Scientific Journal for Damietta Faculty of Science 5 (1) 2015, 48-61
ISSN Print 2314-8594
ISSN Online 2314-8616

Efficiency assessment of drinking water treatment processes in the removal of phytoplankton at Damietta – Egypt

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Received: 24 May 2015 / Accepted: 7 August 2015

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Abstract

The present study intended to evaluate the efficiency of removal of phytoplankton of four different techniques used in the drinking water treatment plants (DWTPs) at Damietta. Water was monthly sampled throughout one year from April 2013 to March 2014. The pH of water as well as the concentrations of ammonia, nitrite, silica, orthophosphate and heavy metals were within the allowable limits and decreased towards the output in the four DWTPs. By contrast, the levels of dissolved oxygen (DO) and aluminium (Al) increased towards the output. Only in one of the four DWTPs examined, turbidity exceeded the allowable limits. Out of the 96 phytoplankton taxa encountered, 48 belong to Chlorophyta, 23 to Bacillariophyta and 11 to Cyanobacteria. The water treatment processes resulted relatively efficient removal of Cyanobacteria which were replaced by Chlorophyta. The efficiency of DWTPs in removal of phytoplankton depended on the technique used; where the most effective technique was the rapid rate gravity sand filter with 94.3% removal, followed by the roughing gravel filter technique with 89.5% removal and the clariflocculator technique with 73% removal, while the least effective one was the plate settler technique with 69.5% removal. In fact, the excessive growth of Cyanobacteria at intakes of all DWTPs needs a preliminary physical removal to avoid cell lysis and cyanotoxin release during chemical treatment.

Keywords: Drinking Water Treatment Plants – Heavy metals - Nutrients- Phytoplankton.

Introduction

Damietta branch of the Nile River is obstructed by a permanent dam at Al-Shoaraa city about 15 km south of the Mediterranean sea. The stagnant water behind the dam -mostly brackish or saline- is completely different from the freshwater in front of the dam (Al-Afify, 2006). Damietta branch of the River Nile is loaded with pollutants from several sources; for example, the fertilizer factory at Talkha which is the main source of chemical and thermal pollution of water, and the electric power station at Kafr Saad. Domestic and sewage effluents and agricultural drainage at El-Serw station represent another source of pollution (APRP, 2002). Recently, the heavy pollutant input of fish boxes further aggravates the problem. Pollution and eutrophication of water lead to the presence of high concentrations of organic and inorganic compounds, which enhance algal blooming particularly the Cyanobacteria that produce cyanotoxins such as microcystins, which negatively affect water quality (Li *et al*., 2011). In this respect, microcystins are the most frequently identified toxins associated with cyanobacterial blooming in many freshwater and brackish environments in temperate climates (Zamyadi*et al*., 2012b). The blooming of phytoplankton at the intakes of drinking water treatment plants has a physical impact (e.g. clogging of filters) and chemical impact such as production of taste and odor, cyanotoxins and by products after oxidation with chlorine in the treatment process (Merel, 2010; Zamyadi *et al.*, 2012a; Liu *et al*., 2013).

The removal of phytoplankton represents a challenge during water treatment processes; for it is often affected by various factors such as: (i) the phytoplanktonic species present; (ii) phytoplankton concentration in the water source; (iii) the coagulation, flocculation and sedimentation processes and (iv) the effectiveness of the sand filtration process (Ewerts *et al*., 2013). Pivokonsky *et al.* (2014) stated that the water treatment processes should be adapted not only to the species composition and the age of algal populations occurring in the water source, but also to the release of cellular organic matter into water. Drinking water must be clear, free of odor, color, taste and infectious microorganisms (USEPA, 1999). Different types of surface water treatment plants, such as the conventional clarifier plants, direct filtration plants and compact unit plants, are now in operation to suffice the increased need of drinking water in Damietta governorate (Hegazy, 2012).The efficiency of these drinking water treatment plants (DWTPs) in removal of contaminants particularly phytoplankton has not yet been sufficiently evaluated. So the objective of this study is to evaluate the efficiency of different types of DWTPsat Damietta in removal of phytoplankton from drinking water.

Materials and methods

The study area

The study area involved four different drinking water plants (DWTPs) built on Damietta branch of the Nile River and located at $31^{o}\,25'$ N and $31^{o}\,67'$ E(Fig.1). DWTP1- located at Dakahla- is an one-stage direct filtration involving the following stages: intake, rapid rate gravity sand filter, final chlorination in reservoir for 2 hr and the outflow. DWTP2 - located at Ezab Elnahda- is two stages direct filtration involving the following stages: intake, roughing gravel filter, rapid rate gravity sand filter, final chlorination in reservoir for 2 hr and the outflow. DWTP3- located at Eladlia- is a compact unit involving the following stages: intake, plate settler, pressure sand filter, final chlorination in reservoir for 1 hr and the outflow. DWTP4- located at Eladlia- is a conventional treatment process involving the following stages: intake, clariflocculator, rapid rate gravity sand filter and final chlorination in reservoirs for 4 hr and the outflow.

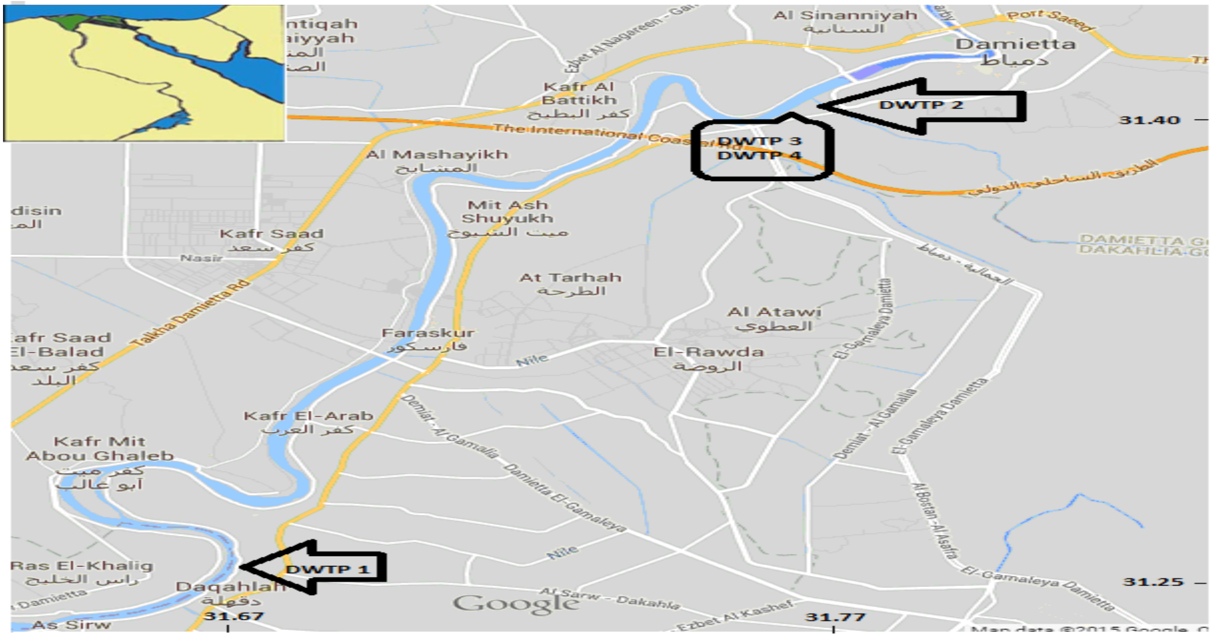

Fig.1. Map shows the localities of four water drinking plants at Damietta, Egypt.

Physico-chemical analysis:

Water samples were monthly collected over a period of one year from April 2013 to March 2014. Temperature and pH of water were determined in situ using YSI model 33 SCT meter and a Horizon pH meter respectively. The other physico-chemical properties including turbidity, dissolved oxygen (DO), reactive chloride (R.Cl), ammonia, phosphate, nitrite, silicon and heavy metals were determined according to APHA (2005).

Phytoplankton analysis

One litter of water samples was treated with 2%Lugol's solution and 2%formaldehyde, and after complete sedimentation the mixture was siphoned using the sedimentation technique of Lund (1958). The treated samples were stored in dark bottles till use. Algal species were identified according to Skuja (1948), Whitford and Shumacher (1973), Cornelius (1971), Prescott (1951, 1969), Hindak *et al.* (1975), Philipose (1967) and Cyrus andSladecek (1973). The cleaning technique of diatoms was adopted according to Cronberg (1982).The biological qualitative assessment was calculated using diversity, Shannon and Evenness indices of were calculated according to Staub *et al.* (1970).

Statistical analysis:

The data of physico-chemical and phytoplankton analyses were statistically analyzed using CANOCO version 4.5 (TerBraak, 1987).

Results and Discussion

Physico-chemical analysis of water

Table (1) shows that there is no remarkable variation in water temperature between the intake basins and the outflows at all the investigated DWTPs. The seasonal water temperature reflected the normal pattern of high temperature (average of 33°C) in summer and of low temperature (average of 13°C) in winter. The seasonal variation of water temperature could control phytoplankton growth and diversity; and this agrees with the findings of Schabhtt *et al.* (2013) who demonstrated efficient growth of green algae and diatoms at low temperatures in contrast to the luxurious growth of cyanobacteria at high temperatures. Phytoplankton diversity and density usually decrease in response to nutrient deprivation and low temperature (Nowrouzi and Valavi, 2011). The water pH generally decreased towards the outputs and ranged between slightly alkaline (pH = 8.6) at DWTP3 intake in April 2013 and almost neutral (pH = 7.29) at DWTP1output in July 2013.By contrast, the level of DO was considerably higher in outputs than intake basins at all DWTPs (Table 1). The increase in DO levels has been attributed to the physical and chemical treatment of water which involves addition of chlorine and alum or removal of microorganisms. The neutral-alkaline pH of water is known to support faster growth and establishment of Cyanobacteria than the other microalgal groups (Renuka *et al*., 2014).This agrees with the findings of AWWA **(**2011) who reported that, chlorine gas decreases pH but increases the DO content of water**.**

Perusal data showed that the highest level of turbidity was found at DWTP3 output, where it was more or less the allowable limit while, the lowest turbidity was recorded at the DWTP2 output. This means that the technique of roughing gravel filter and rapid rate gravity sand filter used in DWTP2 is more effective in treatment of water than the pressure sand filter technique used in DWTP3. Generally, turbidity of water decreases while aluminum concentration increases in the direction from intake basins towards the output. This is due to the addition of alum (aluminum sulphate) as a coagulant during the coagulation stage. In this respect, Schabhtt *et al* (2013) stated that aluminum-based coagulants such as alum resulted in the elevation of Al concentrations in the treated water. The effective removal of ammonia, nitrite and iron by initial and final chlorination in treatments in agreement with AWWA (2011) who reported that, chlorine is the most widely used oxidant for nitrite, ammonia and reduced iron in water treatment practices.

The levels of silica, orthophosphate and heavy metals in water considerably decreased in the direction from intake basins towards outflow in all DWTPs, and the concentration of silica was in the range suitable for diatom growth and those of heavy metals were reduced at the output to extremely low levels. This may be due to the chemical treatment in the coagulation stage. Hammad and Ibrahim (2012) concluded that silica, nitrate and phosphate of water are limiting factors for the abundance of diatoms.

Table 1: Monthly variations of physico-chemical parameters of four different drinking water plants at Damietta, Egypt.

			Apr. 2013	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 2014	Feb.	Mar.	Permissible levels	
															Egyptian Standar	USEPA
Temp. °C	DWTP1	I.	21.00	25.00	30.00	32.00	27.00	27.00	18.00	17.50	14.00	15.00	18.00	24.50	(458/2007)	2009
		O.	21.00	28.00	30.00	32.00	28.00	28.00	17.00	18.00	14.00	14.00	18.00	25.00	NM	
	DWTP2	I.	21.00	26.00	33.00	33.00	29.00	28.00	20.00	17.00	18.50	16.00	20.00	27.00		
		O.	21.00	26.00	31.50	33.00	27.00	26.00	19.00	17.00	18.00	15.00	20.00	25.00		
	DWTP3	I.	23.00	27.00	30.30	31.00	29.50	29.00	20.00	17.00	16.00	13.00	20.00	25.00		
		O.	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00		
	DWTP4	I.	23.00	24.00	30.70	30.00	30.00	25.00	20.00	20.00	15.00	16.00	21.00	24.00		
		O.	23.00	27.00	29.00	30.00	28.00	24.00	19.00	18.00	15.00	16.00	20.00	22.00		
pH	DWTP1	I.	8.00	7.85	7.97	7.98	8.01	7.99	8.00	8.10	8.01	8.27	8.01	7.80	6.5 - 8.5	6.5 - 8.5
		O.	7.37	7.49	7.44	7.29	7.49	7.52	7.54	7.58	7.47	7.58	7.42	7.58		
	DWTP2	I.	8.28	7.34	8.20	7.86	8.42	7.87	7.98	8.31	8.05	8.21	8.34	8.35		
		O.	7.48	7.60	7.40	7.45	7.53	7.52	7.61	7.66	7.46	7.73	7.59	7.50		
	DWTP3	I.	8.60	7.38	8.33	8.07	8.30	8.02	7.96	8.10	8.10	8.26	8.33	8.37		
		O.	7.67	7.60	7.57	7.73	7.70	7.53	7.61	7.83	7.58	7.80	7.72	7.55		
	DWTP4	I.	8.47	7.40	8.18	8.05	8.55	7.90	7.96	8.03	8.11	8.32	8.32	8.35		
		O.	7.55	7.46	7.48	7.42	7.66	7.41	7.52	7.51	7.51	7.63	7.33	7.56		
Turbidity (NTU)	DWTP1	I.	4.45	5.39	3.90	5.87	4.49	4.45	4.72	7.00	3.08	3.26	5.20	6.87	1	1
		O.	0.60	0.95	0.49	0.38	0.50	0.98	0.70	0.97	0.70	0.60	0.84	0.96		
	DWTP2	I.	3.94	3.91	2.62	3.96	4.02	4.25	3.15	5.78	3.54	4.03	4.65	5.68		
		O.	0.38	0.50	0.29	0.68	0.37	0.44	0.40	0.42	0.52	0.38	0.90	0.85		
	DWTP3	I.	4.30	6.80	3.37	4.45	7.90	4.55	3.42	4.13	5.00	6.03	4.46	5.51		
		O.	1.00	1.20	0.98	1.00	1.30	0.50	0.70	0.95	0.81	1.00	0.92	1.10		
	DWTP4	I.	3.50	4.10	3.39	3.30	5.45	3.97	2.99	6.65	4.55	5.73	5.80	5.25		
		O.	0.78	0.98	0.64	0.70	1.00	0.40	0.50	0.57	0.85	0.70	0.95	0.94		
DO (mg/L)	DWTP1	I.	8.20	9.00	8.00	8.50	7.60	9.40	8.50	9.50	9.00	9.60	8.80	6.60	NM	
		O.	9.30	10.10	9.34	9.40	9.20	10.50	9.60	10.30	10.00	10.54	9.30	8.80		
	DWTP2	I.	9.80	8.80	8.94	8.70	8.00	9.50	7.30	9.30	10.00	10.20	9.30	9.70		
		O.	10.80	9.40	10.60	9.80	9.50	10.70	8.80	10.50	11.20	11.80	10.50	10.80		
	DWTP3	I.	8.86	8.40	8.80	7.70	8.20	9.00	8.70	8.50	8.90	9.10	10.20	8.10		
		O.	10.60	10.20	9.84	8.90	9.40	10.60	10.00	9.50	10.30	10.60	11.50	10.00		
	DWTP4	I.	9.30	8.80	9.10	8.10	8.70	9.70	10.00	9.50	9.50	10.30	10.50	8.30		
		O.	10.83	9.80	9.84	9.40	10.00	10.70	11.00	10.40	10.70	11.12	11.50	9.10		
R.Cl (mg/L)	DWTP1	I.													5	4
		O.	1.50	1.30	1.50	1.80	1.80	1.50	1.80	1.50	1.70	1.80	1.20	1.20		
	DWTP2	I.														
		O.	1.70	1.80	1.70	1.80	1.50	1.50	1.80	1.80	1.50	1.70	1.40	1.50		
	DWTP3	I.														
		O.	1.50	1.80	3.00	1.30	1.80	1.00	1.80	0.60	1.00	1.50	1.30	1.50		
	DWTP4	I.														
		O.	1.80	1.50	1.30	1.30	1.30	1.80	1.50	1.30	1.30	1.60	3.00	1.50		
Chloride (mg/L)	DWTP1	I.	24.00	27.00	24.00	25.00	25.00	21.00	26.00	30.00	34.00	29.00	30.00	26.00	250	250
		O.	30.00	33.00	29.00	30.00	31.00	26.00	30.00	36.00	39.00	34.00	36.00	30.00		
	DWTP2	I.	30.00	30.00	32.00	23.00	32.00	28.00	27.00	36.00	41.00	34.00	30.00	26.00		
		O.	36.00	37.00	38.00	30.00	38.00	34.00	35.00	42.00	47.00	41.00	36.00	33.00		
	DWTP3	I.	29.00	31.00	32.00	26.00	33.00	23.00	26.00	33.00	38.00	32.00	29.00	29.00		
		O.	36.00	36.00	38.00	32.00	39.00	36.00	31.00	39.00	43.00	38.00	35.00	35.00		
	DWTP4	I.	31.00	29.00	30.00	24.00	35.00	31.00	29.00	33.00	42.00	35.00	34.00	31.00		
		O.	35.00	34.00	34.00	28.00	40.00	36.00	33.00	38.00	48.00	40.00	39.00	37.00		
Ammonia (mg/L)	DWTP1	I.	0.18	0.21	0.24	0.25	0.19	0.17	0.14	0.15	0.19	0.17	0.16	0.22	0.5	NM
		O.	0.02	0.04	0.02	0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01		
	DWTP2	I.	0.10	0.12	0.12	0.12	0.10	0.08	0.09	0.07	0.09	0.08	0.07	0.09		
		O.	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01		
	DWTP3	I.	0.05	0.13	0.10	0.09	0.07	0.07	0.08	0.07	0.08	0.07	0.09	0.09		
		O.	0.00	0.01	0.01	0.00	UDL	0.00	0.01	0.01	0.00	0.01	0.00	0.01		
	DWTP4	I.	0.08	0.10	0.09	0.08	0.14	0.09	0.07	0.06	0.08	0.06	0.07	0.08		
		O.	0.00	0.00	0.01	0.00	UDL	UDL	UDL	0.00	0.00	UDL	0.00	0.01		
Nitrite (mg/L)	DWTP1	I.	0.48	0.50	0.54	0.56	0.45	0.48	0.40	0.42	0.50	0.62	0.48	0.50	0.2	1
		O.	UDL	UDL	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01		
	DWTP2	I.	0.30	0.35	0.30	0.40	0.38	0.40	0.38	0.52	0.40	0.38	0.36	0.40		
		O.	UDL	0.01	UDL	UDL	0.01	UDL	0.02	UDL	0.01	0.01	UDL	0.01		
	DWTP3	I.	0.20	0.30	0.19	0.40	0.20	0.30	0.35	0.40	0.36	0.38	0.36	0.38		
		O.	UDL	UDL	UDL	0.001	UDL	UDL	0.01	0.02	0.01	0.01	0.01	0.01		
	DWTP4	I.	0.16	0.20	0.20	0.30	0.34	0.38	0.40	0.40	0.34	0.28	0.26	0.36		
		O.	UDL	0.003	UDL	UDL	UDL	0.01	0.02	0.01	0.01	0.02	0.01	0.01		
Aluminum (mg/L)	DWTP1	I.	0.02	0.05	0.02	0.02	0.03	0.01	0.03	0.02	0.04	0.01	0.03	0.02	0.2	0.2
		O.	0.08	0.13	0.13	0.14	0.08	0.05	0.07	0.08	0.11	0.09	0.14	0.06		
	DWTP2	I.	0.02	0.00	0.02	0.07	0.02	0.00	0.01	0.02	0.06	0.01	0.03	0.03		
		O.	0.05	0.04	0.10	0.15	0.07	0.08	0.07	0.05	0.09	0.04	0.11	0.12		
	DWTP3	I.	0.01	0.03	0.01	0.07	0.00	0.02	0.01	0.01	0.03	0.04	0.04	0.04		
		O.	0.08	0.08	0.09	0.14	0.04	0.06	0.09	0.07	0.06	0.12	0.16	0.14		
	DWTP4	I.	0.01	0.05	0.02	0.08	0.00	0.03	0.02	0.01	0.03	0.05	0.01	0.04		
		O.	0.05	0.11	0.14	0.14	0.04	0.14	0.05	0.03	0.05	0.16	0.10	0.17		
Orthophosphate (mg/L)	DWTP1	I.	0.76	0.82	0.86	0.90	0.80	1.00	0.40	0.50	0.82	0.70	0.60	0.89	NM	
		O.	0.12	0.10	0.20	0.06	0.20	0.10	0.31	0.10	0.20	0.22	0.05	0.20		
	DWTP2	I.	0.64	0.52	0.71	0.60	0.63	0.68	0.43	0.41	0.50	0.70	0.60	0.50		
		O.	0.20	0.11	0.30	0.17	0.14	0.21	0.05	0.10	0.12	0.22	0.19	0.10		
	DWTP3	I.	0.25	0.8	0.68	0.61	0.3	0.5	0.4	0.5	0.3	0.4	0.61	0.54		
		O.	0.25	0.30	0.11	0.10	0.35	0.10	0.08	0.10	0.24	0.06	0.04	0.12		
	DWTP4	I.	0.49	0.55	0.52	0.50	0.62	0.50	0.40	0.50	0.30	0.30	0.20	0.40		
		O.	0.13	0.10	0.10	0.03	0.21	0.10	UDL	0.15	0.06	0.05	0.03	0.10		
Silica (mg/L)	DWTP1	I.	2.62	2.82	3.07	2.72	1.88	2.23	2.52	1.33	2.27	2.66	2.42	2.95	NM	
		O.	1.82	1.73	1.83	1.18	1.72	1.21	1.82	1.68	1.85	1.76	1.62	1.36		
	DWTP2	I.	2.88	2.45	3.14	2.97	3.34	2.28	2.16	2.67	2.22	3.01	3.37	2.22		
		O.	2.53	1.95	1.70	1.29	1.62	1.14	1.60	1.90	1.32	1.18	1.51	1.58		
	DWTP3	I.	3.51	2.60	3.38	2.51	3.54	3.34	2.73	2.61	2.24	2.79	2.04	2.25		
		O.	1.24	2.03	1.73	1.91	1.22	2.86	1.24	1.61	1.61	1.28	1.44	1.80		
	DWTP4	I.	3.61	3.30	2.95	2.28	3.29	2.69	2.81	2.63	2.04	2.83	3.27	2.66		
		O.	1.92	1.67	1.73	1.42	1.42	2.30	1.60	1.18	1.20	1.12	1.45	1.75		

I: intake. O: Output. UDL: Under detectable level. NM: Not mentioned

Continued Table 1: Monthly variations of physico-chemical parameters of four different drinking water plants at Damietta, Egypt.

			Apr. 2013	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 2014	Feb.	Mar.	Permissible levels	
															Egyptian Standar	USEPA
Zinc (mg/L)	DWTP1	I.	0.020	0.049	0.021	0.024	0.034	0.005	0.030	0.021	0.036	0.009	0.031	0.022	3	5
		O.	0.080	0.128	0.130	0.137	0.084	0.048	0.072	0.076	0.110	0.087	0.142	0.064		
	DWTP2	I.	0.021	0.003	0.024	0.070	0.024	0.002	0.011	0.017	0.062	0.008	0.028	0.031		
		O.	0.047	0.042	0.095	0.150	0.065	0.083	0.067	0.049	0.094	0.042	0.110	0.120		
	DWTP3	I.	0.009	0.030	0.014	0.072	0.004	0.017	0.008	0.006	0.030	0.040	0.044	0.038		
		O.	0.077	0.085	0.086	0.137	0.042	0.059	0.091	0.069	0.058	0.120	0.163	0.142		
	DWTP4	I.	0.006	0.052	0.017	0.075	0.004	0.035	0.018	0.006	0.032	0.050	0.013	0.041		
		O.	0.047	0.110	0.137	0.143	0.038	0.135	0.050	0.030	0.050	0.156	0.101	0.170		
Iron (mg/L)	DWTP1	I.	0.030	0.028	0.040	0.030	0.060	0.080	0.070	0.060	0.050	0.050	0.040	0.080	0.3	0.3
		O.	0.003	UDL	UDL	UDL	UDL	0.005	UDL	0.002	UDL	UDL	UDL	0.004		
	DWTP2	I.	0.021	0.018	0.020	0.030	0.030	0.020	0.010	0.080	0.070	0.050	0.032	0.030		
		O.	UDL	UDL	UDL	UDL	0.005	UDL	UDL	UDL	0.002	UDL	0.005	0.002		
	DWTP3	I.	0.021	0.022	0.034	0.024	0.029	0.027	0.026	0.038	0.036	0.041	0.029	0.026		
		O.	0.002	UDL	0.004	UDL	UDL	0.003	UDL	UDL	UDL	0.001	UDL	0.003		
	DWTP4	I.	0.018	0.022	0.028	0.013	0.026	0.018	0.021	0.029	0.034	0.036	0.031	0.024		
		O.	UDL	0.003	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	0.001	UDL		
lead (mg/L)	DWTP1	I.	0.081	0.076	0.050	0.050	0.045	0.050	0.030	0.050	0.020	0.037	0.035	0.040	0.01	0.015
		O.	0.004	0.004	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL		
	DWTP2	I.	0.034	0.026	0.030	0.008	0.030	0.035	0.010	0.030	0.020	0.030	0.040	0.025		
		O.	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	0.004	UDL		
	DWTP3	I.	0.028	0.040	0.020	0.009	0.047	0.023	0.040	0.027	0.025	0.050	0.022	0.017		
		O.	UDL	0.006	UDL	UDL	0.003	UDL	0.002	UDL	UDL	0.003	UDL	UDL		
	DWTP4	I.	0.012	0.014	0.030	0.020	0.050	0.025	0.010	0.030	0.015	0.040	0.025	0.016		
		O.	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL		
Nickel (mg/L)	DWTP1	I.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.02	
		O.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
	DWTP2	I.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
		O.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
	DWTP3	I.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
		O.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
	DWTP4	I.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
		O.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		

I: intake. O: Output. UDL: Under detectable level. NM: Not mentioned.

Generally, all the physico-chemical characteristics of water were within the allowable limits according to the Egyptian standards (458/2007) and USEPA (2009), except turbidity which was mostly above the allowable limits in DWTP3.

Phytoplankton composition before (Intakes) and after treatment (Outputs)

Species number at Intakes

The total number of phytoplankton species encountered in the non-treated Nile River water supplied to the four DWTPs was 99 species; and was sorted into 8 phytoplankton groups (Table 2). Chlorophyta contributed with the highest number of species (47 species), followed by Bacillariophyta (22 species), Cyanobacteria (12 species), Cryptophyta (4 species), Euglenophyta and Dinophyta (3 species each), whereas Chrysophyta and Xanthophyta were the least contributing groups with 2 species each.

Species number at Outputs

The total number of phytoplankton species investigated at output of the DWTPs decreased to 36 algal species, belonging to 5 phytoplankton groups as shown in Table (2). The efficiency of the four DWTPs in clearing water from algal cells was in the following order: DWTP4 > DWTP2 > DWTP3 > DWTP1 for Cyanobacteria, DWTP2 > DWTP1 > DWTP3 > DWTP4 for Chorophyta and DWTP2 ≥ DWTP1 > DWTP4 > DWTP3 for Bacillariophyta. The relative contribution of the different groups of phytoplankton at the outputs of the four DWTPs was in the following order: Chlorophyta > Bacillariophyta > Cyanobacteria.

The results revealed that DWTP2 was the most effective station in removal of Chlorophyta and Bacillariophyta; whereas DWTP4 was the most effective station in removal of Cyanobacteria, followed by DWTP2. Although DWTP4-with the clariflocculator technique- was more efficient in removal of Cyanobacteria than DWTP2, yet the gravel and sand filter technique used in DWTP2 seems to be more safe than the clariflocculator technique since chlorine added in the last technique could lead to lysis of the cyanobacterial cells and release of toxins into water (Zamyadi *et al*., 2013).

Table 2: The total number of phytoplankton species in intakes and outputs of different drinking water plants at Damietta, Egypt.

Phytoplankton groups	DWTP1				DWTP2				DWTP3				DWTP4			
	Intake		Output		Intake		Output		Intake		Output		Intake		Output	
	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species	Genus	Species
Cyanophyta	8	12	7	10	8	12	5	6	8	12	7	8	8	12	3	3
Chlorophyta	30	47	20	32	28	45	15	21	30	46	23	32	28	44	15	21
Euglenophyta	2	3	1	2	2	3	1	2	1	2	1	2	2	3	1	2
Xanthophyta	2	2	1	1	2	2	2	2	2	2	1	1	2	2	0	0
Dinophyta	3	3	1	1	3	3	0	0	3	3	2	2	3	3	1	1
Cryptophyta	3	4	0	0	3	4	1	1	3	4	3	3	3	4	2	2
Chrysophyta	2	2	0	0	2	2	1	1	2	2	1	1	2	2	1	1
Bacillariophyta	18	22	8	10	16	20	8	8	17	21	10	14	15	18	8	9
Total number of species	68	95	38	56	64	91	33	41	66	92	48	63	63	88	31	39

The canonical corresponding analysis (CCA) revealed significant correlation between abundance of the different phytoplankton groups and the environmental variables (Fig. 2). A positive correlation is expressed by the relatively long vector roughly pointed in the same direction, whereas arrow pointing into the opposite direction indicates a negative correlation. Thus, abundance of Cyanophyta and Xanthopyta was positively correlated with levels of ammonia, phosphorus, nitrite, nickel and iron in the intake basins at DWTP1; that of Bacillariophyta and Euglenophyta was positively correlated with the level of silica in the intake basins at DWTP3 and DWTP4 and that of Cryptophyta and Chrysophyta was positively correlated with temperature and the levels of chloride and DO in the intake basins at DWTP3 and DWTP2**.**

This result completely agrees with findings of **Deyab *et al*. (2015**) who included that Cyanobacterial cell density at the intake of Damietta WTP increased with the increase in nutrients; (**AWWA, 2011**) who reported that silica is a limiting factor for diatoms growth, therefore the lack of silica can cause the diatoms blooms to collapse.

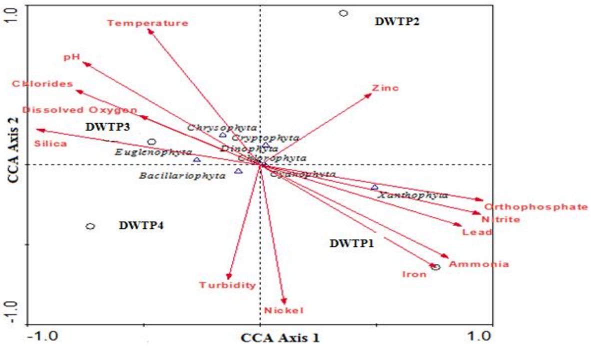

Fig. (2): Canonical correspondence analysis (CCA) ordination between physico-chemical parameters and phytoplankton groups in studied DWPTs, Damietta, Egypt.

Biological quality of water

1.Intakes

As seen in Fig. 3A, the taxa of phytoplankton were comparable in the intakes of the four DWTPs; with 95, 91, 92 and 88 taxa at DWTP1, DWTP2, DWTP3 and DWTP4 respectively. The diversity index ranged from 3.1 to 3.4. Moreover, the evenness ranged between 0.241 at the intake of DWTP1 and 0.319 at the intake of DWTP3. This indicates that water in the studied area is slightly polluted (Staub *et al*., 1970). This may be attributed to the predominance of Cyanobacterial standing crop at the intakes of the four DWTPs, and this agrees with findings of Deyab *et al.* (2015) who revealed that the River Nile water at the intake of Damietta WTP contained intense cyanobacterial population dominated by *Microcystis aeruginosa*.

2.Outputs

The taxa of phytoplankton were more or less close to each other in DWTP2 and DWTP4 outputs. The four DWTPs involving 56, 41, 63 and 39 recorded in DWTP1, DWTP2, DWTP3 and DWTP4 respectively. Generally, the taxa of phytoplankton decreased towards the output in the four DWTPs. The results showed that DWTP4 was the most efficient in removal of phytoplankton, followed by DWTP2 (Fig. 3B). The diversity index ranged from 5.12 at DWTP1to 3.33 at DWTP3, while the index of evenness ranged from 0.44 at DWTP3 and 1.48 at DWTP4. The two indices indicate that, the water status ranged between slightly polluted at DWTP3 and satisfactorily clean at DWTP1 and DWTP2. This suggests that the gravel filter and / or sand filter technique used at DWTP1 is more efficient in removal of phytoplankton than the pressure sand filter and the clariflocculator techniques at DWTP3 and DWTP4 respectively.

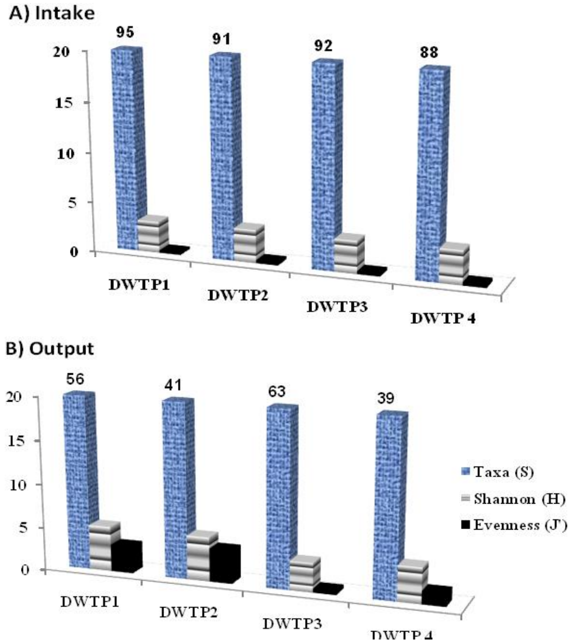

Fig. 3: Taxa of phytoplankton (S), Shannon (H) and Evennes (J') recorded at A) Intakes and B) Outputs of four different drinking water plants at Damietta, Egypt.

Total phytoplankton standing crop (Total cell number)

1.Intakes

Table 3 and Fig. 4A show that the total phytoplankton standing crop at the intake of the DWTPs was in the following order: DWTP1 (79322x 10^4cell/L) > DWTP3 (742945 x 10^4cell/L)>DWTP2 (70038 x10^4cell/L)> DWTP4 (69218 x10^4 cell/L). Cyanobacteria contributed with the highest total cell number, with 53.6 % of the total phytoplankton standing crop at the intake of all the DWTPs investigated and was dominated by *Microcystis aeruginosa* and *M. flosaqua*. Chlorophyta came next with 25.6% of the total phytoplankton standing crop and was represented by *Pediastrum simplex* and *P. duplex*; followed by Bacillariophyta with 15.1% and was represented by *Aulacoseira granulata* and *Stephanodiscus hantzschii*. Cryptophyta, Xanthophyta, Chrysophyta, Euglenophyta and Dinophyta were marginal groups with 3.75%, 0.57%, 0.56%, 0.52% and 0.31% of the total phytoplankton standing crop respectively. The high cell number at the intake of DWTPs can be related to the high concentrations of N and P in water arising from the agricultural drainage station at El-Serow. This is in agreement with the findings of **Karadzˇic´** ***et al.*** **(2013)** who showed that high phosphorus and nitrogen concentrations in water support the massive development of Cyanobacteria.

2.Outputs

Fig. 4B and Table 3 show that, the total phytoplankton standing crop at output of the DWTPs ranged between a maximum of 1440 x10^4cell/L) at DWTP3 and a minimum of 246 x10^4 cell/L) at DWTP2. In general, the total phytoplankton standing crop sharply decreased towards the outputs of all the DWTPs, and the efficiency of removal reaching 0.74%, 0.35%, 1.94% and 0.39 % at DWTP1, DWTP2, DWTP3 and DWTP4 respectively. DWTP1, DWTP3 and DWTP4 outputs recorded the highest cell number of Chlorophyta, followed by Bacillariophyta and Cyanobacteria compared to DWTP2 output which was dominated by Chlorophyta followed by Cyanobacteria and Bacillariophyta. The DWTPs output was arranged according to the total phytoplankton standing crop as follows: DWTP3>DWTP1 >DWTP4 > DWTP2. This means that, DWTP2 remove total phytoplankton cell number more effectively than other DWTPs particularly, DWTP3 which is considered the least efficient system in drinking water treatments.

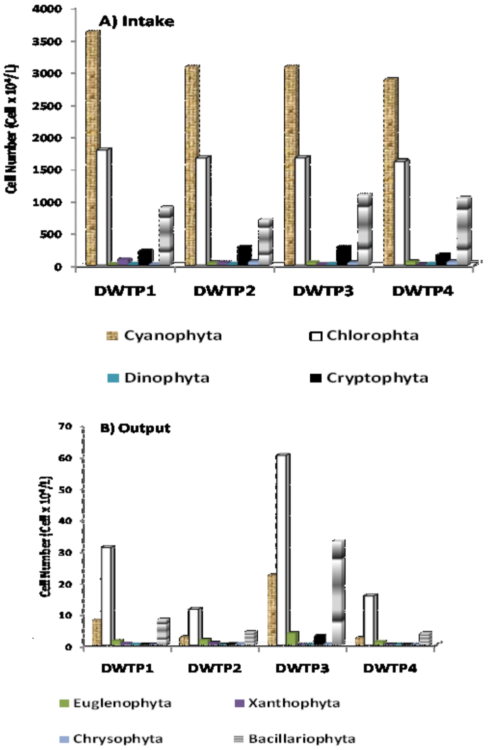

Fig. 4: Total cell number of phytoplankton groups (cell x 10 ^{4}/L) for A) intakes or before treatment process compared with B) outputs or after treatment process at four different drinking water plants at Damietta, Egypt.

All phytoplankton groups decreased towards the output of all DWTPs and the magnitude of decrease differed according to DWTPs and phytoplankton groups. Regard to the cell number of Chlorophyta decreased to 325.68x 10^4cell/L, 83.21 x 10^4 cell/L, 545.23 x 10^4 cell/L and 179.30 x 10^4 cell/L at output of DWTP1, DWTP2, DWTP3 and DWTP4 respectively. Generally, DWTPs output can be arranged according to Chlorophyta cell numbers as follows: DWTP3> DWTP1> DWTP4> DWTP2. The results appeared that DWTP2 is the most effective system in the decrease of Chlorophyta. Also, the cell number of Cyanobacteria decreased to 116.17 x 10^4cell/L, 81.73 x 10^4cell/L, 405.60 x 10^4cell/L and 32.90 x 10^4cell/L at output of DWTP1, DWTP2, DWTP3 and DWTP4 respectively. Accordingly, DWTPs output was descending arranged according to Cyanobacteria cell numbers as follows: DWTP3 > DWTP1 > DWTP2 > DWTP4. This means that DWTP4 followed by DWTP2 is the most effective system in Cyanobacterial cell removal, but there is a doubt about DWTP4, it may be unsafe, because the chlorination flocculation step may lysis the Cyanobacterial cells releasing their toxin into water.

The breakthrough of cyanobacteria cells into the clarified water can lead to the accumulation of potentially toxic cells while the filter run cycle proceeds (Zamyadi *et al*., 2013). So the results established that DWTP2 is the most suitable and safe system for Cyanobacterial cell removal. Regarding the cell number of Bacillariophyta, decreased to 120.64 x 10^4 cell/L, 48.45 x 10^4 cell/L, 394.78 x 10^4cell/L and 42.65 x 10^4cell/Lat output of DWTP1, DWTP2, DWTP3 and DWTP4 respectively.

Generally, DWTPs output was descendingly arranged according to Bacillariophyta cell numbers as follows: DWTP3> DWTP1> DWTP2>DWTP4. The results exhibited that DWTP4 followed by DWTP2 is the most effective system in Bacillariophyta cell removal. Chlorophyta was predominated by *Crucigenia tetrapedia* in output of DWTP1, *Chlorella vulgaris* in output of DWTP2, *Pediastrum duplex* in output of DWTP3 and *Scenedesmus obliquus* in output of DWTP4, followed by Bacillariophyta with a high cell density of *Aulacoseira granulata* in output of DWTP1, DWTP3 and DWTP4 and by *Stephanodiscus hantzschii* in output of DWTP2 and Cyanobacteria with an elevated cell number of *Chroocococcus turgida* in output of DWTP1, DWTP2 and DWTP4 and by *Merismopedia punctata* in output of DWTP3. **Deyab *et al.* (2011)** attributed the higher Chlorophyta and Bacillariophyta cell numbers in output water DWTPs to the tolerance of Chlorophyta and some diatom cells to the treatment processes. Also, **Shehata *et al.* (2008)** exhibited that the trapped frustules of diatoms cause some obstructions in sand filters.

It is obvious that, Chlorophyta gradually substituted Cyanobacteria throughout all treatment stages, forming the most dominant group in the output of all DWTPs. The predominance of Chlorophyta followed by Bacillariophyta and Cyanophyta agrees with the findings of Deyab ***et al.* (2011)** who, found that Chlorophyta dominated outflow of Faraskour and Bostan DWTPs. It was worthily mentioned that, Euglenophyta, Dinophyta, Xanthophyta and Chrysophyta were represented by very low percentage (if present) in outputs than intakes in all DWTPs. Chlorophyta, in addition to very little species of Euglenophyta, Dinophyta, Xanthophyta and Chrysophyta in output water may be actively growing in the house reservoirs when exposed to light, forming some bad taste and odour.

Bray-Curtis similarity index, based on the annual average of the total phytoplankton standing crop (Fig.5A), showed that intake of DWTP2 was similar with intake of DWTP3 with more than 81%. That may be explained by the short distance between the intakes of the two DWTPs. The results showed that output of DWTP2 was more similar with DWPT1 with more than 50% (Fig.5B). This indicates that the phytoplankton removal efficiency in these two plants is more or less similar. The efficiency of DWTPs in phytoplankton removal was arranged as follows: DWTP2 ≥ DWPT1> DWTP4> DWTP3. This result emphasizes that DWTP2 followed by DWPT1 is more efficiently in phytoplankton removal than DWTP3 and DWTP4. Based on the previous literatures, the results predict that the DWTP2 is the most safest strategy where, Coagulation/flocculation in conventional strategy (DWTP4) induced the release of microcystin into the ambient water, and the toxins were not completely removed or degraded during further treatment stages (Deyab *et al*. 2015).

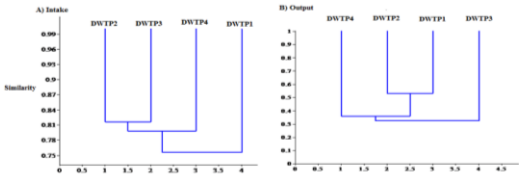

Fig. (5): Cluster analysis of the annual average of phytoplankton standing crop at A) Intakes and B) Outputs of four different drinking water plants at Damietta, Egypt.

Table 3: Monthly variation of total cell number of phytoplankton (cells x10 ^{4}/L) and percentage of their annual average at four different drinking water plants in Damietta, Egypt.

			Apr. 2013	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 2014	Feb.	Mar.	Annual average percentage (%)
Cyanophyta	DWTP1	I.	3361.06	5328.18	6706.00	6373.50	1958.19	3357.50	1527.00	1970.00	4529.15	2784.25	2111.50	5866.50	57.83
		O.	3.60	6.20	18.70	20.10	4.00	4.97	5.00	10.60	6.67	15.63	7.60	13.10	19.79
	DWTP2	I.	3931.83	5074.50	5693.55	5982.50	3607.50	2292.25	1628.93	1610.50	1901.42	907.00	1887.56	3245.25	53.92
		O.	12.00	14.00	8.40	9.00	2.50	11.10	0.00	2.50	3.33	0.00	6.50	12.40	33.26
	DWTP3	I.	288.00	6180.25	6078.07	4333.90	2188.63	2663.65	3129.52	3506.45	2073.40	1335.50	3228.35	3163.00	51.37
		O.	18.20	143.30	79.80	60.70	15.00	49.30	24.30	15.00	0.00	0.00	0.00	0.00	28.16
	DWTP4	I.	3105.86	4071.07	4243.18	3427.27	4401.31	3903.93	1315.29	2827.50	2677.51	1080.84	1281.71	2760.24	50.70
		O.	0.00	12.80	5.60	1.80	10.10	2.60	0.00	0.00	0.00	0.00	0.00	0.00	12.06
Chlorophyta	DWTP1	I.	1293.20	2298.23	2567.27	2151.45	1571.12	966.75	1065.40	636.43	1442.17	1726.82	1388.70	1707.58	23.72
		O.	13.13	45.30	31.60	9.00	14.50	16.70	31.60	13.53	36.70	58.95	32.40	22.27	55.47
	DWTP2	I.	1386.92	2082.40	2049.95	3437.20	1261.68	1455.72	1153.33	1603.73	1073.65	1050.33	1176.30	1267.18	27.13
		O.	2.32	11.67	20.20	0.93	2.55	17.86	1.88	4.14	7.07	1.10	7.50	6.00	33.87
	DWTP3	I.	2266.89	2239.95	2622.68	1893.00	1711.42	1359.27	881.28	1028.25	1089.85	886.75	1009.45	1621.70	25.05
		O.	73.97	116.57	134.97	91.40	9.00	11.80	24.50	14.77	17.60	0.70	4.70	45.27	37.85
	DWTP4	I.	1500.66	1972.64	1570.27	2354.03	2933.33	1568.41	1168.19	863.64	1136.15	1022.91	1181.94	1273.44	26.79
		O.	9.23	36.45	34.23	21.40	27.80	4.60	9.90	4.58	9.80	15.50	4.90	0.90	65.70
Euglenophyta	DWTP1	I.	15.56	20.50	16.42	20.00	17.78	6.00	16.75	10.75	3.00	18.08	5.33	5.00	0.20
		O.	0.00	0.00	1.40	4.80	1.00	0.00	2.00	1.25	0.00	0.00	5.50	0.00	2.72
	DWTP2	I.	48.37	48.50	35.00	56.00	37.00	28.00	23.83	16.63	4.83	4.95	4.40	11.50	0.46
		O.	2.67	4.00	2.50	2.50	3.67	0.00	2.67	0.00	0.00	0.00	0.00	1.25	7.83
	DWTP3	I.	131.44	71.65	65.10	15.10	49.05	68.75	30.45	14.20	0.00	0.00	14.65	8.20	0.63
		O.	22.60	9.50	1.70	0.00	1.40	9.60	0.00	0.00	0.00	0.00	0.00	0.00	3.11
	DWTP4	I.	109.39	139.93	16.60	38.39	145.65	47.96	12.63	15.65	0.00	14.56	26.13	20.19	0.85
		O.	0.60	4.80	0.00	0.00	7.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.58
Xanthophyta	DWTP1	I.	38.60	39.92	49.00	57.80	66.50	81.50	94.50	122.00	168.50	132.50	97.00	82.50	1.30
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	1.02
	DWTP2	I.	33.00	31.00	28.00	33.00	44.00	37.00	46.00	49.50	61.00	40.50	13.50	26.50	0.63
		O.	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	6.67	0.00	0.00	0.00	3.12
	DWTP3	I.	0.00	2.45	0.00	0.00	0.00	2.25	0.00	0.00	97.60	0.00	55.10	0.00	0.21
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.08
	DWTP4	I.	0.70	9.18	0.00	0.00	4.90	0.00	4.85	0.00	12.20	0.00	4.30	13.55	0.07
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dinophyta	DWTP1	I.	4.17	13.28	21.15	2.51	42.22	42.50	6.25	10.35	9.00	1.89	3.33	65.52	0.28
		O.	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	1.00	0.00	0.00	0.00	0.45
	DWTP2	I.	24.10	26.25	32.85	23.50	22.10	21.70	21.00	14.01	11.52	14.77	12.02	16.53	0.34
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DWTP3	I.	21.05	14.55	15.90	7.50	23.00	43.30	13.40	15.70	5.50	7.82	16.12	34.13	0.29
		O.	2.50	0.00	0.00	0.00	1.20	5.40	0.00	0.00	0.00	0.00	0.00	3.80	0.90
	DWTP4	I.	15.16	21.55	24.76	11.56	79.46	9.92	0.07	5.04	6.15	12.84	5.66	46.10	0.34
		O.	0.00	0.00	0.00	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59
Cryptophyta	DWTP1	I.	133.28	322.88	86.54	20.00	39.17	220.00	212.50	245.00	475.00	158.75	107.50	510.83	3.19
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DWTP2	I.	176.44	335.50	106.85	113.00	155.00	307.50	298.75	471.83	384.42	120.25	358.00	528.25	4.79
		O.	0.30	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.16
	DWTP3	I.	783.14	148.44	165.57	71.60	75.98	337.60	505.42	355.00	180.25	215.00	206.35	278.75	4.47
		O.	9.87	0.00	0.00	0.00	0.00	0.00	10.50	4.50	0.00	0.00	0.00	7.20	2.23
	DWTP4	I.	208.92	74.22	78.89	67.96	118.19	93.14	416.72	12.00	240.57	94.87	206.16	170.12	2.57
		O.	1.20	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.90
Chrysophyta	DWTP1	I.	6.67	0.00	0.00	17.50	11.39	2.50	11.25	55.00	7.50	5.83	17.50	2.50	0.17
		O.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DWTP2	I.	28.00	26.50	139.00	16.00	103.00	77.50	48.50	30.00	36.00	34.00	25.50	14.00	0.83
		O.	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03
	DWTP3	I.	8.25	0.00	25.50	56.00	123.75	46.50	40.65	16.30	20.70	20.00	23.90	0.00	0.51
		O.	0.00	0.00	0.00	0.00	3.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26
	DWTP4	I.	0.00	0.00	75.00	13.00	165.55	53.50	53.00	76.40	37.50	62.00	5.00	0.00	0.78
		O.	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55
Bacillariophyta	DWTP1	I.	824.02	1155.42	1395.99	1019.90	1143.52	486.69	428.06	575.12	709.26	663.48	858.45	1297.50	11.95
		O.	0.56	24.50	15.00	5.50	5.83	11.00	2.25	6.00	11.67	12.17	16.00	10.17	20.55
	DWTP2	I.	545.32	664.10	895.60	653.05	967.83	538.30	472.81	562.42	500.52	720.44	1245.29	574.70	11.91
		O.	1.60	7.20	6.50	12.00	7.50	6.30	3.90	1.40	0.00	1.50	0.00	0.55	19.72
	DWTP3	I.	1609.74	1079.74	1298.45	962.50	1757.40	1160.35	847.27	783.48	847.87	1145.75	728.40	745.96	17.45
		O.	64.80	38.90	58.40	21.70	77.28	31.60	15.80	4.50	13.00	16.70	39.20	12.90	27.41
	DWTP4	I.	1428.90	1818.39	1167.95	659.29	1651.41	656.07	779.42	556.56	697.86	900.93	1615.56	446.60	17.88
		O.	3.10	6.50	10.85	8.80	8.90	0.00	0.40	0.60	0.00	3.00	0.50	0.00	15.63

I: intake. O: Output.

Efficiency of Phytoplankton removal at treatment stages

As seen in Tables (4), the two stages direct filtration technology of DWTP2 has been recognized as the most effective model in removing total phytoplankton (99.7%), followed by the conventional model of DWTP4 (99.6% of total phytoplankton), one stage of DWTP1 (99.3% of total phytoplankton) and the compact unit model of DWTP3 (98% of total phytoplankton). The process of coagulation, flocculation, sedimentation and filtration on gravel filters in DWTPs are highly efficient in removing intact cyanobacterial cells with intracellular toxins **(Chow *et al*., 1998 & 1999; Fan *et al*., 2014),** however, these processes may don't eliminate microcystins dissolved in the water (**Fouad *et al*., 2005).** An optimum coagulant dose depends largely on the type of algae, in particular on the surface of cells or colonies of microorganism and their mutual affinity (**Fouad *et al*., 2005).**

Cyanobacteria was the most removal phytoplankton group by the four plants (>99.3%) especially during initial and final chlorination. Where, it was removed by 99.9 % in both DWTP 2 and DWTP4, 99.8% by DWTP1 and 99.3% by DWTP3. This result agrees with **Zamyadi *et al*. (2013)** who reported that, *Microcystis*, *Anabaena*, and *Pseudanabaena* cells were adequately removed by clarification and filtration processes. Chlorophyta was removed by 99.3 % at DWTP2, 98.8% at DWTP4, 98.3% at DWTP1 and 96.6% at DWTP3, compared to Bacillariophyta which was removed by 99.7 % at DWTP4, 99.4 % at DWTP2, 99.1 % at DWTP1 and 97 % at DWTP3. Totally, the removal of Chlorophyta and Bacillariophyta by the four plants exceeds 96.6% and 97.0%, respectively.

Depending on the data presented in Table (4), the efficiency of DWTPs in the phytoplankton removal through different stages in four DWTPs can be arranged as follows: the rapid rate gravity sand filter occurred in DWTP1(94.3%) > roughing gravel filter in DWTP2 (89.5%) > clariflocculator in DWTP4 (73 %) > plate settler in DWTP3 (69.5%). This means that, the rapid rate gravity sand filter is the effective system for phytoplankton removal whereas, plate settler is the least effective system for phytoplankton removal. This full agrees with the findings of **Deyab *et al*. (2011)**, who found that compact water treatment plant involving plate settler was the lowest efficiency in the removal of phytoplankton.

Generally, DWTP2 was the most efficient in phytoplankton removal with percent of 99.7%, while DWTP3 was the least efficient one. The efficacy of DWTP2 in phytoplankton removal could be attributed to the presence of the roughing gravel filter concomitant with the rapid rate gravity sand filter. The results expected that roughing gravel filter with a rapid rate gravity sand filter is safer than clariflocculator for the Cyanobacteria removal. This result is explained by the findings of **Deyab *et al.* (2015)**, who reported that Coagulation / flocculation induced the release of MCs into the ambient water, and the toxins were not completely removed or degraded during further treatment stages (filtration and chlorination). The clariflocculator certainly needs increasing care of maintenance, control of alum added dose and chlorine, and increase manpower skills, to obtain safe and good water in DWTP4.

These DWTPs may be needed for further treatment processes such as application of micro-sieves as pre-filtration treatment, or the increment of the filter bed layer depth with fewer diameters, as well as periodic monitoring to improve its removal efficiency. Moreover, the application of micro-sieves as pre-filtration devices can satisfy the growing demand for water without affecting the amount of water produced .Micro-sieves have been used not only in Europe, but also in New Zealand for 50 years **(Ministry of Health (2005**). The removal efficiency may reach 99 % when the filter depth reaches 1.2 m according to **Journey *et al.* (2013).**

The predominance of Cyanobacteria in the intake of all DWTPs necessarily needs a safe removal method such as physical pretreatment, to avoid their cell lysis and cyanotoxin release during the chemical treatment **(Zamyadi*et al*., 2013)**. Although a wide range of techniques has shown promise for cyanobacteria bloom control and cyanobacterial cell/metabolite removal in reservoirs and water treatment plants (WTPs), these treatments may have negative consequences through the release of intracellular metabolites including cyanotoxins into the surrounding water **(Fan *et al*., 2014)**.

Table (4): Monthly variation of total phytoplankton cell number and percentage of their removal through different treatments stages in four DWTPs at Damietta.

		DWTP1			DWTP2				DWTP3				DWTP4			
		Intake	Sand filter	Output	Intake	Gravel filter	Sand filter	Output	Intake	Plate setler	Presure filter	Output	Intake	Calrifier	Sand filter	Output
Apr. 2013	Cell x 10^4/L	5676.55	250.89	17.29	6173.98	856.90	180.63	18.89	5108.50	1920.97	442.90	191.93	6369.58	1646.26	97.00	14.13
	R.%		95.58	99.70		86.12	97.07	99.69		62.40	91.33	96.24		74.15	98.48	99.78
May	Cell x 10^4/L	9178.42	470.50	470.50	8288.75	843.40	162.73	36.87	9737.03	3586.80	1122.85	308.27	8106.98	1646.26	294.37	60.55
	R.%		94.87	94.87		89.82	98.04	99.56		63.16	88.47	96.83		79.69	96.37	99.25
Jun	Cell x 10^4/L	10842.37	557.60	557.60	8980.80	1001.50	186.80	37.60	10271.27	3848.90	839.20	274.87	7176.65	1646.26	333.87	50.68
	R.%		94.86	94.86		88.85	97.92	99.58		62.53	91.83	97.32		77.06	95.35	99.29
Jul.	Cell x 10^4/L	9662.66	382.00	382.00	10314.25	1114.10	180.50	24.43	7339.60	2476.20	448.50	173.80	6571.50	1646.26	180.90	32.00
	R.%		96.05	96.05		89.20	98.25	99.76		66.26	93.89	97.63		74.95	97.25	99.51
Aug.	Cell x 10^4/L	4849.88	355.27	355.27	6198.12	688.24	140.42	17.22	5929.23	1666.40	387.07	107.68	9499.80	1646.26	319.69	57.00
	R.%		92.67	92.67		88.90	97.73	99.72		71.90	93.47	98.18		82.67	96.63	99.40
Sept.	Cell x 10^4/L	5163.44	374.92	250.10	4757.97	688.24	205.92	40.26	5681.67	1704.17	338.70	107.70	6332.93	1646.26	91.22	7.20
	R.%		92.74	95.16		85.54	95.67	99.15		70.01	94.04	98.10		74.00	98.56	99.89
Oct.	Cell x 10^4/L	3361.71	250.10	250.10	3693.16	841.00	99.10	8.55	5447.98	1499.17	228.80	75.10	3750.16	1646.26	70.70	11.55
	R.%		92.56	92.56		77.23	97.32	99.77		72.48	95.80	98.62		56.10	98.11	99.69
Nov.	Cell x 10^4/L	3624.65	230.00	30.50	4358.63	462.96	75.75	8.04	5719.38	1320.03	221.35	38.77	4356.79	1646.26	80.22	5.18
	R.%		93.65	99.16		89.38	98.26	99.82		76.92	96.13	99.32		62.21	98.16	99.88
Dec.	Cell x 10^4/L	7343.57	299.70	42.33	3973.35	174.84	83.10	17.07	4315.17	1103.08	158.57	31.80	4807.93	1646.26	71.20	9.80
	R.%		95.92	99.42		95.60	97.91	99.57		74.44	96.33	99.26		65.76	98.52	99.80
Jan. 2014	Cell x 10^4/L	5491.60	523.27	45.00	2892.24	316.78	75.37	2.60	3610.82	686.30	104.37	17.40	3188.95	1646.26	102.70	18.50
	R.%		90.47	99.18		89.05	97.39	99.91		80.99	97.11	99.52		48.38	96.78	99.42
Feb.	Cell x 10^4/L	4589.32	369.15	40.00	4722.56	299.30	changed into one stage		5282.32	1235.58	212.60	43.90	4326.46	1646.26	107.67	5.40
	R.%		91.96	99.13		93.66				76.61	95.98	99.17		61.95	97.51	99.88
Mar.	Cell x 10^4/L	9537.93	513.20	25.00	5683.91	258.15			5851.74	1619.52	223.60	69.17	4730.23	1646.26	67.57	0.90
	R.%		94.62	99.74		95.46				72.32	96.18	98.82		65.20	98.57	99.98
Cell x 10^4/L		79322.11	4576.59	587.11	70037.71	7377.76	1390.31	245.71	74294.71	22667.11	4728.50	1440.38	69217.97	1646.26	1817.09	272.90
T.R %			94.23	99.26		89.47	98.01	99.65		69.49	93.64	98.06		97.62	97.37	99.61

R= Removal, T.R: Total removal

Based on the alert levels of the World Health Organization (WHO) for managing drinking water source containing cyanobacterial cells (2000 and 1.00.000 cells/mL) **(Zamyadi *et al*., 2013)**, and the Ministry of Development, Sustainability of Environment and Parks (MDSEP) of the Province of Quebec (Canada) involving two supplementary quality control levels: 10,000 cells/mL (alert level for the water intake of DWTPs) and 20,000 cells/mL (alert level in the water body) **(Zamyadi *et al*., 2013;Ellis, 2009)**, the cyanobacterial cell number obtained in the studied intakes (from 1080 x10^4 to 6706 x 10^4cells/L) exceeds the acceptable range. Accordingly, the danger of cyanobacteria will exceed the nuisance effects of phytoplankton on water quality in the Nile River to cause the toxicity to human, if these cyanobacteria species have the ability to produce cyantotoxins such as microcystins (MC). **Deyab *et al.* (2015)** found *that* the bloom *of Microcystis aeruginosa* at the intake of Damietta WTP produce MC-RR and MC-LR**.** Consequently, further studies are required to certain whether cyantotoxins present in the Nile River water and during these four DWTPs or not. General this result warn from the continuous pollution to Nile River.

Conclusion

Physico-chemical parameters decreased towards the permitted limits in outputs. Ninety nine taxa belonging to 8 different phytoplankton groups in intakes of DWTPs decreased to reach 34 taxa in outputs. The total cell number of Cyanobacteria at intakes of DWTPs exceeds the acceptable range in the Nile River raw water. Chlorophyta substituted Cyanobacteria in DWTPs output, recording the highest cell number especially at DWTP3 output. The rapid rate gravity sand filter followed by roughing gravel filter is the most effective system for phytoplankton particularly, Cyanobacteria removal than clariflocculator, whereas plate settler is the least effective system for phytoplankton removal. Finally, DWTP2 (two stages direct filtration) is the most efficient DWTP in the phytoplankton removal (99.7%), in contrary, DWTP3 (compact unit) is the least efficient one.

Recommendation

The clariflocculator in DWTP4 certainly needs increasing care of periodic monitoring, control and maintenance, also control of added dose of alum and chlorine, and increase manpower skills to obtain nearly good water. The improvement of the phytoplankton removal efficiency in DWTPs needs the application of micro-sieves before filtration treatment and / or increasing the filter bed layer depth with less diameters, as well as periodic monitoring. Finally, this study recommended that cyanotoxins need to be monitored and periodically measured in the Nile River water and during DWTPs.

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الملخص العربي

عنوان البحث: تقييم كفاءة عمليات معالجة مياه الشرب في إزالة العوائق الطحلبية في دمياط – مصر

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تهدف الدراسة الى تقييم كفاءة إزالة العوالق الطحلبية أثناء عمليات المعالجة في أربع محطات مختلفة لمياه الشرب بدمياط، مصر، وهي كالتالي: المحطة الأولي (ذات مرحلة الترشيح الواحدة) في دقهلة، المحطة الثانية (ذات مرحلتي الترشيح) في عزب النهضه، المحطة الثالثة (الكومباكت او المدمجة) في العدلية والمحطة الرابعة (السطحية) في العدلية. تم جمع عينات المياه شهريا من الأربع محطات من ابريل ٢٠١٣ إلى مارس ٢٠١٤. أظهرت النتائج انخفاض قيم الخواص الفيزيائية والكيميائية مثل الأس الهيدروجينى، الأمونيا، نيتريت، والفوسفات في مياه طرد المحطات الأربع إلى الحد المسموح به ماعدا العكارة في المحطة الثالثة (الكومباكت) حيث تأرجحت بين اعلي / أو أقل من قيمة الحد المسموح به، كما انخفضت المعادن الثقيلة إلى ما دون مستوى كشفها. في حين زاد مستوي الاكسيجين الذائب و الالمونيوم في مياه طرد المحطات الاربعة. كما تم تسجيل ٩٦ نوع من العوالق النباتية، ينتمون إلى ٨ مجموعات مختلفة. منهم ٤٨ نوع من الطحالب الخضراء، ٢٣ نوع من الدياتومات و ١١ نوع من الطحالب الخضراء المزرقة. وقلت تلك الأنواع لتصل الي ٦٦ نوع في الطرد، منهم ٤١ نوع من الطحالب الخضراء، ١٥ نوع من الدياتومات و ١١ نوع من الطحالب الخضراء المزرقة. وسجلت الطحالب الخضراء المزرقة أعلي إجمالي من عدد الخلايا عند المآخذ وقبل عملية المعالجة لكل المحطات، في حين سجلت الطحالب الخضراء أعلى عدد كلي من الخلايا بعد عملية المعالجة (في طرد كل المحطات)، وبخاصة في المحطة ٣ (٥٤٥,٢٣×٤١٠ خلية / لتر). أكدت النتائج أن الطحالب الخضراء المزرقة تمت إزالتها بكفاءة عالية أثناء مراحل المعالجة في الأربع محطات. بينما سجلت الطحالب الخضراء النسبة الأكبر أثناء مراحل المعالجة وطرد الأربع محطات. وأخيرا، كانت المحطة الثانية (محطة معالجة مياه الشرب ذات مرحلتي الترشيح المباشر) الأكثر كفاءة في إزالة العوالق النباتية بنسبة٩٩,٧٪، في حين أن المحطة الكومباكت كانت الأدنى كفاءة في إزالة العوالق النباتية (٩٨٪)، مع ملاحظة نقص كفاءة الإزالة للمروقات والواح الترسيب. كما تم ملاحظة انخفاض كفاءة إزالة المرشحات التي تعمل كمرحلة ثانية للتنقية بالمحطات (لا تزيد عن ٢٦,٩%). لذا نوصى بالتحسين والمتابعة المنتظمة لكفاءة هذه المراحل ، و بتحسين كفاءة المرشحات بواسطة تطبيق نظام المناخل الصغيرة مع / او زيادة عمق الوسط الترشيحي بطبقات ذات قطر أصغر لتحسين الإزالة مع المراقبة الدورية. كما توصي باستخدام الطرق الفيزيائية الأكثر آمانا من الطرق الكيميائية في إزالة الطحالب الخضراء المزرقة المحتوية علي سموم . كما تحذر الدراسة من الاستمرار في تلوث مياه النيل.