RELATION BETWEEN WATER QUALITY AND PHYTOPLANKTON STANDING CROP IN THE RIVER NILE AT BENI SUEF (EGYPT).

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Abstract

Water quality and phytoplankton standing crop were monitored seasonally for a year. Seasonal variability in effluent discharge explained much of the variation in water quality parameters; however, deviations from this correspondence were significant. Nutrient (N and P) concentrations remained low through late fall and suddenly increased, which was hypothesized to be due to turnover in this large, relatively deep river. Algal biomass increased earlier than nutrients, but decreased rapidly in early winter and remained low for approximately 3 months. The winter decrease in algal biomass was hypothesized to be caused by elevated turbidity levels in the River Nile - associated with hyacinth removal and channel dredging activities. Diatoms dominated the phytoplankton throughout the year, with greater relative abundances of green algae near the city. *Aulacosira granulata* was the dominant species throughout the period of study. The city affected water quality by increasing the concentrations of nutrients and most other ionic compounds, as well as algal biomass

Key words: Algae, Human activities, Pollution, Rivers, Water quality.

Introduction

Urbanization, as a landscape-level process, is considered a long-term disturbance with cumulative effects (Weaver and Garman, 1994). Urbanization adversely affects stream ecological condition through increased storm water runoff, erosion and sediment loading, as well as changes in substrate composition, water temperature, reduced base-flow, and elevated concentrations of nutrients and toxic substances (Jones and Clark, 1987; Walsh, 2000). These impacts may affect the structure and function of biological communities, including their development, species composition and within-watershed distribution (Fitzgerald *et al.*, 1998; Miltner *et al.*, 2004). Since the early 20th century, substantial research has been conducted to assess the integrity of stream ecosystems and ecological processes based on biological communities (e.g. Jones and Clark, 1987; Fitzgerald *et al*., 1998).

Large rivers are important ecosystems that provide many uses for humans and other organisms. Assessment of the ecological health of large rivers is the

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subject of new research programs in the United States (Great Rivers Environmental Monitoring and Assessment Program) and in Europe (Water Framework Directive) (USEPA, 2002; Griffiths, 2002). Planktonic algae have a key function in large rivers (Wehr and Descy, 1998) and should be a central component of efforts directed at assessing the ecological condition of such systems. Algal communities are major producers of organic carbon in larger rivers, are a food source for planktonic consumers, and may represent the primary source of dissolved oxygen in many low-gradient rivers (Reynolds and Descy, 1996). Phytoplankton are responsive to excessive supplies of inorganic nutrients and may pose problems related to low dissolved oxygen concentrations, as well as taste, odor, filter clogging, and toxicity problems in water supplies (Palmer, 1962). But phytoplankton in moderate densities can also enhance water quality for humans in rivers by taking up nutrients directly and fueling the biological processes that breakdown many contaminants (Wehr and Descy, 1998). Many studies have documented the use of algal community structure in large-scale analyses of water quality in streams and lakes (see reviews in Witton *et al*., 1991; Lowe and Pan, 1996; Stevenson and Smol, 2003).

Great interest has been shown in some aspects of the Nile water quality and ecology. El Nayal (1935 and 1936) – a pioneer investigator of Egyptian fresh water algae. He was able to increase the number of reported species from 136 to 379, with representatives of most known algal phyla. Abdin (1948a and b) studied the water quality of the River Nile near Aswan and Cairo in relation to algal growth. After construction of the Aswan High Dam, agricultural and industrial human activities led to dramatic changes in the River Nile water chemistry. Now, the River Nile has the highest dissolved salt concentration of the major African rivers (Dekov *et al*., 1997). The concentrations of P, N, Si, Ca and Mg in the River Nile have been affected by progressive increases in nutrient loading from agricultural and urban activities (Mahmoud, 1989) as well as regulation of river discharge. A seasonality of phytoplankton was also observed (Massoud and Abbas, 1985).

The scope of our investigation was restricted for relating the seasonal and spatial variability in physicochemical parameters, as well as abundance of phytoplankton, to environmental factors, river discharge and water temperature were hypothesized to be the most important seasonal factors due to their effect on retention time, growth rate, and accrual of phytoplankton in rivers (Reynolds and Descy, 1996; Wehr and Descy, 1998). We hypothesized that discharge from a city would be an important determinant of the spatial patterns in the ecological characteristics of the River Nile, but that the level or degree of resilience demonstrated by the river would be detected with a recovery in water quality downstream. To test these hypotheses we measured physicochemical and phytoplankton parameters in the River Nile monthly for a year at locations upstream, immediately downstream, and far downstream from Beni Suef (Figure 1)

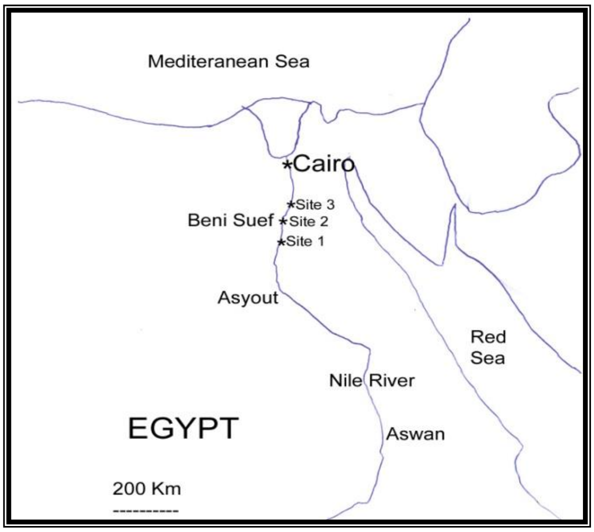


Figure (1): Map of Egypt showing the three sampling sites.

Materials and Methods

Algal populations and water quality were studied at three sites on the main stream of the River Nile near the Beni Suef Governorate (Figure 1 – map). These sites were: (Site 1) located 30 km upstream from the city of Beni Suef at El Fashn; (Site 2) at the city of Beni Suef to determine effects of a city discharge; and (Site 3) located 30 km downstream from the city of Beni Suef at El Wasta to determine recovery from city effects. The population of Beni Suef city is approximately 200,000 while land use both upstream and downstream of the city consists mainly of intensive agriculture. In the city, on the west side of the River Nile, there are many clubs and a marina for berthing traveling ships, which discharge their wastes directly into the river. On the east side of the river, there is an industrial zone which contains cement factories, factories for drying and processing of agricultural crops, a medical supplies factory, and many poultry farms. In the middle of the River Nile there is an island that is cultivated for much of the year, except during the summer months when it is often inundated by rising flood waters. The climate is hot and dry during the summer and warm and usually dry during the winter months. River discharge is regulated by summer rainfall in the headwaters of the Nile and by water releases from the Aswan High

Dam, which is located more than 700 km upstream from the city of Beni Suef. In addition, low head dams and locks regulate water depth in the river to sustain navigation by large ships. The River Nile is large in the study area, with an average width of approximately 750 m and an average depth of 7 m.

Water samples were collected monthly from the three selected locations for one year from July 2005 to June 2006. Sub-surface water samples were taken (1-m depth) from all sites in wide-mouthed 1.0 L capacity polyethylene bottles. Composite samples were obtained by mixing five replicate samples collected from different locations within each sampling site. The samples used for nutrient analysis were filtered through 0.45 μm-pore diameter membrane filters (Whatman, Inc) before analysis.

Water transparency was measured with a (20 cm diameter) Secchi disc. Water temperature was measured by using a mercury thermometer. Water pH values were recorded with an Orion 210 digital pH meter. Water alkalinity was determined by the potentiometric titration method as described in APHA (1989). Dissolved oxygen and chemical oxygen demand (COD) were determined by the procedures cited in APHA (1989). Nitrate and ammonia concentrations were determined colorimetrically by reacting with sodium salicylate and sulphuric acid, or ammonium chloride solution and Nessler's reagent, respectively, according to Markus *et al*. (1985). Phosphate, silicate and sulphate were determined according to APHA (1989). All other analyses except chlorophyll were done according to APHA (1992). Chlorophyll a concentrations were estimated spectrophotometrically according to Parsons and Strickland (1965) after 12 h extraction in 90% acetone in a dark freezer.

Phytoplankton samples were collected at three month intervals to provide the basis for a quantitative analysis of cell densities and the taxonomic composition of algal populations. The samples (collected as above) were preserved with 4% formalin and concentrated by sedimentation (Stein, 1973). For diatom counts, samples were cleared first by conc. Nitric acid and mounted on glass microscope slides with Canada balsam. Quantification of phytoplankton was performed microscopically using a haemocytometer. Algal cells in all the squares in the grid were counted, which represented at least 0.1 ml of water and a minimum cell count of 10^4 cells. The cyanoprokaryotic and eukaryotic phytoplankton were identified to species according to the following references: Smith (1950), Prescott (1954), Bourrelly (1970; 1972; 1981), Desikachary (1959).

Statistical analysis

Seasonal variation in water quality parameters was evaluated by identifying groups of variables with similar seasonal patterns and by comparing differences in conditions among them. Similarity in seasonal patterns of water quality parameters was analyzed with results from the 12 sets of monthly samplings at the 3 locations in the River Nile and with principle components analysis using the statistical program SYSTAT® version 10. Groups of variables were identified based on their similar loading on the principle components axes. All other statistical analyses were conducted with the statistical program R. We tested the hypothesis that water quality parameters varied among months with a one-way analysis of variance using month as a factor and the three observations at the three River Nile locations as replicates (n=36). Tukey's 'Honest Significant Difference' (Tukey HSD) method was used to test the null hypothesis that differences did not occur between the compared months for all possible combinations of months. The Tukey HSD created a set of confidence intervals for the differences between the means resulting in multiple comparisons with the specified family-wise probability of equality between means ($P<0.05$).

The effects of Beni Suef on water quality in the River Nile were determined with paired comparisons. Two paired comparisons were calculated for each parameter. The effect of city was determined with the comparison between values near the city and upstream for each monthly sampling period separately (n=12) or for season sampling periods (n=4), depending upon the frequency of measurement of the water quality parameter. The other comparison was the same, but to determine recovery from the city effect by comparing conditions downstream and near the city. The hypothesis that the mean difference between locations was significantly different than zero was determined with a t-test. Percent recovery for each water quality parameter was calculated by dividing recovery by the city effect and multiplying by 100.

Results

Seasonal patterns

River Nile waters were warm and turbid with relatively high ionic and nutrient concentrations when compared to most freshwater ecosystems in Africa (Table 1). Water temperature ranged between 16 and 30°C. Sodium, potassium, calcium, and magnesium were greater that 20, 2, 14, and 8 mg L^{-1}, respectively. Chloride concentrations were between 105 and 280 mg L^{-1}. Total hardness, alkalinity, carbonate, and bicarbonate were greater than 25, 90, 7, and 150 mg L^{-1}, respectively. pH was between 7.4 and 8.4. Nitrate and phosphate concentration ranged from 1.5-70 mg L^{-1} and 4.5-150 µg L^{-1}, respectively.

Waters of the River Nile near Beni Suef were turbid and productive (Table 1). Turbidity and Secchi disk transparency ranged from 2.2-15.6 NTU and 44-80 cm, respectively. Total suspended matter (TSM) ranged from 3-85 mg L^{-1}. Total soluble salts (TSS) ranged from 2.4-4.3 mg L^{-1}. COD ranged from 0.3-4.3 mg L^{-1}. Chlorophyll a ranged from 5.4-12.4 µg L^{-1}. Surface waters of the Nile remained oxygenated with a range between 8.8 and 19.6 mg L^{-1}.

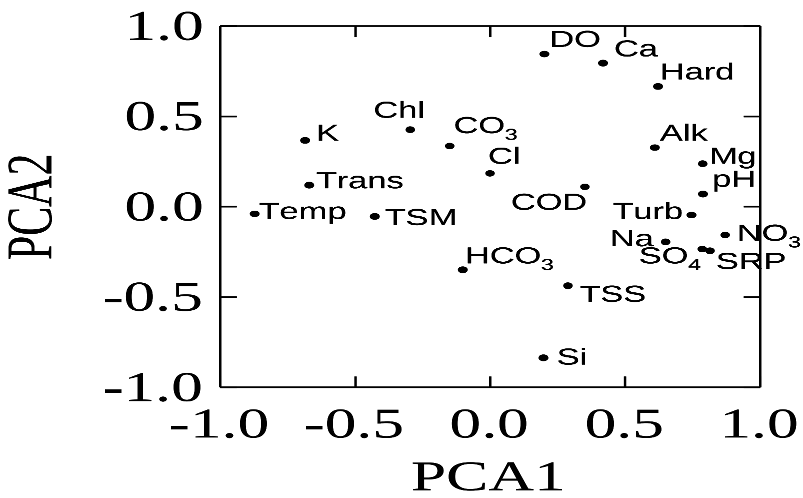
Table (1): Monthly records of the physical and chemical parameters at the three sites during the period of study.

Parameters	Sites	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
T. (cm)	I	75	78	57	65	60	63	48	63	60	80	74	75
	II	60	75	47	62	55	55	44	60	55	75	65	70
	III	69	76	55	64	55	58	45	62	60	75	70	70
Tur. (NTU)	I	3	2.5	8.6	3.4	8	4	14	4.6	6.4	2.2	3.5	2.2
	II	4.1	2.7	9.3	3.7	8.8	9.5	15.6	5.2	7.1	3.4	3.8	2.7
	III	3.5	2.7	8.5	3.5	8.3	9.6	13.5	4.5	6.3	3.2	3.4	2.2
Temp (C)	I	28.5	30	27.5	25	19.5	16	17	18	21	22	24	26.5
	II	28.5	30	28.5	25.5	19.5	16.5	17.5	19	21.5	22.5	25	27.5
	III	28	30	27	24.5	19	16.5	17.5	18.5	21	22	25	27
pH value	I	7.8	8.15	7.8	7.9	7.9	8.2	8.3	8.2	8.3	7.8	8	7.6
	II	7.8	8	8	8	7.9	8.3	8.3	8.3	8.4	8	8	7.8
	III	7.6	8	7.9	7.8	7.9	8.2	8.2	8	8.3	7.8	8	7.4
D O mg/L	I	11.1	15	14.6	16.8	19.6	13.8	13.8	14.8	12	14.5	15	10
	II	8.8	13.5	13.4	15.7	18.4	12.6	13.8	12.6	11.5	13.8	14.6	8.8
	III	10.5	14	13.9	16	19.2	13.2	13.8	13.5	11.5	14	14.8	9.5
T Alk (mg/L)	I	120	120	135	130	130	140	140	145	125	135	195	90
	II	135	125	138	135	145	185	145	140	130	130	125	95
	III	130	125	136	132	135	155	140	140	130	130	130	95
T Har (mg/L)	I	27.6	35	37.8	36	36.5	38.2	37	37.4	36.5	41.8	36.2	33
	II	31.2	38.5	39.4	37.5	41	41.5	40	37.8	37.8	43	37.8	28.5
	III	31	36.5	38.6	37	38.6	39.8	38.6	37.5	37	42	37.8	30.8
Cl (mg/L)	I	105	106.5	106	106.5	106.5	106.5	106.5	105	210	170	170	106.5
	II	240	140	142	142	160	140	142	175	190	280	170	250
	III	190	115	110	110	120	115	125	130	170	210	170	180
S (mg/L)	I	13	16	11	12.5	16	25	30	25.5	26.5	20	26	16
	II	19	19	13.5	15	17	31.4	33	25.5	27	26	30	16
	III	15	17	13	13.5	17	28	32	25	26	21	27	16
Carb. (mg/L)	I	7.5	15	15	15	7.5	7.5	7.5	7.5	15	15	7.5	7.5
	II	7.5	15	15	7.5	7.5	7.5	7.5	7.5	15	15	7.5	7.5
	III	7.5	15	15	7.5	7.5	7.5	7.5	7.5	15	15	7.5	7.5
Bicar (mg/L)	I	180	175	183	213.5	183	210	213.5	213.5	213.5	189	153	180
	II	210	200	213.5	200	213.5	210	213.5	213.5	213.5	189	180	198
	III	198	180	200	200	200	210	213.5	213.5	213.5	189	165	188
N (mg/L)	I	4	3.2	1.5	4.7	7.5	50	70	35	24	40	5	5
	II	7.5	4.1	1.5	5.2	10	70	70	38	25	50	5	5
	III	5.5	3.6	1.5	4.8	8	55	70	38	25	45	5	5
P (µg/L)	I	13	7.5	4.5	20	5	100	50	100	85	50	10	10
	II	18.5	11	5	24	10	100	150	150	100	100	10	10
	III	16.2	9.6	5	24	8	100	120	110	92	85	10	10
S (mg/L)	I	350	155	112	35	25	265	360	210	315	160	250	300
	II	385	200	185	55	50	280	435	275	395	240	370	420
	III	365	170	135	48	35	260	385	235	365	210	310	340
COD (mg/L)	I	1.6	0.8	0.3	2.6	3.9	2.5	2.1	2.3	2.5	1.3	1.8	1.7
	II	1.9	1	0.3	3.3	4.3	3	2.3	2.3	3	2	2	2
	III	1.6	1	0.3	2.9	4	3	2	2.3	2.8	1.5	2	1.9
T Chl. (µg/L)	I	6.45	6.1	6.8	8.6	8.9	9.3	4.9	4.8	5.4	10.2	9.6	10
	II	8.9	8.5	9	11.2	11.8	11	6.8	6.3	6.5	12.4	10.8	11.1
	III	7.5	7.4	8.2	9.8	10.6	10	6	5.8	6.3	10.8	10.6	10.5
Ca (mg/L)	I	18	25	27	25	26	26	23	25	20	27	26	14
	II	21	27	28	27	29	26	25	26	26	28	27	17
	III	20	27	27.5	26.5	28	26	25	25	24	28	26	15
Mg (mg/L)	I	9.6	9	10.8	11.4	10.8	12	14.4	11.4	10.6	14.5	11	9
	II	10.4	11.4	11.4	12	12.4	14	15.8	12	12.1	15	11	9.8
	III	10.2	10.6	11	11.7	11.5	13.4	14.9	12	11.5	15	11	9.4
K	I	5	6	6	6	4.3	3.7	3.1	3.7	2.5	6.1	6.5	5

(mg/L)	II	6	6.5	6.5	6.4	5	3.7	3.9	3.8	3.1	6.9	8	6.5
	III	6	6.5	6.5	6	4.6	3.7	3.3	3.7	3	6.5	7.3	6
Na (mg/L)	I	25	27	32	29	20.5	39	38.5	38.5	23	29	27.5	25
	II	28.5	29.5	32	30	22.4	39	46	39	25	29	28	26.5
	III	27.4	26.2	32	30	21.6	28	42.5	39	23.8	29	28	26
T.S.S. (mg/L)	I	2.4	2.4	2.7	2.4	2.6	2.4	3.1	2.3	2.8	2.4	2.6	2.4
	II	4	2.9	2.8	3.6	3.2	2.8	3.9	3.5	4.3	3	2.6	3.3
	III	3.6	2.6	2.8	2.8	3	2.5	3.4	3.1	3.3	2.6	2.6	2.8
T S M (mg/L)	I	11	28.5	7	19	13	3	3	43	11	15	18	49
	II	18	42.1	14	85	38	8	7.5	59	19	28	33	65
	III	14	34.6	9.6	33	19.8	7	4.8	45	14	20	24	54

T=Transparency, Tur=Turbidity, Temp=Temperature, DO=Dissolved oxygen, T Alk=Total alkalinity, T Har=Total hardness, Cl=Chlorides, S=Sulphate, Carb=Carbonate, Bicar=Bicarbonate, N=Nitrate, P=Phosphate, S =Silicate, COD=Chemical oxygen demand, T Chl.=Total chlorophyll, Ca=Calcium, Mg =Magnesium, K=Potassium, Na=Sodium, T.S.S.=Total Soluble salts, TSM=Total suspended matter.

Ordination of water quality attributes indicated differences in seasonal patterns of groups of environmental parameters. The first two principle components explained 34.0 and 16.5% of the variation among variables. Nitrate, phosphate, and sulfate were most highly and positively correlated with the 1st PCA axis, while temperature was most negatively related to that axis (Figure 2).



Figure(2): Ordination of water quality attributes at the sampling sites over a 12 month period in the River Nile at Beni Suef Governorate using principle components analysis (PCA). Codes: Alkalinity (Alk), Bicarbonate (HCO_3), Calcium (Ca), Carbonate (CO_3), Chemical Oxygen demand (COD), Chlorides (Cl), Chlorophyll a (Chl), Dissolved oxygen (DO), Hardness (Hard), Magnesium (Mg), Nitrate (NO_3), pH, Potassium (K), Silicate (Si), Sodium (Na), Soluble reactive phospate (SRP), Sulphate (SO_4), Temperature (Temp), Total soluble salts (TSS), Total suspended matter (TSM), Transparency (Trans), and Turbidity (Turb).

These parameters had opposite seasonal cycles. Temperature was highest in August and lowest in December (Tukey HSD, $p<0.005$), with a relatively smooth sinusoidal pattern during the year. Nutrients were low in the summer and fall, increased dramatically between November and December, and then decreased to the summer minimum (Tukey HSD, $p<0.005$).

Sulfate, magnesium, sodium, pH, alkalinity, hardness, turbidity and silicate also had summer minima and winter maxima (Table 1) and were correlated relatively well to the 1^{st} PCA axis. Seasonal changes in concentrations were relatively greater for silicate and sulfate than for other variables in this group. Silicate differed seasonality from other nutrients (nitrate and phosphate) by persisting in high concentrations during the spring and then decreasing to a summer minimum. This persistence of relatively high concentrations from winter through spring was the same for most of this second group of parameters that were positively correlated to the 1^{st} PCA axis. Turbidity was the most changing variable from month to month in this group of parameters.

Dissolved oxygen, calcium, and hardness were highly correlated with the 2^{nd} PCA axis. These parameters had their lowest values in June and July and highest concentrations throughout the rest of the year (Tukey HSD, $p<0.005$).

Algal biomass varied with seasonal averages ranging from 4-10 μg chl a L^{-1} (Table 1) and 15.79×10^6 - 73.52×10^6 cells L^{-1} (Figure 3). Greater biomass was observed during the fall and spring months compared to the summer and winter months (Tukey HSD, $p<0.001$). This seasonal pattern was substantially different from other temporal patterns in discharge, temperature, and water chemistry. Chlorophyll a was lower during the high discharge period from July through September than during either of the preceding or following three months periods (Tukey HSD, $p<0.005$). However, the sudden decrease in chlorophyll a from December to January and persistently low algal biomasses from January through March (Tukey HSD, $p<0.005$) do not correspond to the predictable sinusoidal pattern in discharge in the River Nile. Variations in chl a concentrations were not correlated to most other environmental variables in both ordination and individual correlation analyses. Chl a was not loaded highly on a PCA axis until the 4^{th} axis, when it and K were positively correlated and pH was negatively related to the fourth axis (Figure 2). Simple Pearson correlation coefficients among chl a, K and pH were respectively 0.573 and -0.459, but only the relationship between the chl a and K was statistically significant when multiple tests were accounted for (Dunn-Sidak probabilities, $P=0.005$).

A total of 123 algal species were recorded from the River Nile samples in this investigation. Among the identified taxa, 48 belong to Chlorophyta, 41 to

Bacillariophyta, 31 to cyanobacteria and 3 to Euglenophyta. Blooms of diatoms were recorded throughout the year dominated by *Aulacosira granulata*, *Tabellaria fenestrata*, and *Fragilaria construens*. Chlorophyta were dominated by *Dictyosphaerium pulchellum*, *Chlorella vulgaris* and *Ankistrodesmus falcatus* var. *acicularis*. *Microcystis aeruginosa* was the dominant cyanobacterial species.

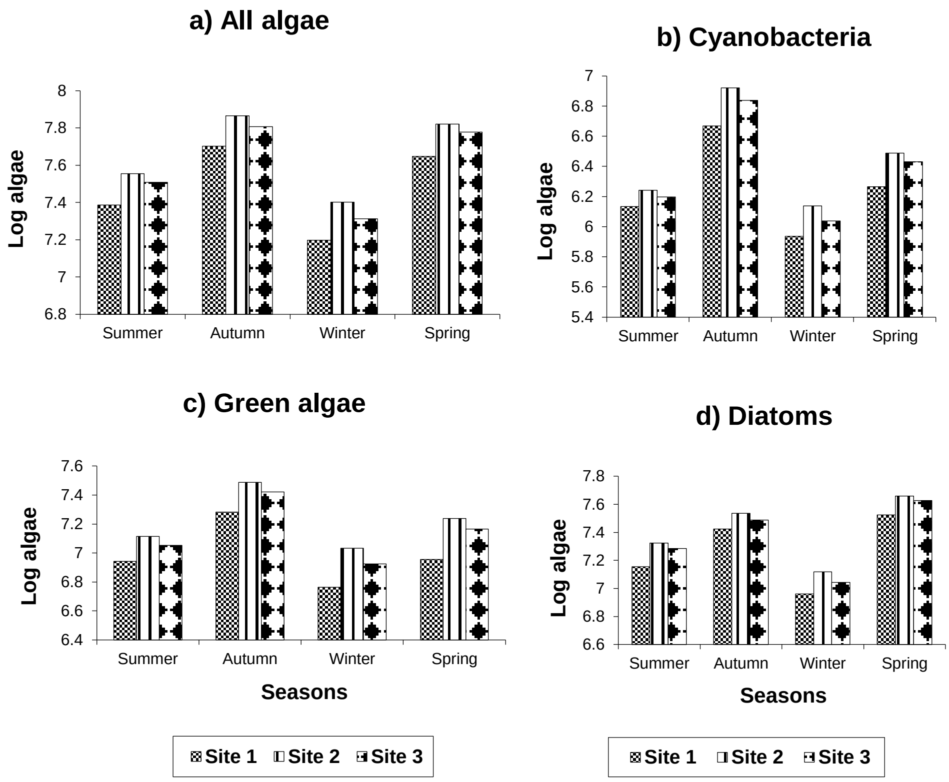


Figure (3): Seasonal variations in a) all algae, b) cyanobacteria, c) green algae and d) diatoms at the sampling sites along the River Nile at Beni Suef Governorate.

Abundance patterns of diatoms, green algae, and cyanobacteria varied similarly among seasons with higher counts during fall and spring than winter and fall. However, relative changes in these divisions of algae did vary among seasons (Table 2). Diatoms were more abundant than green algae. Cyanobacteria had relative abundances less than 11% and euglenoids were relatively rare. Cyanobacteria relative abundances were highest during autumn (Tukey HSD, $p<0.005$). Green algae were relatively low in spring and diatoms were relatively high in spring (Tukey HSD, $p<0.001$). Euglenoids were also relatively high in spring (Tukey HSD, $p<0.005$).

Table (2): Seasonal variation in the percent composition of the different algal groups at each sites (S1=upstream, S2=city, S3=downstream).

Seasons	Blue green			Green			Diatoms			Euglenoids		
	S 1	S2	S3	S 1	S2	S3	S 1	S2	S3	S 1	S2	S3
Summer	**5.58**	**4.84**	**4.89**	**35.85**	**36.25**	**35.13**	**58.43**	**58.64**	**59.75**	**0.12**	**0.25**	**0.21**
Autumn	**9.26**	**11.31**	**10.73**	**38.03**	**41.86**	**41.25**	**52.63**	**46.65**	**47.89**	**0.05**	**0.16**	**0.10**
Winter	**5.45**	**5.43**	**5.31**	**36.78**	**42.65**	**40.90**	**57.75**	**51.91**	**53.78**	**0**	**0**	**0**
Spring	**4.14**	**4.65**	**4.50**	**20.26**	**26.15**	**24.46**	**75.29**	**68.70**	**70.61**	**0.29**	**0.48**	**0.41**

City effects

Most water quality variables and algal biomass were higher near the city of Beni Suef (site 2) than the other two sites (Tables 1 and 2). Only transparency and DO were lower at the Beni Suef river site than at the other two sites. For most variables, seasonal variability was greater than the city effect. However, city effects were relatively large for silica during winter and spring, phosphate during winter, plus chloride, TSM, and TSS throughout the year. Differences in chl a concentrations among sites ranged from 0.5-3.5 µg chl a L^{-1}, which was as much as 50% of the seasonal variation from 4-10 µg chl a L^{-1}.

The values for the relative abundances of algal taxa were different for the city site when compared to the upstream and downstream sites (Table 2). Cyanobacteria did not change predictably among sites, but green algae were usually higher and diatoms were usually lower in relative abundance at the city site versus the upstream and downstream sites ($p<0.005$).

Recovery in the various water quality parameters at the site located 30 km downstream from Beni Suef ranged between 42 and 70% of the effects that were considered to be related to the city itself (Table 3).

Table (3): City effect on some parameters recorded at site 2 (with the standard error) and their recovery or persistence downstream.

Parameter	City effect	Persistence	% Recovery
Transparency (cm)	-6.25 (1.04)	-3.25 (0.57)	48
Turbidity (NTU)	1.12 (0.41)	0.56 (0.47)	50
DO (mgL^{-1})	-1.12 (0.19)	-0.59 (0.09)	47
Total hardness (mgL^{-1})	1.75 (0.67)	1.01 (0.39)	42
Chlorides (mgL^{-1})	55.5 (14.6)	20 (9.6)	64
Sulphate (mgL^{-1})	2.9 (0.66)	1.08 (0.3)	63
Bicarbonate (mgL^{-1})	12.29 (4.6)	5.29 (2.7)	54
Nitrate (mgL^{-1})	3.7 (1.7)	1.6 (0.57)	56
Phosphate (mgL^{-1})	19.45 (9)	11.2 (6)	43
Silicate (mgL^{-1})	62.75 (10.3)	26.75 (5.5)	58
COD (mgL^{-1})	0.33 (0.06)	0.15 (0.04)	52
TSS (mgL^{-1})	0.77 (0.14)	0.37 (0.09)	52
TSM (mgL^{-1})	16.34 (4.8)	4.9 (0.95)	70
Chl a (μgL^{-1})	1.93 (0.17)	1.03(0.09)	47

Chlorophyll a values decreased approximately 0.9 µg L^{-1} and dissolved oxygen increased 0.5 mg L^{-1} from the city to the downstream location. Concentrations of nutrients, chloride, suspended solids and organic matter (TSM and TSS) decreased from the city to downstream.

Discussion

Seasonal patterns

Many water quality parameters were related to seasonal variations in river discharge, which is often typified by a sinusoidal seasonal pattern with high flow during the summer and low flow during spring (Palmer and O'Keeffe, 1990; Uys and O'Keeffe, 1997). The amplitude of the seasonal variability in River Nile discharges has been reduced by the Aswan High Dam (AHD), but the sinusoidal pattern persists (Karyabwite, 2000). The results of our work indicate that algal biomass was most probably regulated by river discharge, and then the algal populations - as well as river discharge and the breakdown of thermal stratification - probably affected other water quality attributes, such as pH, alkalinity and nutrient concentrations.

In common with the patterns shown for the River Nile, river discharge and retention time are commonly identified as the most important attributes that regulate phytoplankton biomass in rivers (Descy *et al*., 1987; Reynolds, 1988). Stevenson and White (1995) reported that phytoplankton densities of the Kentucky River and its tributaries were highest in fall and summer and lowest in the winter, which was inversely related to discharge. Algal biomass in the River Nile increased from summer to fall, i.e. as discharge decreased from highest levels and retention time increased. During this summer-fall period, nutrient concentrations were relatively low, compared to the annual average but high relative to concentrations that likely regulate phytoplankton growth (Sin *et al.* 1999). Although herbivorous fish and zooplankton consume algae in rivers, they probably do not have a major role regulating algal biomass. Light availability for phytoplankton is regulated by suspended sediments in rivers and is also recognized as an important determinant of algal biomass (Reynolds, 1988; Kohler and Hoeg, 2000); however turbidity was poorly correlated to algal biomass during most of the year in this study of a segment of the River Nile.

The sharp decrease in algal biomass of the River Nile during the winter months did not correlate well to seasonal changes in discharge. River discharge continues to decrease during the winter months, which supports high biomasses. Nutrient concentrations were highest in the Nile during this period, so nutrient limitation could not explain the sharp decrease in algal biomass during winter. And water temperatures were not considered to be "cold" compared to the water temperatures recorded in temperate climates. A spike in turbidity was noted during January, when phytoplankton numbers decreased. This turbidity may be related to waterway cleaning activities during the closure period of the Aswan High Dam. Waterway cleaning involves machinery moving into the river and its tributaries to remove water hyacinth. This physical disturbance by humans' likely causes resuspension of large amounts of sediments and may cause the observed low algal biomass during winter. Turbidity can reduce light and phytoplankton photosynthesis and thereby restrict biomass development (Holst and Dokulil, 1987).

Decreases in nutrient concentrations in the River Nile from the early winter pulse through summer indicated that phytoplankton uptake of nutrients and settling may be a significant sink for wastes in this large river. Low loading rates of nutrients into the Nile and dilution with groundwater could also explain the season depletion of nutrients; however more work is needed to understand causes for these patterns in large rivers.

The relative abundances of different algal phyla also varied seasonally, and were probably related to temperature changes. del Giorgio *et al*. (1991) reported that seasonal changes in phytoplankton composition in the River Lujan (Buenos Aires, Argentina) were related mainly to temperature and light conditions. The successive transition from diatoms to green algae and then to cyanobacteria as waters become warmer is the usual phytoplankton trend in lakes and rivers worldwide and appears to be linked to both temperature and nutrient limitation. Water temperature is probably the more important of these regulatory factors for the relative abundance of algal phyla in the River Nile because silica, phosphorus, and nitrogen concentrations were always high. There was no evidence of cyanobacteria dominance due to nitrogen limitation in the Nile near Beni Suef as in eutrophic lakes.

The increase in nutrient concentrations between November and December was unusually large. The river discharge was decreasing during this time and local rainfall did not occur, so neither of these causes could be linked to this large increase in nutrient concentrations. Many other chemical parameters also changed most during this time period, such as sulphate and silicate. This November-December increase in the concentrations of nutrients and sulphate may have been due to turnover either in Aswan High Dam Reservoir or in the River Nile itself. Thermal stratification of the water column starts usually in May extending from north to south throughout most of the Aswan High Dam Reservoir. At the beginning of the flood period in late July, thermal stratification usually breaks down in the southern reaches of the reservoir, whereas the northern sectors remain stratified until late October; then seasonal cooling leads to deep convective mixing (Abu-Zeid, 1987; El-Otify *et al*., 2003). The large increase in nutrient and cation concentrations in the River from November to December may have been due to mixing of nutrient rich bottom waters with surface waters.

City effects

Human activities near Beni Suef increased concentrations of pollutants in the River Nile, including nutrients, COD, and chloride concentration. Observation of this relationship is important for understanding the effects of small cities on large rivers. High temporal variability in river conditions often reduces ability to detect effects of small cities, such as Beni Suef.

Here a small city of approximately 200,000 people had measurable effects of many water quality attributes, including increased nutrient concentrations and phytoplankton biomass.

Increases in phytoplankton biomass and the slight shift in algal phyla from diatoms to green algae in association with the city indicated that nutrients stimulated algal growth, despite the high upstream nutrient concentrations. Higher algal biomass and COD may have lead to the slight reduction in dissolved oxygen, but dissolved oxygen in the surface waters of the River Nile were never lower than 8.8 mg L^{-1} at the locations studied.

The River Nile maintained “self-purification” capacity downstream from Beni Suef, despite the enormous loads of organic matter released into the system (Logo South Country Programme Egypt 2006). When compared to major rivers in Europe and the USA, many attributes of the River Nile are considered moderately clean with severe pollution only in localized areas (Abdel-Hamid *et al*., 1992). Within 30 km downstream of Beni Suef, ecological conditions had recovered approximately 50% to upstream conditions. Abdel-Hamid *et al.* (1992) reported that the River Nile receives increasing amounts of waste discharges from point and non-point sources as it flows northward to the Mediterranean. Industrial wastes are known to greatly affect the water quality. Thus the resilience, or self-purification capacity, of the River Nile is a vitally important attribute and is observed in downstream from Beni Suef. Whether or not full recovery occurs further downstream would be an important issue to determine in future work. Recovery from pollution from urban areas is commonly observed in rivers (e.g. Tubbing *et al*., 1995), but not always (Khan and Kamuru, 1997).

Conclusions

Future work requires the application of an integrated assessment and management approach that more completely characterizes current conditions of a greater extent of the River Nile to determine the extent and intensity of impact and whether the Nile maintains its resilience to pollution, it’s self-purification capacity. We must understand more about the ecology of the River itself, the potential role of stratification, and of upstream effects of the Aswan High Dam Reservoir. A more holistic approach of assessment should more thoroughly relate human activities, contaminants, and ecosystem services throughout the watershed, thereby including associated tributaries, canals, and waterway cleaning activities. As agricultural, urban, and on river activities associated with tourism and shipping increase, understanding these basic relationships will be essential for predicting future impacts and sustainable management of the River Nile.

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العلاقة بين نوعية المياه ومحصول الطحالب في مياه نهر النيل عند بني سويف (مصر)

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تم دراسة نوعية المياه ومحصول الطحالب في نهر النيل موسميا لمدة عام. فسرت الاختلافات الموسمية في معدل صرف المياه العديد من الاختلافات في نوعية المياه ولكن كان هناك العديد من الحيود. بقي تركيز المغذيات (نيتروجين و فسفور) منخفضا خلال الخريف ثم ارتفع فجأة وقد يعزي السبب في ذلك إلي عملية التقليب في نهر النيل. زاد محصول الطحالب مبكرا عن المغذيات ثم انخفض سريعا في بداية الشتاء وظل منخفضا لفترة ثلاثة أشهر تقريبا. ويعزي هذا الانخفاض إلي زيادة العكارة في نهر النيل المرتبطة بعملية إزالة ورد النيل و أنشطة تنظيف المجاري المائية. سادت مجموعة الدياتومات خلال العام مع زيادة كثافة الطحالب الخضراء بالقرب من المدينة. كان طحلب *Aulocosira granulata* هو السائد طوال فترة الدراسة. أثرت المدينة علي نوعية المياه بزيادة تركيز المغذيات ومعظم العناصر الاخري بالإضافة إلي محصول الطحالب.