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Water Quality Assessment of Irrigation and Drainage Systems on the Basis of Phytoplankton Analysis

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ABSTRACT

Water systems in Upper Egypt appear to be vulnerable for Egyptians uses and abuses. Recognition of the ever increasing pressure on those resources and the inevitable conflicts of water utility always require promotion of strategies for better environmental management of this valuable resource. WHO has reported that about 40 thousand people worldwide are dying daily due to consumption of polluted water. Hence, it was thought imperative to assess the water quality and pollution status of aquatic habitats in Upper Egypt. Irrigation and drainage canals have an important role in controlling the water balance, for irrigation of agricultural lands and discharge from the cultivated soils. They may be subjected to anthropogenic impact that lead to perceptible changes in their regime particularly in the drainage canals. In such habitats, planktonic algae are sensitive to the dramatic fluctuations of water quality, and are therefore could be regarded as predictors for monitoring environmental conditions. Obvious differences were observed between the irrigation and drainage canals in water quality and phytoplankton abundance as well as its community structure. For instance, the species diversities in the irrigation canals were relatively higher than those in the drainage canals. Furthermore, some euglenoid and cyanoprokaryotic phytoplankton appeared in the drainage canals and completely disappeared in the irrigation canals. These observations provide evidence for possible use of phytoplankton to assess water quality.
Key words: cyanobacteria, ecological status, euglenoid algae, eutrophic, mesotrophic, oligotrophic

INTRODUCTION

Aquatic habitats appear to be susceptible to substantial alterations in water quality that may be reflected by distinct changes in water's physico-chemical parameters as well as by biological indicators and phytoplankton formation. Subsequently, water quality assessment was repeatedly performed depending on qualitative and quantitative structures of the phytoplankton community. Use of phytoplankton for assessment of freshwater quality dated back to 1940's (Thunmark, 1945; Nygaard, 1949). Subsequently, some saprobic and trophic indicator species were listed during 1950's by Järnefelt (1952) and Teiling (1955). Later on further works were carried out during the last two decades of the twentieth century (Heinonen, 1980; Hörnström, 1981; Rosén, 1981; Brettum, 1989; Kümmerlin, 1990; Tremel, 1996; Schönfelder, 1997; Gulyás, 1998; Lepistö and Rosensröm, 1998; Lepistö, 1999) dealing with the phytoplankton development as a criterion of freshwater quality assessment. Padisák *et al*. (2006); Borics *et al*. (2007); Reavie *et al*. (2010) discussed the usefulness of phytoplankton assemblages in studying ecological status for monitoring purposes of aquatic habitats. Besides, Andrade and Giroldo (2014) concluded that, the trophic status of shallow freshwater ecosystems could be roughly assessed depending on chlorophyll-*a* concentration which indicates the phytoplankton biomass. The structure and functioning of aquatic ecosystems is termed as ecological status that can be explained through hydro biological conditions and water quality. Accordingly, freshwater ecosystems are generally classified into different main categories (Hutchinson, 1967). Oligotrophic water habitats are characterized by relative richness with humic compounds, low phytoplankton biomass and no occurrence of water blooms with abundance of certain Phytoplankton species. Mesotrophic water bodies have moderate nutrient concentrations and phytoplankton population densities. Eutrophic freshwater systems are characterized by high phytoplankton biomass communities that are dominated by certain phytoplankton taxa and sometimes resulting in water blooms. The aim of this work was to evaluate the feasibility of phytoplankton as a monitored environmental variable in response to changes of water quality in shallow running water ecosystems in Upper Egypt.

MATERIALS AND METHODS

This study based on phytoplankton records and the data set of water quality measurements that were obtained by El-Otify (2003); El-Otify and Sheded (2003) during the investigations of irrigation and drainage canals in Upper Egypt. The studied canals are shallow- running water systems (length: < 2 -31 Km, width: < 10 -15 m, depth: < 0.5 -3.7 m) located in Aswan Province.

These investigated aquatic habitats are situated in an area of 34608 km^2 (85 m a. s. 1.) at 24˚ 2̀' north latitude and 32˚ 2̀ east longitudes. Water quality parameters were monitored according to APHA (1985). Phytoplankton abundance and biomass were analyzed using the methods described by Wetzel and Liknes (2001). Shannon-Weaver function (Shannon and Weaver, 1949) was applied to estimate phytoplankton species diversity index using the following equation:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

Where: *s* is the number of phytoplankton species in the sample; *pi* is the density measured (in this case is the cell, colony, coenobium or trichome counts) of *i* species.

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RESULTS AND DISCUSSION

Water Quality

Different parameters of water quality were measured and summarized in Table (1). Water temperature could be regarded as a limiting factor for aquatic biota and an important physical factor for creating currents, in affecting the density as well as viscosity of water. The recorded mean value of water temperature (16.23˚C) for irrigation canals was lower than that (18.05˚C) recorded for drainage canals. pH of water is the negative logarithm of the hydrogen ion concentration that indicates water alkalinity or acidity. The slightly recorded alkaline pH value that exceeded 7.5 in this study lay in the vicinity of the safe range for irrigation purposes of cultivated lands (Ayres and West cot, 1985). The reported mean values for the dissolved oxygen were; 8.21 mgl^{-1} in the irrigation canals and 9.4 mgl^{-1} in the drainage canals. The data also apparently indicated that the water of the drainage canals were mostly over saturated with dissolved oxygen. In this respect, the oxygen production through the photosynthetic activity by phytoplankton could be regarded as a major contribution for the increase of oxygen contents. Such correlations were confirmed for running water habitats by Friedrich and Pohlmann (2009); Andem *et al*. (2014). Electrical conductivity of the irrigation canals (mean values: 247.31 μScm^{-1}) was significantly lower than the reported values (1063.06 μScm^{-1}) of drainage canals. These values are mainly related to the ion concentrations of the aqueous solution and indicate the ability of the solution to carry an electrical current. Subsequently, the irrigation canal salinity which is regarded as a direct function of electrical conductivity appeared to be entirely safe for agriculture irrigation in Upper Egypt. This is in accordance with the measurements that were performed by Pumia and Lal (1979) of water for the irrigation purposes. Mean values (88.57 mgl^{-1}) of total hardness estimated in the drainage canals were greatly higher than those (43.96 mgl^{-1}) in irrigation canals. Generally, water hardness is principally governed by the concentrations of the divalent cations namely, calcium and magnesium (Tebbutt, 1977). The levels of total hardness are responsible for preventing lethal formation with soap. Regarding to the main nutrients, nitrate is considered as a common content of freshwater and the most highly oxidized form of nitrogen compounds or an end product of organic nitrogenous matter (Bartram and Balance, 1996). Mean values of nitrate contents were 1.02 mgl^{-1} in the irrigation and 27.06 mgl^{-1} in the drainage canals.

The reported phosphate concentrations were 28.01 μgl^{-1} for the irrigation canals and 36.05 μgl^{-1} for the drainage canals. According to Lepistö (1999) these relatively high values of nitrogen and phosphorus concentrations indicated euotrophy of the investigated water habitats. Mean values of the soluble reactive silica as essential nutrients for the growth and development of planktonic diatoms were reported to be of relatively high values both in the irrigation canals (11.18 mgl^{-1}) and in the drainage canals (16.54 mgl^{-1}). Sulphate contents were reported to be of relatively higher values in drainage canals than those in irrigation canals. A wide difference appeared between the mean values of sulphate concentrations of irrigation and drainage canals amounted to 41.47 mgl^{-1}.

Phytoplankton Biomass

Microscopic examination and counting of phytoplankton species as well as estimation of phytoplankton biomass are regarded as useful measurements in studying freshwater ecosystems. The data set of the monitored habitats indicated that the phytoplankton densities in terms of total counts of the irrigation canals were significantly higher than those of the drainage canals in Upper Egypt (Fig. 1). Furthermore, the total biomass levels and chlorophyll *a* concentrations (Table 2) supported these results. In this context, chlorophyll *a* concentration was evaluated as a predictor of freshwater phytoplankton biomass and standing crop measured from microscopic counts (Kasprzak *et al*., 2008; Wu *et al*., 2014). According to Heinonen (1980), the data illustrated in Fig. (2) demonstrate the phytoplankton biomass as indicator for ecological status of the irrigation and drainage canals in Upper Egypt. The vast majority of the investigated canals could be regarded as eutrophic water habitats.

However, more than 6% of the drainage canals lay in the vicinity of mesotrophic habitats. Furthermore, about 45% of the irrigation canals were of hypertrophic aquatic systems. In irrigation canals and drainage canals (Fig. 3) diatoms contributed with high percentage compositions in eutrophic and hypertrophic water. However, considerable percentage contributions were recorded for cyanophytes in mesotrophic water of drainage canals.

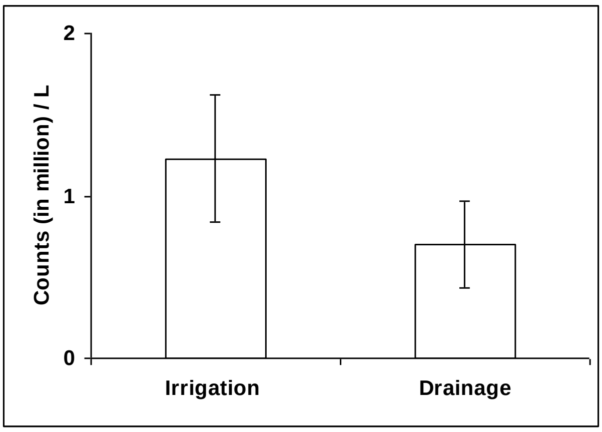

Figure (1): Mean values (±SD) of phytoplankton population densities in irrigation and drainage canals in Upper Egypt.

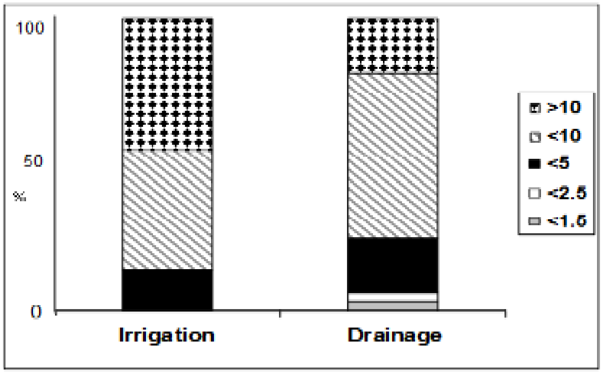

Figure (2): The proportion of different sites in irrigation and drainage canals determined as total phytoplankton biomass (wet. weight mgl^{-1}). The limits, according to the classification of Heinonen (1980) are:< 1.5-2.5=mesotrophic <2.5 -10=eutrophic and >10 = hypertrophic.

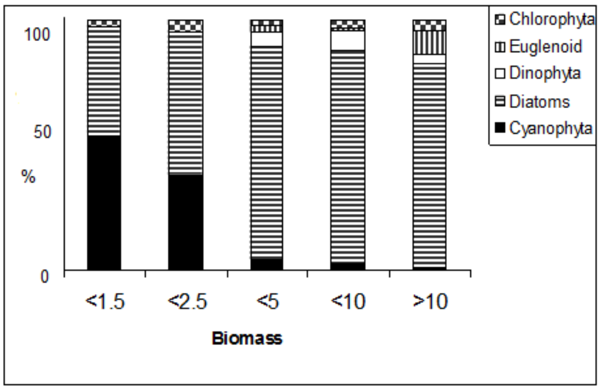

Figure (3): The proportion of different phytoplankton groups of different productivity determined as phytoplankton biomass (wet weight, mgl^{-1}) in the drainage canals.

Table (1): Water quality data and phytoplankton species diversity index for irrigation and drainage canals in Upper Egypt. SD denotes standard deviation.

Water quality parameters	Irrigation canals		Drainage canals	
	Mean	**SD**	**Mean**	**SD**
Temperature (°C)	16.23	2.67	18.05	3.14
pH value	7.59	0.48	7.62	0.32
Oxygen mgl-1	8.21	2.76	9.40	4.07
Oxygen % saturation	86.04	29.82	105.29	47.62
Salinity (%)	0.17	0.04	0.53	0.38
Electrical conductivity µScm-1	347.31	69.31	1063.06	758.27
NO3-N mgl-1	1.02	0.89	27.06	20.17
PO4-P µgl-1	28.01	21.91	36.05	13.31
SiO2 mgl-1	11.18	2.90	16.54	7.93
SO4 mgl-1	33.07	22.85	74.54	52.80
Total hardness mgl-1	43.96	5.10	88.57	42.44

Phytoplankton Abundance and Group Composition

The investigated water habitats differed from each other in terms of phytoplankton group composition (fig. 5). Major phytoplankton groups (divisions), listed in their overall contribution to total phytoplankton abundance were: Bacillariophyta, Cyanophyta, Chlorophyta and Pyrrophyta in irrigation canals. Whereas, in drainage canals (Fig. 6) the same group composition in addition to Euglenophyta was reported. Generally, the phytoplankton floristic composition was characterized by the dominance of diatoms. It can be observed that, this group contributed more than 80% of the total phytoplankton densities in irrigation and drainage canals.

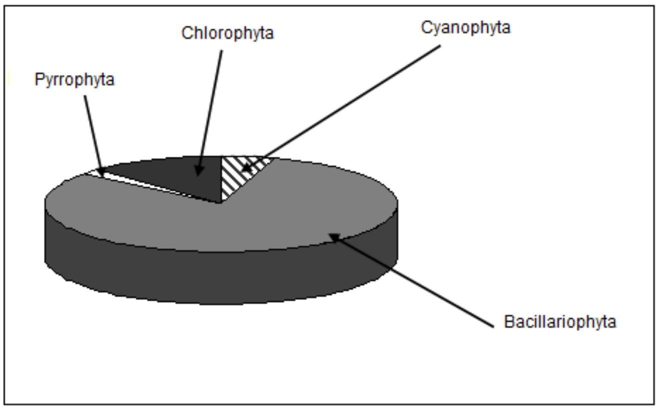

Figure (5): Relative densities of the different phytoplankton groups in the irrigation canals.

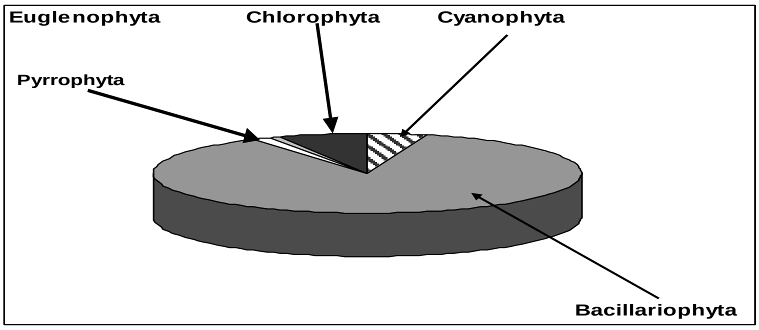

Figure (6): Relative densities of the different phytoplankton groups in the drainage canals.

Species Diversity

The number of species in irrigation canals was relatively higher than those observed in drainage canals (Table 2). Mean values of species diversity index (*H*') for the investigated canals, were calculated and presented in table (3). The mean *H*' values were more or less similar for the irrigation and drainage canals and did not exceed 2.2. However, the number of species in the irrigation canals was relatively higher than that in the drainage canals. The diversity index of these habitats was generally lower than that recorded for shallow aquatic ecosystems (Padisák, 1993) due to the abundance of few species that mainly represent high percentage contribution of the total phytoplankton density. A list of the recorded phytoplankton species in the irrigation and drainage canals and their frequency of occurrence are presented in table (3). In irrigation canals, the most frequent species that were recorded in all investigated samples were: the centric diatom *Cyclotella meneghiniana*, the pennate diatoms *Cocconeis placentula* and *Fragilaria uln*. In addition, other nine species were recorded in more than 90% of the samples. These species were: the cyanobacterium *Merismopedia warmingiana*, the centric diatom *Aulacoseira granulata*, the pennate diatoms *Gomphonema olivaceum*, *Navicula cryptocephala*, *Navicula gastrum* as well as the green coccoid phytoplankton: *Ankistrodesmus falcatus*, *Crucigenia rectangularis*, *Dictyosphaerium pulchellum* and *Scenedesmus* sp. Furthermore, nineteen species were recorded in more than 50% of the samples and considered as species of high occurrence. These species were represented by four cyanobacteria: *Anabaenopsis cunningtonii*, *Chroococcus* sp., *Planktolyngbya* sp., *Planktothrix agardhii*, seven pennate diatoms: *Amphora ovalis*, *Cymbella ventricosa*, *Gyrosigma* sp., *Melosira varians*, *Navicula radiosa*, *Nitzschia holsatica*, *Nitzschia* sp., two dinoflagellates: *Ceratium hirundinella*, *Peridinium* sp and six green phytoplankton namely: *Coelastrum reticulatum Elakatothrix genevensis Golenkinia radiate*, *Lagerheimia ciliate*, *Oocystis* sp. and *Tetraedron minimum*. At the other extreme, fifteen species were of moderate occurrence and recorded in more than 25% of the samples. Ten species were recorded in more than 12.5% (low occurrence) and 27 species were recorded in less than 12.5% of the samples (rare occurrence).

In drainage canals, the centric diatom *Cyclotella meneghiniana* as well as the pennate diatoms *Cocconeis placentula*, *Fragilaria ulna* and *Navicula cryptocephala* constituted the most frequent phytoplankton members. In general these species were recorded in more than 90% of the samples. Further thirteen species were of high occurrence: *Planktolyngbya* sp. (cyanobacteria), *Aulacoseira granulate Cymbella ventricosa Gomphonema olivaceum Gyrosigma acuminatum Navicula gastrum Nitzschia holsatica Nitzschia parvula Nitzschia* sp. (diatoms), *Ankistrodesmus falcatus*, *Crucigenia rectangularis*, *Scenedesmus* sp and *Schroederia setigera* (green phytoplankton). A further, twenty-three species were of moderate occurrence, ten others were of low and twenty-eight were regarded as rare. In the drainage canals, the euglenoid algae were represented by five species. However, this group was not reported in the irrigation. This may give evidence for organic pollution in the drainage canals. Furthermore, the high occurrence of the cyanophyte: *Planktothrix agardhii* in the irrigation canals and its moderate frequency of occurrence in the drainage canals could be in part attributed to high nitrate concentrations. The cyanobacterium *Planktothrix agardhii* was noticed as a common phytoplankton species in eutrophic freshwater resources (Bonilla *et al*., 2012). In this respect, it could be recommended that the combinations of species and phytoplankton groups may be useful in the prediction of water quality.

Table (2): Number of the investigated samples and recorded taxa as well as the mean values, standard deviation (%) of diversity index, phytoplankton biomass and chlorophyll *a* concentration of irrigation and drainage canals in Upper Egypt. n: number of samples or taxa. SD denotes standard deviation.

	Samples	Taxa	Diversity index (*H* ')		Biomass mgl^{-1}		Chlorophyll *a* μgl^{-1}	
	n	N	Mean	SD %	Mean	SD %	Mean	SD %
Irrigation canals	42	83	2.19	12.8	9.16	38.5	13.23	99.3
Drainage canals	32	78	2.20	15.9	7.72	54.8	6.27	98.4

Table (3): Phytoplankton species and their frequency of occurrence in irrigation and drainage canals in Upper Egypt.

Phytoplankton species	Author	Frequency (%)	
		Irrigation canals	Drainage canals
Cyanophyta:			
Anabaena sp.	Bory de Saint Vincent ex Bornet & Flahault	7.1	18.8
Anabaenopsis cunningtonii	Taylor	71.4	9.4
Aphanocapsa sp.	Nägeli	4.8	0
Chroococcus sp.	Nägeli	52.4	6.3
Merismopedia warmingiana	Lagerheim	90.5	31.3
Oscillatoria sp.	Vaucher	14.3	31.3
Phormidium sp.	Kützing	4.8	0
Planktolyngbya sp.	Anagnostidis & Komárek	71.4	56.3
Planktothrix agardhii	(Gomont) Anagnostidis & Komárek	50.0	43.8
Spirulina sp.	Turpin	16.7	28.1
Bacillariophyta:			
Amphora ovalis	Kützing	50.0	46.9
Aulacoseira granulata	(Ehrenberg) Simonsen	97.6	62.5
Bacillaria paradoxa	Gmelin	28.6	46.9
Caloneis silicula	(Ehrenberg) Cleve	31.0	43.8
Cocconeis placentula	Ehrenberg	100	90.6
Cyclotella meneghiniana	Kützing	100	90.6
Cymatopleura elliptica	(Brébisson) W. Smith	21.4	15.6
Cymatopleura solea	(Brébisson) W. Smith	31.0	37.5
Cymbella ventricosa	Kützing	76.2	75.0
Cymbella sp.	J. G. Agardh	4.8	0
Epithemia adnata	(Kützing) Rabenhorst	9.5	6.3
Epithemia sorex	Kützing	11.9	3.1
Fragilaria ulna	(Nitzsch) Lange-Bertalot	100	96.9
Fragilaria sp.	Lyngbye	4.8	0
Gomphonema acuminatum	Ehrenberg	2.4	0
Gomphonema angustatum	(Kützing) Rabenhorst	14.3	25.0
Gomphonema olivaceum	(Hornemann) Brébisson	95.2	75.0
Gyrosigma acuminatum	Kützing	28.6	81.3
Gyrosigma sp.	Hassall	57.1	40.6
Melosira varians	J. G. Agardh	52.4	28.1
Navicula confervaceae	Kützing	7.1	3.1
Navicula cryptocephala	Kützing	95.2	90.6
Navicula exigua	Gregory	40.5	15.6
Navicula gastrum	Ehrenberg	92.9	50.0
Navicula pupula	Kützing	2.4	3.1
Navicula radiosa	Kützing	69.1	18.8
Navicula rhynchocephala	Kützing	47.6	46.9
Navicula sp	Bory de Saint Vincent	23.8	21.9
Nitzschia holsatica	Hustedt	81.0	78.1
Nitzschia parvula	W. Smith non Lewi	23.8	75.0
Nitzschia sigmoidea	(Nitzsch) Ehrenberg	21.4	40.6
Nitzschia sp.	Hassall	69.1	87.5
Pinnularia sp.	Ehrenberg	2.4	15.6
Rhoicosphenia curvata	(Kützing) Grunow	11.9	9.4
Rhopalodia gibba	(Ehrenberg) O. Müller	35.7	31.3
Stauroneis sp.	Ehrenberg	11.9	34.4
Surirella ovata	Kützing	16.7	34.4
Surirella robusta	Ehrenberg	2.4	25.0
Pyrrophyta:			
Ceratium hirundinella	(O. F. Müller) Dujardin	54.8	28.1
Peridinium sp.	Ehrenberg	66.7	25.0
Euglenophyta:			
Euglena acus	Ehrenberg	0	9.4
Euglena sp.	Ehrenberg	0	3.1
Lepocinclis sp.	Perty	0	3.1
Phacus sp.	Dujardin	0	25.0
Trachelomonas sp.	Ehrenberg	0	3.1
Chlorophyta:			
Ankistrodesmus bibraianus	Korshikov	2.4	0
Ankistrodesmus falcatus	(Corda) Ralfs	95.2	71.9
Ankistrodesmus stipitatus	(Chodat) Komarekova-Legnerova	31.0	9.4
Closterium acutum	Brébisson	33.3	9.4
Closterium moniliferum	(Bory) Ehrenberg	4.8	6.3
Coelastrum microporum	Nägeli	26.2	6.3
Coelastrum reticulatum	(Danjeard) Senn.	71.9	0
Cosmarium botrytis	Meneghini	2.4	3.1
Cosmarium depressum	Lundell	9.5	18.8
Crucigenia rectangularis	(Nägeli) Gay	97.6	50.0

Dictyosphaerium pulchellum	Wood	92.9	40.6
Elakatothrix genevensis	(Reverdin) Hindák	61.9	9.4
Gloeocystis sp.	Nägeli	26.2	3.1
Golenkinia radiate	Chodat	57.1	18.8
Kirchneriella lunaris	(Kirchner) Moebius	2.4	3.1
Lagerheimia ciliata	(Lagerheim) Chodat	88.1	21.9
Micractinium sp.	Fresenius	14.3	0
Oocystis sp.	A. Braun	66.7	9.4
Pandorina sp.	Bory	0	3.1
Pediastrum boryanum	(Turpin) Meneghini	2.4	0
Pediastrum duplex	Meyen	4.8	3.1
Pediastrum ovatum	(Ehrenberg) A. Braun	9.5	0
Pediastrum simplex	Meyen	26.2	3.1
Pediastrum tetras	(Ehrenberg) Ralfs	7.1	6.3
Scenedesmus acuminatus	(Lagerheim) Chodat	11.9	0
Scenedesmus acutus	Meyen	11.9	9.4
Scenedesmus arcuatus	Lemmermann	16.7	6.3
Scenedesmus brevispina	(G. M. Smith) Chodat	4.8	3.1
Scenedesmus ecornis	(Ralfs) Chodat	0	3.1
Scenedesmus quadricauda	(Turpin) Brébisson	42.9	43.8
Scenedesmus tibiscensis	Uherkovich	2.4	0
Scenedesmus sp.	Meyen	97.6	65.7
Schroederia setigera	(Schröder) Lemmermann	31.0	62.3
Staurastrum paradoxum	Meyen	40.5	12.5
Tetraedron minimum	(A. Braun) Hansgirg	69.1	25.0

CONCLUSION

From the preceding survey of the aforementioned data concerning water quality and phytoplankton assemblages in shallow running water ecosystems of irrigation and drainage canals in Upper Egypt, it can be concluded that: from a hydro biological point of view, the assessment of water quality of the shallow running water habitats in Upper Egypt cannot be obtained by use of one parameter from different chemical and biological water features. It seems to be better to take in account different chemical parameters and species combinations of phytoplankton in addition to phytoplankton quantitative compositions.

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تقييم نوعية مياه الرى و الصرف على أساس التحاليل البيولوجية للهائمات النباتية

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الملخص العربي

قد تتعرض النظم البيئية للمياه فى صعيد مصر الى بعض التجاوزات التى تؤدى أحيانا الى انتهاكها من خلال سوء استعمالها. و يستدعى ذلك أن تنال الموارد المائية اهتماما خاصا لمواجهة التحديات التى تتمثل فى تعارض الحاجة الملحة للمياه بصفة مستمرة مع متطلبات المحافظة على الموارد المائية و نوعية تلك الموارد وجودة مياهها. كما يوحى ذلك بالضرورة الملحة التى تتطلب تعزيز الاستراتيجيات اللازمة لتحسين الادارة البيئية لتلك الموارد. خصوصا وقد ورد فى أحد تقارير منظمة الصحة العالمية أن حوالى أربعين الف شخص حول العالم يموتون يوميا بسبب استعمال المياه الملوثة. و من ثم فان الحاجة الملحة لتقييم نوعية المياه و مدى تأثير عوامل التلوث عليها أصبحت أمرا ضروريا. تعتمد الأراضى الزراعية فى صعيد مصر على شبكة متكاملة من قنوات الرى والصرف و التى قد تتعرض لتأثير النشاط البشرى على نوعية مياهها. وتعتبر الطحالب المجهرية التى تعيش فى مياه تلك القنوات و تمثل عشائر الهائمات النباتية بها كائنات حساسة لما قد تتعرض له المياه فى تلك البيئات من تغيرات فى نوعيتها و بالتالى فانه يمكن الاعتماد على التقدير الكمى و النوعى لمجتمعات الهائمات النباتية لرصد الظروف البيئية للمياه. لقد اتضح من خلال النتائج التى أسفرت عنها الدراسة الحالية وجود اختلافات فى نوعية المياه و وفرة الهائمات النباتية وتركيبها النوعى بين قنوات الرى و الصرف. وعلى سبيل المثال كانت الأنواع التى تمثل مجتمعات الهائمات النباتية أكثر تباينا فى قنوات الرى عنها فى قنوات الصرف، و علاوة على ذلك فقد ظهرت بعض الأنواع من الطحالب اليوجلينية و الخضراء المزرقة فى مياه قنوات الصرف واختفت تماما فى قنوات الرى. و تدل هذه النتائج على امكانية استخدام الهائمات النباتية و اعتبارها كواشف بيولوجية لتقييم نوعية مياه قنوات الرى و الصرف فى صعيد مصر.