	741.5	0.83	18	0.78
Total (T Phyto)	90539	100	89709.5	100	2315	100

Table 4: Taxonomic composition of the phytoplankton in Aswan High Dam Reservoir.

Species	Riverine	Transition	Lacustrine
Bacillariophyceae:			
Cocconies sp.	-	-	+
Cyclotella sp.	+	+	+
Gomphonema sp.	-	+	+
Melosira sp.	+	+	+
Navicula sp.	+	+	+
Nitzschia sp.	+	+	+
Synedra sp.	+	+	+
Chlorophyceae:			
Ankistrodesmus sp.	-	-	+
Botryococcus sp.	-	+	+
Coelastrum sp.	+	+	+
Cosmarium sp.	+	+	+
Crucigenia sp.	+	+	+
Dictyosphaerium sp.	+	+	+
Eudorina sp.	+	+	+
Nephricytium sp.	-	-	+
Oocystis sp.	+	+	+
Pandorina sp.	-	+	+
Pediastrum sp.	+	+	+
Scenedesmus sp.	+	+	+
Schroederia sp.	+	+	-
Staurastrum sp.	+	+	+
Tetraedron sp.	+	+	-
Volvox sp.	+	+	+
Westella sp.	-	-	+
Quadrigula sp.	+	+	+
Spirogyra sp.	+	+	-
Cyanophyceae:			
Anabaena sp.	+	+	+
Aphanizomenon sp.	+	-	-
Chroococcus sp.	+	+	+
Lyngbya sp.	-	+	+
Merismopedia sp.	-	-	+
Microcystis sp.	+	+	+
Nostoc sp.	+	+	-
Oscillatoria sp.	-	+	+
Phormidium sp.	-	-	+
Spirulina sp.	+	-	-
Rare groups:			
Dinophyceae:			
Ceratium sp.	+	+	+
Peridinium sp.	+	+	+
Eugelnophceae: *Euglena* sp.	+	-	-

In the riverine zone, twenty two species were recorded. The most commonly encountered groups were in the following order: Bacillariophyceae, Cyanophyceae, Chlorophyceae and rare groups constituting 85.95%, 6.57%, 5.80% and 1.68% form the total phytoplankton composition respectively (Fig. 3). The average number of total phytoplankton along the different stations in this zone was 90539×10^4 cell l^{-1}. The maximum number was recorded at Amka (33833×10^4 cell l^{-1}), while AlMalk El Nasser recorded the minimum number (5910.5×10^4 cell l^{-1}). *Melosira* sp., was the most abundant species (76925.5×10^4 cell l^{-1}) while *Euglena* sp. was the lowest abundant species (2×10^4 cell l^{-1}) in the main dominant group (Bacillariophyceae) *Aphanizomenon* sp. *Spirulina* sp. and *Euglena* sp. were appeared only in this part of the reservoir, while eleven species disappeared (*Cocconies* sp., *Gomphonema* sp., *Ankistrodesmus* sp., *Botryococcus* sp., *Nephricytium* sp., *Pandorina* sp., *Westella* sp., *Lyngbya* sp., *Merismopedia* sp., *Oscillatoria* sp. and *Phormidium* sp.).

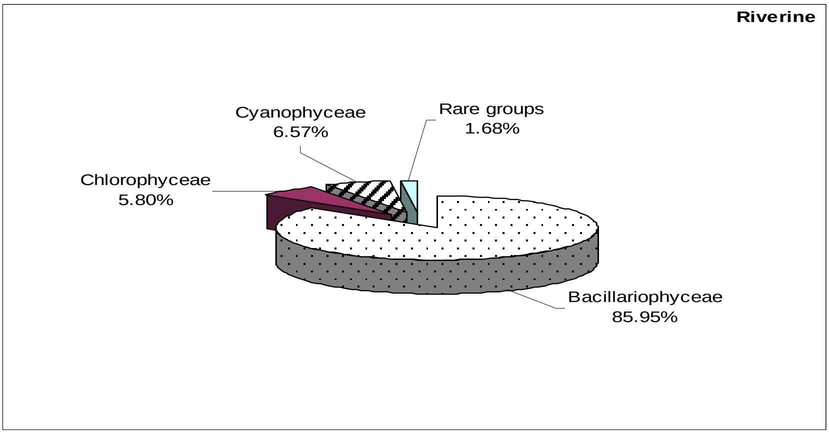

Fig. 3: Percentage occurrence of average number of the dominant phytoplankton groups recorded from the riverine zone.

In the transition zone, thirty species were recorded. The most commonly encountered groups were in the following order: Cyanophyceae, Bacillariophyceae, Chlorophyceae, and rare groups, constituting 56.42%, 40.24%, 2.52% and 0.83% form the total phytoplankton composition respectively (Fig. 4). The average number of total phytoplankton along the different stations in this zone was 89709.5×10^4 cell l^{-1}. The maximum number was recorded at Halfa (25560.5×10^4 cell l^{-1}), while Sara recorded the minimum number (56×10^4 cell l^{-1}). *Melosira* sp. was the most abundant species (35911×10^4 cell l^{-1}) while *Pandorina* sp. was the lowest abundant species (0.5×10^4 cell l^{-1}).

Nine species disappeared from this part of the reservoir (*Cocconies* sp., *Ankistrodesmus* sp., *Nephricytium* sp., *Westella* sp., *Aphanizomenon* sp., *Merismopedia* sp., *Phormidium* sp., *Spirulina* sp., and *Euglena* sp.).

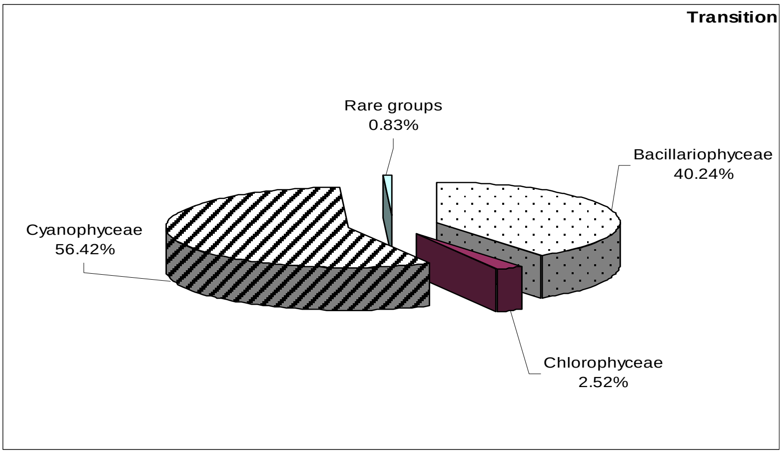

Fig. 4: Percentage occurrence of average number of the dominant phytoplankton groups recorded from the transition zone.

In the Lacustrine zone, thirty two species were recorded. The most commonly encountered groups were found in the following order: Cyanophyceae, Bacillariophyceae, Chlorophyceae, and rare groups, constituting 65.81%, 17.02%, 16.39% and 0.78% form the total phytoplankton composition respectively (Fig. 5). The average number of total phytoplankton along the different stations of this zone was $2315x10^4$ cell l^{-1}. The maximum number was recorded at Kalabsha ($561.5x10^4$ cell l^{-1}), while Toushka recorded the minimum number ($243.5x10^4$ cell l^{-1}). *Microcystis* sp. was the most abundant species ($804x10^4$ cell l^{-1}), while *Cocconies* sp., *Gomphonema* sp., and *Nephricytium* sp. were the lowest abundant species (1 $x10^4$ cell l^{-1}). *Cocconies* sp., *Ankistrodesmus* sp., *Nephricytium* sp., *Westella* sp., *Merismopedia* sp., *Phormidium* sp. appeared only in this part of the reservoir, while seven species were disappeared from this part (*Schroederia* sp., *Tetraedron* sp., *Spirogyra* sp., *Aphanizomenon* sp., *Nostoc* sp., *Spirulina* sp. and *Euglena* sp.).

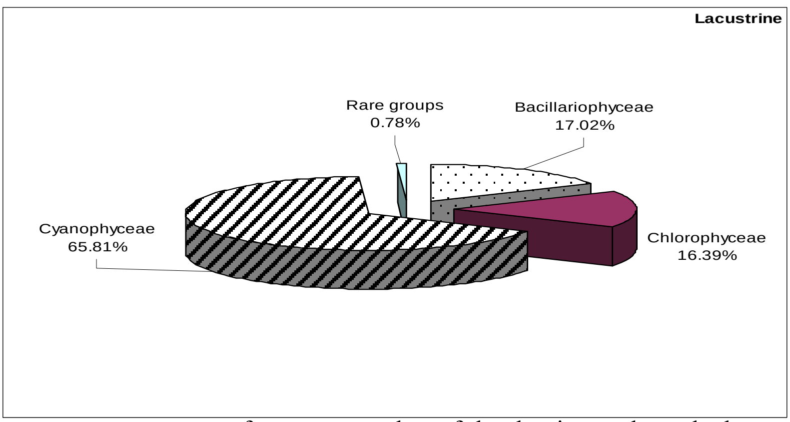

Fig. 5: Percentage occurrence of average number of the dominant phytoplankton groups recorded from the lacustrine zone.

Statistical analysis

The results of one way analysis of variance between the different zones of Aswan High Dam Reservoir (lacustrine, transition and riverine) showed significant differences ($p<0.05$) in the main phytoplankton groups (Bacillorophycae and Chlorophycae) and environmental factors (dissolved oxygen, water temperature, secchi depth, water velocity, turbidity, nitrate, total phosphorus, magnesium, total dissolved solids, and trophic state index). Standard deviation of the environmental factors and phytoplankton groups in riverine , transition and lacustrine zones showed wide variation and significant differences ($p<0.05$) in water velocity, secchi depth, turbidity, dissolved oxygen, nitrate, total phosphorus, magnesium, total dissolved salts, trophic state index,. The result of correlation coefficients showed significant differences ($p<0.05$) between phytoplankton groups and environmental factors of the reservoir (Table 5).

Table 5: Correlation coefficients between phytoplankton groups and environmental factors of Aswan High Dam Reservoir.

Parameter	*Bacil*	*Chloro*	*Cyano*	*Chl a*	*T Phyto*	*DO*	*Temp*	*SD*	*Turb.*	*Velocity*	*NO3*	*TP*	*Mg*	*TDS*
Chloro	0.43													
Cyano	0.45	-0.03												
Chl a	0.55	0.37	0.69											
T Phyto	0.88	0.29	0.82	0.73										
DO	0.49	0.24	0.52	0.35	0.59									
Temp	-0.67	-0.48	-0.33	-0.58	-0.61	-0.47								
SD	-0.50	-0.48	-0.16	-0.28	-0.41	-0.65	0.81							
Turb.	0.50	0.67	-0.11	0.42	0.27	0.35	-0.80	-0.77						
Velocity	0.39	0.68	-0.04	0.50	0.25	0.26	-0.67	-0.69	0.92					
NO3	-0.64	-0.66	-0.27	-0.72	-0.57	-0.23	0.66	0.29	-0.64	-0.57				
TP	0.36	0.37	0.08	0.12	0.28	0.50	-0.70	-0.86	0.63	0.49	-0.14			
Mg	-0.69	-0.63	-0.30	-0.59	-0.61	-0.63	0.91	0.86	-0.87	-0.75	0.69	-0.67		
TDS	-0.55	-0.55	-0.24	-0.42	-0.49	-0.71	0.82	0.93	-0.78	-0.69	0.41	-0.71	0.90	
TSI	0.67	0.62	0.26	0.66	0.58	0.55	-0.92	-0.85	0.91	0.85	-0.70	0.67	-0.96	-0.87

Shadow data meaning $p < 0.05$.

DISCUSSION

Temperature affects physical, chemical and biological processes in reservoirs water (Chapman, 1992). The increase in surface water temperature observed in lacustrine portions of the reservoir is due to surface heating and lesser mixing of the water unlike in riverine part where water current is fast and turbulent, thus allowing an even distribution of heat throughout water column. This is supported by negative and significant correlation between water velocity and temperature (-0.669).

Water turbidity in the reservoir was recorded with increasing values in the riverine than in the transition and lacustrine zones. The lesser turbidity of lacustrine portion can be attributed to the water velocity been reduced in this part and thus leading to settling of silt. The positive correlation (0.67) between chlorophyll *a* and turbidity means that algal turbidity was present in the riverine and transition zones (Sivakumar and Karuppasmy, 2008). Factors affecting transparency of water are silting, microscopic organisms and suspended organic matter (Bamforth, 1958). The waters of the reservoir area became more turbid in riverine zone due to water velocity and silt and suspended matters being carried with the post-flooded water (Agarwal and Thapliyal, 2005). This is supported by negative correlation between water velocity and transparency (-0.690). Water velocity was nearly nil in the lacustrine portions of the reservoir compare to faster current in riverine. The pH was found in alkaline range with maximum in the transition zone and minimum in lacustrine zone. Wani and Subla, (1990) reported that pH values above 8.0 in natural water are produced by photosynthetic rate that demands more CO_2 than quantities furnished by respiration and decomposition. High value of pH (more than 8.5) was recorded in water with high organic content and eutrophic condition (Kalff, 2002). The dissolved oxygen concentration was found above 8.0 mg/l in the three zones. The distribution of dissolved oxygen in the reservoir water is governed by a balance between input from the atmospheric aeration rate and photosynthetic activity and losses by the chemical and biotic oxidations (Gautam *et al.*, 1993). Also fast flow of riverine portion allowed replenishment of oxygen.

Total dissolved solids value showed increasing trend northward. The lacustrine zone recorded the highest values, while the riverine zone recorded the lowest values. The decrease in the dissolved salts in the riverine zone could be related to the adsorption of dissolved salts in the surface of suspended particles coming with flood water and precipitated to bottom sediment (Toufeek and Korium, 2009). Turbidity and total dissolved solids exhibit an inverse relationship (-0.78). Nutrients are essential for microbial production and algal growth. The reservoir acts as a nutrient sink, especially for phosphorus. The majority of phosphorus reaching the reservoir is in particulate form or is associated with suspended sediment particles. A large fraction of this phosphorus load is deposited within the reservoir by sedimentation (Gloss, 1977). Most of the remaining dissolved phosphorus is removed from water by uptake from biological activity. Phosphorus concentrations are usually much lower in lacustrine zone than in the transition and riverine zones of the Aswan High Dam Reservoir. Low phosphate may be attributed to locking up of phosphate by phytoplankton (Wani and Subla, 1990). Phosphate is considered the limiting factor for phytoplankton productivity, because of geochemical shortage of phosphate in the lacustrine zone. Nitrate concentration recorded low value in the lacustrine portion and this can be attributed to utilization by plankton and aquatic plants (Chapman, 1992). Magnesium is absolutely essential for chlorophyll bearing algae and plants. Cells need magnesium for phosphate transfer and it serves as the transition metal at the heart of the reactive center in the chlorophyll molecule. (Goldman and Horne, 1983 and Jhingran, 1975). The decrease in magnesium ion concentration in riverine and transition zones is mainly due to consumption by algae. This is supported by the negative correlation with Bacillariophyceae (-0.69), Chlorophyceae (-0.63), and chlorophyll *a* (-0.59).

In general, the results of the environmental factors showed wide variations in their values along the different zones of the reservoir.
Chlorophyll *a* concentration was low in the lacustrine zone than in the riverine, although turbidity and secchi depth values were all optimal for increased light availability. Algal biomass as reflected in Chlorophyll *a* concentrations may have been limited by nutrient availability. The negative correlation between water transparency and chlorophyll *a* showed that light conditions in the Aswan High Dam Reservoir seemed not to be a limiting factor for phytoplankton development. This result was influenced by higher abundances in the reservoir, where riverine conditions predominate, with phytoplankton assemblages dominated by species tolerant to turbulent conditions and typical high mineral turbidity (Almazan and Boyd, 1978 and Reynolds *et al*., 2002). Calculation of trophic state index showed that riverine and transition zones are classified as eutrophic, while lacustrine zone is mesotrophic.

Phytoplankton composition recorded thirty nine species belonged to Bacillariophyceae, Cyanophyceae, Chlorophyceae, Dinophyceae and Eugelnophceae. Green algae contributed more genera to the phytoplankton than any rare group. However, diatoms and blue-green algae were found to be alternatively dominant groups. These results coincided with the findings of Latif (1974), Zaghloul (1985) and Abdel-Monem (1995). The distribution of the phytoplankton abundance is much influenced by the availability of inorganic nitrate and phosphate (Wetzel, 1983). In the present study, the phytoplankton productivity was higher in the riverine than lacustrine, where subsequently nutrients in riverine water were increased. The low level of phytoplankton in the lacustrine zone may be due to nutrient limitation or grazing by zooplanktons and fishes. The riverine zone of the reservoir was dominated by Bacillariophyceae. This is an algal group, mostly centric diatoms, that dominate quantitatively the phytoplankton composition in reservoirs characterized by varying water currents, turbid and at nutrient-rich floodwater (Allan, 1998 and Talling *et al*., 2009). The lacustrine zone showed domination by Cyanophyceae and reduction in the total phytoplankton abundance. This is due to that Cyanophyceae prefers steady, transparent and low nutrients water. Cyanophyceae assimilates phosphate at a faster rate than other algal groups and accumulates large amount of reserve phosphate for extended growth periods at low phosphate concentration (Lam and Silvester, 1979). These results coincided with the findings of Tessy (2001) at Lake Taxoma. Aboul-Ela and Khali (1989) found that diatoms and blue-green algae dominate the phytoplankton community of many tropical lakes in Africa. The results indicated that abundance of phytoplankton was affected by nutrients and ions availability.

Statistical analysis using correlation matrix showed that certain environmental factors do affect the phytoplankton growth. The results of the one-way ANOVA revealed that the different environmental factors (DO, water temperature, secchi depth, water velocity, turbidity, nitrate, total phosphorus, magnesium, total dissolved solids, and trophic state index) and biotic factors (such as chlorophyll *a* and phytoplankton groups) were significantly different at the three different zones of Aswan High Dam Reservoir ($p<0.05$). These results support the speculation of variation in water quality and phytoplankton in the different zones of the reservoir.

Finally, a marked spatial heterogeneity in environmental factors and biotic factors from the inflow to the dam was revealed; so more attention to these gradients must be paid.

Conclusions

The results of the environmental factors showed wide variations in their values and concentrations along the different zones of the reservoir.

Chlorophyll *a* concentration was low in the lacustrine zone than in the riverine, although turbidity and secchi depth values were all optimal for increased light availability. This result was influenced by higher abundances in the reservoir, where riverine conditions predominate, with phytoplankton assemblages dominated by species tolerant to turbulent conditions and typical high mineral turbidity. Trophic state index showed that riverine and transition zones are classified as eutrophic, while lacustrine zone is mesotrophic.

Phytoplankton productivity was high in the riverine portion, where subsequently the nutrients in the water were increased. The riverine zone of the reservoir was dominated by Bacillariophyceae, while the lacustrine zone was dominated by Cyanophyceae Statistical analysis revealed that the different environmental factors and biotic factors were significantly different at the three different zones of Aswan High Dam Reservoir.

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