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Nile-Trophic Diatom Index (TDI-Nile): a new constructed index for assessment eutrophication in River Nile basine in Egypt

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ABSTRACT

In the present study, a new index (Nile-Trophic Diatom Index ,TDI-Nile) was constructed for the assessment of eutrophication in River Nile and its branches in Egypt depending on using the total phosphorus (TP) , total inorganic nitrogen (TIN) and diatoms. Epilithic diatom samples wee collected from 40 locations during autumn-2013 and spring-2014. Over 224 diatom taxa were identified and 91 taxa (frequency ≥ 3) were sufficiently abundant to include in index development.

Multivariate data exploration revealed strong responses of the diatom assemblages to stressor variables, including total phosphorus (TP). Weighted average method was used to develop the TP and TIN indices. According to Nile-Trophic Diatom Index (TDI-Nile), most of the samples which classified in bad quality were belonging to Rosetta branch and Kema station.

Canonical correlation analysis revealed that the newly developed indices significantly well correlated (Canonical correlation = 0.79, $p < 0.0001$) with environmental variables which make them reliable indices of water quality and they can be suggested as the best indices for monitoring purposes in the River Nile.

Key words: River Nile, Water quality assessment, Nile-Trophic Diatom Index , TDI-Nile.

INTRODUCTION

The typical method for biomonitoring of freshwater quality is largely based on bioindicators, which are highly useful, especially diatoms in biomonitoring and recording biological responses, so the bioindicators are valuable in measurements of abiotic stressors (Stevenson and Smol, 2002). Developing effective indicators of ecological condition requires that indicators can be calibrated to identify their responses to important environmental stressors (Niemi and McDonald, 2004; Karr and Chu, 2000; Seegert, 2001). The main goals of calibration are to identify environmental optima and tolerances of indicator taxa, and to define systems with similar biota that respond similarly to anthropogenic stresses (Radar and Shiozawa, 2001).

Many of diatom indices were developed to demonstrate the ability of diatom to infer water quality as Descy's Index or DES (Descy, 1979), the Specific Pollution Sensitivity Index or SPI (Cemagref, 1982), the Biological Diatom Index or BDI (Lenoir and Coste, 1996), the Eutrophication/ Pollution Index or EPI (Dell'Uomo, 1996), Sladecek's Index or SLA (Sladecek, 1986), the Trophic Diatom Index or TDI (Kelly and Whitton, 1995) and the Watanabe Index or WAT (Watanabe *et al*., 1986 ; Watanabe, 1990). These indices are generally based on species and sub-species levels identifications, with the exception of a few based on genus-level identifications (Rumeau and Coste, 1988; Wu, 1999; Chessman *et al*., 1999). These indices differ in respect to diatom species included in the calculation and the applicability of most indices has been limited in some cases, especially for rivers, since distribution of species may differ markedly (Potapova and Charles, 2007).

The effectiveness of the application of diatom index, developed in certain country, at another area was a subject of study of many authors. However, existing indices must be tested when applied to a basin different from the ones where it erected (Prygiel *et al*., 1999). This testing is usually done by comparing the values given by the indexes with the physicochemical data from the same sites. The Spearman correlation between an index and chemical variables is enough to determine whether that index can be applied to the basin or not. There are many studies regarding this issue and it has been proved that these indexes are applicable and work in different parts of the world (Torrisi and Dell'Uomo, 2006; Atazadeh et al., 2007; Taylor *et al*., 2007). On the other hand, the application of previously developed indices was not acceptable for other authors (Descy and Ector, 1996; Kelly *et al*., 1998; Pipp, 2002; Rott *et al*., 2003; Szulc and Szulc, 2013) where these indices assessed the streams with incompatible data to the real state.

In River Nile, Belal (2012) applied four diatom indices to assess water quality in the River Nile from Aswan to Cairo, Trophic Diatom Index (TDI), Eutrophication Pollution Index (EPI), the Pampean Diatom Index (IDP) and the pollution tolerance index (PTI). However, the applications of these indices were not effective to represent the actual status of the River Nile. So, the need for the development of unique diatom index specific to the River Nile region was necessary and is the aim of this study.

MATERIALS AND METHODS

Site description, sampling, environmental conditions, diatom permanent slides preparation and diatoms identifications and counting were represented in details in Abd El-Karim *et al*. (2016.). In brief, the present study covered the area from Aswan Old Reservoir N 24º 02′ 1″ E 32°51'57" passing its bifurcation at El-Kanater Barrage N 30° 10' 25" and E 31° 8' 20", and its two main branches Rosetta and Damietta. Forty sites were selected for representing the different ecological areas of the river and most of the pollution sources. These sites were visited during autumn-2013 and spring-2014 and water samples for chemical (Nitrogen-Nitrate, Nitrogen-Ammonium, Nitrogen-Nitrite, soluble reactive meaurments of phosphorus, total phosphorus, reactive silicate and biochemical oxygen demand) were taken as well as biological samples of epilithic diatom were collected. In situ, water temperature, pH, electric conductivity, dissolved oxygen and total dissolved salts were measured.

The homogenized gravels samples were digested using conc. nitric and sulphuric acids in a tightly closed 100 ml tephlon bottles, heated until all organic matter had been oxidized. The digested samples were prepared on permanent slides using a high refractive index medium (Naphrax) according to the Academy of Natural Sciences (ANS, 2002). Hereafter diatoms valves were identified and counted using an inverted microscope (Zeiss, Axiovert 25C). For chemical variables, water samples were analyzed according to APHA (2005).

Species optimum and tolerance

A species optimum represents the environmental variable concentration at which that species is most abundant. A species tolerance represents the range of environmental variable concentrations around the optimum from sites in which the species may be found. The species optimum and tolerance were calculated according to the weighted average method of Birks *et al*. (1990) using C2 software version 1.7.3 (Juggins, 2003).

The weighted average optimum (U_k):

$$U_k = \Sigma_{ni=1} Y_{ik} X_i / \Sigma_{ni=1} Y_{ik}$$

The weighted average species tolerance:

$T_k = \sqrt{[\Sigma_{ni=1} Y_{ik} (X_i - U_k)^2 / \Sigma_{ni=1} Y_{ik}]}$

Y_{ik} is the abundance of taxon K in sample i,

X_i is the value of environmental variable in sample i.

The weighted average estimated optima and tolerances for total phosphorus (TP) and total inorganic nitrogen (TIN) were determined to only those species which occurred in at least three samples (frequency ≥ 3). Calculation of Nile-Trophic Diatom Index (TDI-Nile) was carried out by using the weighted average equation of Zelinka and Marvan (1961):

TDI-Nile = $\sum_{j=1}^{n} ajsjij / \sum_{j=1}^{n} ajsj$

where

aj = abundance (proportion) of species j in sample,

ij = indicator value (0-5) and

sj = pollution sensitivity (1-3) of species *j*.

Data analysis

Pearson correlation was used to determine the relationship between the diatom indices scores and the measured environmental variables. One-way ANOVA was used to compare the indices scores. Pearson correlation and ANOVA were performed using Palaeontological Statistics (PAST) software version 3.0 (Hammer, 2013). Canonical correlation analysis of xlstate (2014) was applied to evaluate the commulative correlation between the developed epilithic TDI- Nile and the entire entire measured environmental variable.

RESULTS

Optima and tolerances of diatom taxa

The TP and TIN optima, tolerance, indicator and senstivity value of 91 species were determined (Table 1). The epilithic tolerant and eutrophic taxa were *Navicula digitoradiata, N. diluviana, N. plathii*, *Nitzschia paleacea* and *Stauroneis groenlandica var. subquadra,* while the sensitive and characteristic species for oligotrophic water were *Cymbella affinis, C. caespitosa*, *Gomphonema gracile* and *G. truncatum.*

The weighted average optima of total phosphorus between epilithic communities ranged from 224.46 μgL^{-1} (*Navicula kriegerii*) to 1275.89 μgL^{-1} (*Achnanthes exigua*). The TP tolerance ranged from 35.73 μgL^{-1} (*Cymbella tumida*) to 677.02 μgL^{-1} (*Nitzschia umbonata*). Many species were mainly associated with high TP like *Cocconeis placentula* var. *euglypta, Navicula diluviana* and *Neidium alpinum*.

Nitzschia frustulum displayed the highest TIN optima (1425.55 μgL^{-1}). On the other hand, *Rhopalodia gibba* displayed the least TIN optima (77.23 μgL^{-1}). The most tolerant species for low TIN was *Navicula anglica* var. *subsalsa* which attained the least value (74.43 μgL^{-1}), whereas *Navicula accomoda* tolerated the high TIN concentrations (1037.8 μgL^{-1}).

When compared with other indices (TDI in England, EPI in Italy Toronto TDI in Canada and Van Dam checklist in Netherland) the TP indicator and sensitivity values of 38 species joint with TDI, of which five species were similar in indicator and 15 in sensitivity value. 34 species of TDI-Nile were matched with EPI, of which five species were similar in indicator and 8 in sensitivity value. 27 species were coincided between TDI-Nile and Toronto TDI, of which 6 species were similar in indicator and 11 in sensitivity value, also 45 species were corresponded with van Dam list, of which 5species were similar in indicator value as listed in Table (2).

Table 1. The epilithic taxa TP and TIN optima and tolerance with indicator and sensitivity values used in constructing the TP and TIN indices.

			TP µgL⁻¹				TIN µgL⁻¹			
No	Code	Name	Optimum	Tolerance	ind value	sen value	Optimum	Tolerance	ind value	sen value
1	ACHEX	*Achnanthes exigua*	224.46	677.03	5	1	350	459	2	2
2	ACHLAN	*Achnanthes lanceolata*	293.69	656.77	2	2	259	266	0	3
3	ACHLANROS	*Achnanthes lanceolata v. rostrata*	299.16	646.34	3	2	152	165	0	3
4	ACHMIN	*Achnanthes minutissima*	305.00	608.47	0	3	324	271	2	3
5	AMPFOG	*Amphora fogediana*	306.19	549.62	1	3	265	389	1	2
6	AMPINA	*Amphora inariensis*	319.31	536.85	2	2	433	485	3	2
7	AMPLIB	*Amphora libyca*	336.54	533.83	1	3	394	583	3	1
8	AMPOVA	*Amphora ovalis*	337.72	519.94	2	3	489	213	4	3
9	AMPPER	*Amphora perpusilla*	357.06	519.49	3	2	282	263	0	3
10	AMPSP1	*Amphora sp1 new*	362.33	516.44	0	1	285	498	1	2
11	AMPVEN	*Amphora veneta*	376.44	515.84	4	1	394	469	3	2
12	BACPAR	*Bacillaria paradoxa*	378.62	501.74	3	1	387	271	2	3
13	COCPL	*Cocconeis placentula*	389.65	496.49	2	2	437	412	3	2
14	COCPLEU	*Cocconeis placentula v. euglypta*	392.41	495.11	5	1	636	790	4	1
15	CYCKUT	*Cyclotella kutzingiana*	400.67	492.67	4	1	352	563	2	1
16	CYCMEN	*Cyclotella meneghiniana*	407.64	488.02	5	2	1417	736	5	1
17	CYCOCE	*Cyclotella ocellata*	415.89	481.01	3	2	298	426	1	2
18	CYCOPE	*Cyclotella operculata*	416.91	468.53	4	1	453	609	3	1
19	CYCSTE	*Cyclotella stelligera*	418.57	467.94	3	1	228	363	0	2
20	CYMAFF	*Cymbella affinis*	419.53	459.56	0	3	297	237	1	3
21	CYMAMP	*Cymbella amphicephala*	423.60	454.31	0	3	362	259	2	3
22	CYMCAS	*Cymbella caespitosa*	428.37	440.27	0	3	280	218	1	3
23	CYMLEP	*Cymbella leptoceros*	430.26	437.67	0	3	527	189	4	3
24	CYMMIC	*Cymbella microcephala*	432.27	435.85	0	3	399	239	3	3
25	CYMSIL	*Cymbella silesiaca*	435.79	435.31	3	3	177	177	0	3
26	CYMTUM	*Cymbella tumida*	449.18	434.87	0	3	488	287	3	2
27	CYMTUMLA	*Cymbella tumidula*	449.35	432.74	0	3	458	292	3	2
28	CYMTUR	*Cymbella turgidula*	450.01	429.25	0	2	398	419	2	2
29	DIPOBL	*Diploneis oblongella*	450.39	424.59	2	3	274	270	1	3
30	EUNSP	*Eunotia sp1*	454.23	415.54	3	1	263	435	1	2
31	FRACON	*Fragilaria construens*	458.62	413.86	3	2	321	379	2	2
32	FRACONAS	*Fragilaria construens v. asymetrica*	461.08	398.45	2	2	184	133	0	3
33	FRACONPUS	*Fragilaria construens v. pusilla*	466.79	393.32	3	2	268	337	1	2
34	FRALEPOBL	*Fragilaria leptostauron v. oblique*	466.88	387.93	2	2	283	381	1	2
35	FRASP	*Fragilaria sp1*	471.10	379.71	3	2	380	493	2	2
36	FRAULACU	*Fragilaria ulna v. acus*	472.20	379.35	5	1	859	889	3	1
37	GOMAPU	*Gomphonema apunctо*	475.04	378.10	1	3	264	268	1	3
38	GOMAUG	*Gomphonema augur*	480.01	376.17	1	3	632	538	4	2
39	GOMGRA	*Gomphonema gracile*	482.45	375.50	1	3	244	223	0	3
40	GOMMIN	*Gomphonema minutum*	494.51	358.41	1	3	294	173	1	3
41	GOMOLIV	*Gomphonema olivaceum*	503.22	356.29	2	2	316	362	1	1
42	GOMPARV	*Gomphonema parvulum*	506.02	353.63	4	2	1128	913	5	1
43	GOMTAC	*Gomphonema tackei*	508.38	349.50	1	3	609	841	4	1
44	GOMTRU	*Gomphonema truncatum*	512.87	346.65	0	3	180	150	0	3
45	GOMNITUNG	*Gomphonitzschia ungeri*	523.49	336.75	2	3	785	587	5	2
46	GYRSPE	*Gyrosigma spenceri*	526.89	335.74	2	3	176	167	0	3
47	MELGRAN	*Melosira granulata*	540.79	327.47	3	1	419	456	3	1
48	MELGRANANG	*Melosira granulata v. angustissima*	541.92	326.16	4	2	701	934	4	1
49	NAVACC	*Navicula accomoda*	548.72	324.91	4	2	1235	###	5	1
50	NAVANGSUB	*Navicula anglica v. subsalsa*	559.53	320.95	3	1	136	74	0	3
51	NAVATO	*Navicula atomus*	561.13	320.50	2	2	345	445	2	2
52	NAVCRY	*Navicula cryptocephala*	561.55	315.70	2	3	458	229	3	3
53	NAVDIG	*Navicula digitoradiata*	573.97	310.48	5	1	1049	795	5	1
54	NAVDIL	*Navicula diluviana*	589.64	303.06	5	1	1321	810	5	1
55	NAVEXI	*Navicula exigua*	606.42	293.62	4	2	441	387	3	2
56	NAVEXICAP	*Navicula exigua v. capitata*	606.79	290.11	3	2	540	547	4	1
57	NAVHEULEP	*Navicula heufleri v. leptocephala*	612.01	284.26	5	2	496	672	4	1
58	NAVKRI	*Navicula kriegeri*	616.07	269.97	0	3	429	257	3	3
59	NAVLANC	*Navicula lanceolata*	616.21	264.06	2	2	277	218	1	3
60	NAVPARV	*Navicula parva*	617.74	253.29	4	1	229	184	0	3
61	NAVPEL	*Navicula pelliculosa*	619.59	251.07	5	1	621	877	4	1
62	NAVPHY	*Navicula phyllepta*	630.69	242.11	5	1	393	567	2	1
63	NAVPLA	*Navicula platni*	631.53	230.44	5	1	1039	###	5	1
64	NAVPUP	*Navicula pupula*	631.92	229.26	5	1	330	432	2	2
65	NAVRAD	*Navicula radiosa*	645.21	224.58	1	3	898	419	5	2
66	NAVSAL	*Navicula salinarum*	660.16	186.43	1	2	523	414	4	2
67	NAVSALINT	*Navicula salinarum v. intermedia*	660.55	182.54	1	2	80.5	87	0	3
68	NAVVIR	*Navicula viridula*	682.63	169.42	4	2	397	501	3	2
69	NAVVIRAVE	*Navicula viridula v. avenacea*	702.69	165.03	3	3	216	125	0	3
70	NEDALP	*Neidium alpinum*	703.04	165.02	5	1	612	878	4	1
71	NEDPRO	*Neidium productum*	723.38	157.99	2	3	386	171	0	3
72	NITAMP	*Nitzschia amphibia*	726.60	156.73	4	3	365	733	3	1
73	NITAMPROS	*Nitzschia amphibia v. rostrata*	731.04	150.11	1	2	369	486	2	2
74	NITDISMID	*Nitzschia dissipata v. media*	739.41	148.62	1	3	309	289	1	3
75	NITFIL	*Nitzschia filiformis*	745.74	146.49	4	1	623	613	4	1
76	NITFILCON	*Nitzschia filiformis v. conferta*	751.17	140.10	4	1	145	91	0	3
77	NITFRU	*Nitzschia frustulum*	792.43	139.31	5	1	1426	419	5	2
78	NITINC	*Nitzschia inconspicua*	757.24	135.97	5	1	749	785	4	1
79	NITLEIS	*Nitzschia leistikowii*	797.32	130.15	0	1	713	820	4	1
80	NITLIEB	*Nitzschia liebetruthii*	818.41	126.68	1	2	523	490	4	2
81	NITOBT	*Nitzschia obtusa*	831.48	126.42	1	2	313	293	2	2
82	NITOBTKUR	*Nitzschia obtusa v. kurzi*	832.19	117.73	4	1	914	990	5	1
83	NITPAL	*Nitzschia palea*	851.17	115.08	4	1	805	576	5	1
84	NITPALC	*Nitzschia paleacea*	854.28	98.17	5	1	955	757	5	1
85	NITUMB	*Nitzschia umbonata*	917.85	91.83	4	1	1169	451	3	2
86	RHOGIB	*Rhopalodia gibba*	927.03	81.62	0	1	77.2	137	0	3
87	STAGRO	*Stauroneis groenlandica v. subgracilis*	973.72	69.17	5	1	752	742	5	1
88	SYNSP	*Synedra sp1*	996.25	51.33	3	2	363	634	2	1
89	SYNULN	*Synedra ulna*	1055.05	42.55	1	3	988	891	5	1
90	SYNULNAQU	*Synedra ulna v. aequalis*	1275.89	40.41	2	3	475	236	3	3
91	SYNULNRAM	*Synedra ulna v. ramesi*	1106.48	35.74	0	3	298	294	1	2

Table 2. Indicator (i) and Sensitivity (s) values of calculated Nile index (TDI-Nile) for TP on epilithic substrate compared with values of TDI, EPI, Toronto TDI and Van Dam list.

	TDI-Nile		TDI		EPI		van Dam	Toronto TDI	
Nme	**i**	**s**	**i**	**s**	**i**	**s**	**i**	**i**	**s**
Achnanthes exigua	5	1					7		
Achnanthes lanceolata	2	2			3	1	5	2	3
Achnanthes lanceolata var. rostrata	3	2			3	1	5		
Achnanthes minutissma	0	3	2	2	3	1	7	2	2
Amphora fogediana	1	3	5	1				3	3
Amphora inariensis	2	2	5	1			1	2	3
Amphora libyca	1	3	5	1				2	3
Amphora ovalis	2	3	5	1	3	2	5	2	3
Amphora venta	4	1	5	1			5		
Bacillaria paradoxa	3	1			5	3	5		
Cocconeis placentula	2	2			1	1	5		
Cocconeis placentula var. euglypta	5	1	3	2			5	2	3
Cyclotella kutzingiana	4	1			3	1			
Cyclotella meneghiniana	5	2	5	1	5	3	5	3	3
Cyclotella ocellata	3	2			3	1	4		
Cyclotella stelligera	3	1			3	1		4	3
Cymbella affinis	0	3	1	3	5	1	5	2	3
Cymbella amphicephala	0	3			3	1	2		
Cymbella caespitosa	0	3			1	2	7	2	2
Cymbella lepoceros	0	3	2	1	3	1	1		
Cymbella microcephala	0	3			1	1	4	2	1
Cymbella silesiaca	3	3			1	2	7	2	3
Cymbella tumida	0	3	2	1			4		
Cymbella turgidula	0	2	2	1					
Diploneis oblengella	2	3	1	1	3	1			
Fragilaria construens	3	2			1	1	4	3	2
Fragilaria ulna var. acus	5	1	3	1	3	1	5	1	2
Gomphonema augur	1	3	3	1			4		
Gomphonema gracile	1	3	3	1			3	2	3
Gomphonema minutum	1	3					5	2	2
Gomphonema olivaceom	2	2	5	2	5	1	5	3	3
Gomphonema parvulum	4	2	5	3	1	2	5	3	2
Gomphonema truncatum	0	3	3	1	3	2			
Gyrosigma spencerii	2	3	5	2	3	3			
Navicula accomoda	4	2			5	4	6		
Navicula anglica var. subsalsa	3	1	4	1					
Navicula atomus	2	2			3	4	6		
Navicula cryptocaphala	2	3	4	1			7	2	3
Navicula diluviana	5	1	2	1					
Navicula exigua	4	2					5		
Navicula lanceolata	2	2	5	2			5	2	3
Navicula pelliculosa	5	1					2		
Navicula pupula	5	1			3	3	4	2	3
Navicula radiosa	1	3	4	1	3	1	4	2	2
Navicula salinarum	1	2	4	1	5	3	5		
Navicula viridula	4	2	4	1	5	2	5	2	2
Neidium alpinum	5	1	2	3	5	1	1		
Neidium productum	2	3	2	3					
Nitzschia amphibia	4	3	5	3	3	3	5	3	3
Nitzschia amphibia var. rostrata	1	2	5	3					
Nitzschia filiformis	4	1					5		
Nitzschia frustulum	5	1	4	1			5		
Nitzschia inconspicua	5	1	4	1			5	3	2
Nitzschia leistikowii	0	1	4	1					
Nitzschia liebetruthii	1	2	4	1					
Nitzschia palea	4	1	4	1	1	3	6	3	2
Nitzschia paleacea	5	1			1	2	5		
Nitzschia umbonata	4	1	4	1	3	3	6		
Rhopalodia gibba	0	1	1	1			5		

TDI-Nile calculation

The species optima coefficients were rescaled from the inference model to assign as species indicator values for the diatom quality index. The indicator values were ranged from 0 (corresponding to lowest TP and TIN optima) to 5 (corresponding the highest TP and TIN coefficients). Each species was assigned a tolerance indicator value from 1(corresponding to highest TP and TIN tolerance) to 3 (corresponding to lowest TP and TIN tolerance), a sensitivity value of 3.

The TDI-Nile scores range from 1 (very low nutrient concentrations or clean water) to 5 (very high nutrient concentrations or grossly polluted water). The TP index classified the river into 9 sites in high quality, 14 sites with good quality, 12 sites in average quality and 6 sites in bad quality. The TIN index classified 16 sites in high water quality, 17 sites in good quality, 3 sites in average quality and 5 sites in bad quality. Most of the samples which classified in bad quality were belonging to Rosetta branch and station 2 at the Kema factory in the main stem of River Nile (Fig. 1).

The index scores were compared with the measured environmental variables using a Pearson correlation matrix (Table 3). The best correlation was obtained between the two developed indices and NO_2, NH_4, PO_4, EC and TDS. According to the canonical correlation analysis, which was used in order to evaluate the cumulative correlation between the developed TDI-Nile and the measured environmental variable, (Canonical correlation r= 0.79, $P < 0.0001$). The TDI-Nile indices represent a useful tool for biomonitoring the eutrophication in the River Nile

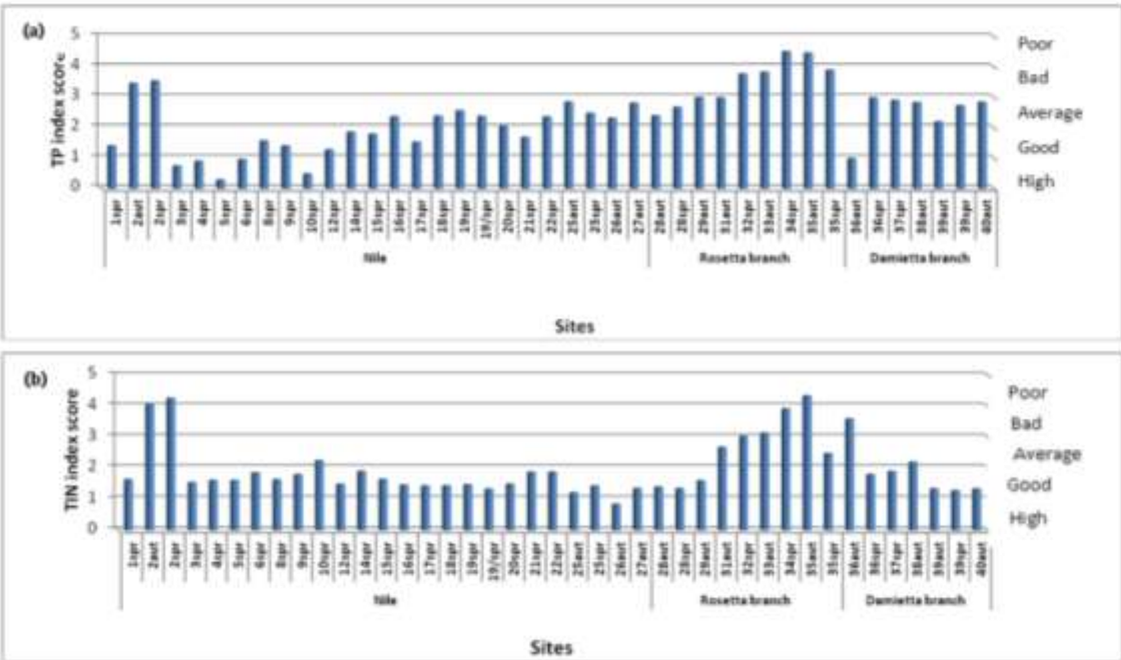

Fig. 1. Site ecological states according to TDI-Nile, a) TP index and b) TIN index

Table 3. Pearson correlation coefficients for epilithic TP and TIN indices with measured environmental variables

Variables	TP index	TIN index	NO2	NO3	NH4	TIN	PO4	TP	SiO3	PH	Temp	E.C	TDS mg/l	BOD
TP index	1													
TIN index	**0.4947**	1												
NO2	**0.4334**	**0.4554**	1											
NO3	-0.0363	0.2742	**0.7439**	1										
NH4	**0.5605**	**0.6898**	0.2034	-0.0276	1									
TIN	**0.4818**	**0.7404**	**0.6506**	**0.5612**	**0.8082**	1								
PO4	**0.4607**	**0.3548**	0.0409	-0.1916	**0.7124**	**0.4784**	1							
TP	**0.5722**	0.2606	0.1894	-0.0241	**0.6194**	**0.5050**	**0.7667**	1						
SiO3	**-0.5360**	0.0930	-0.2829	-0.0197	0.0393	-0.0130	-0.1382	-0.2862	1					
PH	-0.2897	**-0.5943**	**-0.5052**	**-0.4720**	**-0.4925**	**-0.6867**	-0.2424	-0.1605	0.0713	1				
Temp	-0.0346	-0.1033	0.1722	0.2745	**-0.3927**	-0.1568	**-0.5035**	-0.2949	0.0132	-0.0144	1			
E.C	**0.5545**	**0.3586**	0.1237	-0.1722	**0.7487**	**0.5271**	**0.6778**	**0.6563**	-0.3206	-0.1801	**-0.6335**	1		
TDS mg/l	**0.5545**	**0.3579**	0.1242	-0.1722	**0.7479**	**0.5265**	**0.6774**	**0.6563**	-0.3211	-0.1790	**-0.6334**	**1.0000**	1	
BOD	-0.1914	-0.3006	-0.0643	-0.0311	**-0.4259**	**-0.3650**	-0.1440	-0.2406	-0.1981	0.1532	-0.2651	-0.0502	-0.0494	1

Bold correlation is significant at the <0.005 level

DISCUSSION

Due to large industrial, agricultural and sewage discharges undoubtedly contribute large amounts of nutrients to Rosetta branch, high concentrations of P and N are common in sites belonging to this area of the river with the appearance of some pollution-tolerant taxa as *Navicula digitoradiata,Navicula diluviana, N. plathii, Nitzschia paleacea, N. umbonata and Stauroneis groenlandica var. subquadra*. Most of these taxa have a widespread distribution and consider being generalist and they can be used as indicator of poor water quality condition because they reach maximum abundance in more polluted sites (Charles *et al*., 2006). Most of the species which harbored an indicator value of 5 were recorded in the other compared indices; Van Dam checklist (van Dam *et al*., 1994), TDI (Kelly and Whitton, 1995), EPI (Dell'Uomo, 1996) and Toronto TDI (Zugic-Drakulic, 2006) and were classified in ranks of preferring eutophic and hypereutrophic water in the van Dam list and TDI. So, these species have been suggested to be found in water disturbed by input of nutrients.

When the TP indicator and sensitivity values of Nile indices compared with other indices constructed in other regions, TP indicator and sensitivity values were matched similar with few species (Table 2). However, although diatoms might have a wide geographical distribution and a globally similar ecology, their response to nutrient conditions may still be different between different ecoregions (Soininen and Niemel, 2002).

The TDI-Nile indices effectively quantify the response of the diatom flora based on the temporally and spatially integrated impacts of TP and TIN. These biotic indices simplify the complicated ecology of streams and rivers into a form that permits rapid assessment of the overall condition of a stream in a manner that is easily understood by non-technical resource managers (Gerritson, 1995). An important feature of these indices is the ability to include all diatom taxa found in the study region. Moreover, TDI-Nile differed from TDI (Kelly and Whitton, 1995), it takes into account centric diatoms, which are dominant in the River Nile, so it may perhaps perform well in rivers of high species richness of Centrales. The TP index of TDI-Nile (after compared with the Van Dam list, TDI and Toronto TDI) had higher significance correlation coefficient values than compared indices especially with pH, TIN, TP and

E.C as listed in Table (4). This comparison confirmed the successful using of the present developed indices in the biomonitoring programs of River Nile.

Table 4. Pearson correlation coefficient between different diatom indices and some measured environmental variables.

	TDI-Nile	Van Dam	TDI	Tronto TDI
pH	-0.28	-0.07	-0.08	-0.13
TIN	0.48**(**)**	0.13	0.03	0.05
TP	0.57**(**)**	0.39**(*)**	0.13	0.44**(*)**
E.C	0.55**(**)**	0.47**(*)**	0.004	0.45**(*)**

(**) Correlation is significant at the <0.003 level
(*) Correlation is significant at the 0.01 level

The developed indices in the present study characterize a wide range of water quality in the River Nile and the obtained results agreed well with the degree of pollution indicated by physical and chemical variables and with the combined effects of these factors (Canonical correlation r= 0.79, $P < 0.0001$).

These developed indices based on two variables, TP and TIN which simply signify the percentage of eutrophication. However, the ratios of the dissolved inorganic nitrogen to TP are better indicators of nutrient limitation in oligotrophic water. This suggests that DIN metrics may provide better measures of N requirements, and would be useful to add in future studies (Bergstrom, 2010).

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مؤشر الأثراء الغذائي الدياتومي (TDI-Nile): مؤشر جديد لتقدير الأثراء الغذائي في نهر النيل – مصر

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المستخلص

تم تطوير مؤشر جديد (**مؤشر الأثراء الغذائي الدياتومي TDI-Nile**) لتقديرجودة مياه نهر النيل وفرعيه باستخدام الدياتومات والفسفور الكلي والنيتروجين غير العضوى الكلي. تم تجميع عينات الدياتومات فوق الصخرية من 40 موقع موزعة علي طول المجري الرئيسي لنهر النيل وفرعيه خلال خريف 2013 وربيع 2014. وقد تم تعريف 224 نوع من الدياتومات واختير من بينهم 91 نوع (ذوي تكرارية $\leq$ 3) لادراجها في استنباط هذا المؤشر. وقد لوحظ من خلال التحليلات الاحصائية متعددة المتغيرات وجود ارتباط قوي لمجتمع الدياتومات مع المتغيرات البيئية بما في ذلك الفسفور الكلي. وقد استخدمت طريقة Weighted average في حساب المؤشر. وطبقا لهذا المؤشر (TDI-Nile) الذي تم أستنباطه فإن معظم المواقع التي تم تصنيفها في مستوي سيئ كانت تنتمي إلى فرع رشيد ومحطة كيما أما باقي المحطات فقد تنوعت بين المستوي المتوسط و الجيد. وكشف التحليل الاحصائي (Canonical correlation) أن مؤشر TDI-Nile أرتبط ارتباطا جيدا (Canonical correlation= 0.79، P < 0.0001) مع المتغيرات البيئية مما يجعله مؤشرا موثوق به لأغراض الرصد و تقييم جودة المياه في نهر النيل.