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Evaluation of Algal Count and Disinfection By-Products Levels in Drinking Water Treatment Plants in Greater Cairo

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ABSTRACT

A program has been conducted to monitor the algal counts and disinfection by-products (DBPs) during conventional treatment of raw water in four drinking water treatment plants (DWTPs) located in Greater Cairo. Besides, all factors that affect DBPs formation were measured. Phytoplankton structure of the Nile River water was composed of diatoms, green and blue- green algae. Percentage composition of algal species was in the order: diatoms >green algae > blue-green algae. Algal composition of the treated water was subjected to wide variation after clarifier and sand filtration. *Diatoma elongatum*, *Cyclotella comta* (diatoms) *Scenedesmus quadricauda*, *Ankistrodesmus acicularis* (green algae) and *Merismopedia elegans* (blue- green algae) were detected in the final outlet water indicating that the studied four DWTPs were not effective in the algal removal. In addition, the studied DWTPs were relatively not very effective in removal of total organic carbon (TOC) since the maximum removal percentage was 32.41% at Embaba DWTP, and hence residual TOC led to the formation of DBPs. However, the concentrations of TTHM in the four drinking water treatment plants were all below the Egyptian standards for Drinking Water Quality (100 µg/L). The proportion of chloroform to the four THMs accounted for up to 50%, and the four THMs species were in the order of chloroform > dichlorobromomethane > dibromochloromethane > bromoform. Whereas, the concentrations of HAA species followed the order: monochloroacetic acid >dichloroacetic acid >trichloroacetic acid >monobromoacetic acid (MBAA).

Key words: Occurrence, Disinfection by-products (DBPs); Greater Cairo; Algae.

Introduction

Drinking water disinfection is vital for preventing the spread of diseases caused by waterborne pathogens. Chlorination is used widely for disinfection in water treatment plants in Egypt to ensure a safe drinking water. Chlorine reacts with natural organic matter (NOM) that has not been completely removed during treatment and it forms carcinogenic disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). Several studies reported that these compounds have been related to the occurrence of cancer, growth retardation, spontaneous abortion, and congenital cardiac defects (Righi *et al.*, 2012; Ivancev-Uyak *et al.*, 2008; Yang *et al.*, 2000). Recently, special attention has been given to the water treatment processes due to the increasing concern with the protection of people's life in Egypt. Due to concerns over the effect that these DBPs have on human health, the Egyptian Standards No (458/ 2007) has set stringent regulatory limits for THMs and HAAs.

NOM is important factor in the water treatment process due to its role as precursor for the formation of disinfection byproducts (DBPs) as well as its role in the concentration and transport of inorganic and organic pollutants (Uyguner-Demirel and Bekbolet 2011). As mentioned earlier, it is well known that DBPs such as THMs, HAAs, and other halogenated organic materials are produced by the reaction between NOM and chlorine (Badawy, 1992; El-Dib *et al.*, 2000; Singer, 1994). Several factors such as pH, temperature, dissolved organic carbon (DOC), bromide concentrations, and operational factors like chlorine dose and contact time were reported to significantly affect the formation of THMs (Nikolaou *et al.*, 2004). However, DOC was found to be the most important factor in the formation of DBPs.

Conventional water treatment is applied in Egypt for the supply of drinking water that meets specific quality standards. Raw surface water is derived from River Nile or fresh water irrigation canals and then subjected to several operations namely prechlorination, coagulation, flocculation, sedimentation, rapid sand filtration and finally post chlorination. Algal removal is an important measure of the treatment efficiency, since algae especially those belonging to blue-green algae are in interest to water treatment authorities due to their production of taste and odor compounds as geosmin and 2-methyl isoborneol which were detected in drinking

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water (Roh *et al.*, 2008). In addition, cyanobacteria such as *Microcystis*, *Anabaena*, *Oscillatoria* and *Nostoc* species produced toxins which pose a health hazard for humans and domestic animals (Codd *et al.*, 2005 and Kujbida *et al.*, 2006). Also diatoms produce a clogging and obstructions in filters because of their silicon frustules and in addition, algae and their extracellular products are important precursors for DBPs, including THMs and HAAs. However, DBPs production levels vary according to algal species (Abd El- Aty *et al.*, 2009).

This research aims to monitor algae and disinfection by-products found during conventional treatment of raw water at Greater Cairo governorate. Furthermore, all factors that affect DBPs formation were measured. The collected data may help in reduction of disinfection by-products by designing a new treatment train or modifying the current treatment sequence.

Experimental:

The monitoring program was conducted in four drinking water treatment plants located in Greater Cairo Governorate including Giza and Cairo cities during 2011. El-Dahab Island and Embaba DWTPs were selected in Giza Governorate. In Cairo Governorate, Mostorod and Fostat DWTPs were chosen. The plants are located at places where conditions are most representative and homogeneous, away from transitional areas such as point source, mixing zones and near-shore regions. The sampling timing was planned in advance without regard to capturing temporary events. Several samples were collected at each treatment step including inlet, after clarifier, after filtration, and finally from plant outlet. Samples were collected in transparent amber glass bottles for the various physico-chemical parameters and algal counts with taxonomic identification. Another water samples were collected from the pre-specified locations in amber glass bottles containing sodium thiosulphate or ammonium chloride for the analysis of trihalomethanes (THMs) and haloacetic acids (HAAs), respectively.

Analytical measurements:

The measured parameters were total organic carbon and dissolved organic carbon (TOC & DOC) which gives an indication on the natural organic matter (NOM), ultraviolet absorption at 254 nm (UV_{254}) for the determination of aromatic organic compounds, Specific Ultraviolet Absorption at 254 nm ($SUVA_{254}$) was calculated by dividing a sample's ultraviolet absorption at a wavelength of 254 nm (UV_{254}) (path width = 1 m) by its concentration of dissolved organic carbon (DOC) (mg/L).

The DBPs was analyzed for all samples including four chlorine and bromine containing THMs (THM4), five chlorine and bromine containing HAAs (HAA5). All the samples were refrigerated at 4°C and analyzed within 2 weeks. THMs were quantified by liquid/liquid extraction with pentane followed by gas chromatography and electron capture detection (GC/ECD). Methyl-tertbutyl-ether extraction of the HAAs samples was done immediately in accordance with the EPA method (2003). The identification and quantification of THMs and HAAs were carried out according to Standard Method 6232 (APHA, 1998). Quantification of DBPs was carried out using external standards with coefficient for calibration curves higher than 0.995. The Calibration program was verified on each working day by the measurement of one or more standards. A random sample was run in triplicate. Laboratory control sample was analyzed with each series of samples (10 samples). Q-chart was used and two values of ± 2 standard deviations were the lower and upper limits. For THM species, analytical procedures ensured detection limits of 0.5 $\mu\text{g/L}$ for chloroform (CF, $CHCl_3$) and 0.3 $\mu\text{g/L}$ for bromodichloromethane (BDCM, $CHCl_2Br$), dibromochloromethane (DBCM, $CHClBr_2$) and bromoform (BF, $CHBr_3$). For HAAs species, the detection limits were 1.2, 1.1, 0.6, 0.9, 1.3 and 0.9 $\mu\text{g/L}$ for monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), dibromoacetic acid (DBAA) and bromochloroacetic acid (BCAA), respectively. The efficiency of the extraction of HAAs was determined by addition of known concentration of 2-bromobutanoic acid as surrogate standard. Recovery for water samples ranged from 83 to 103%. Egyptian (Ministry of Health 2007) and United States (USEPA 2003) drinking water quality standards were used as a basis for assessing the water quality data obtained in the study.

Concentration of phytoplankton present in water samples were performed by using the Sedgwick Rafter funnel and preserved in lugol's iodine solution (APHA, 1965). Identification of algal community structure were examined using identification keys (Starmach, 1966; Streble and Krauter, 1978; Palmer, 1980; APHA, 1998). A Sedgwick Rafter counting cell was used for phytoplankton counting. The results were expressed as number of organisms/mL according to (APHA, 1998).

Results And Discussion

Efficiency of DWTPs Specially for Parameters Related to DBPs Formation:

To assess the Efficiency of DWTPs, samples were collected from the treatment stages. The parameters related to DBPs formations were analyzed in each sample. The averages of collected data from each treatment

step in DWTPs under study are presented in Table 1-4. Current treatment processes were found to be effective in the removal of suspended solids as turbidity values reduced by 90.06%, 87.25%, 90.73% and 87.86% in Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively. The conductivity removals were 25.91, 15.90, 1.79 and 8.25% for Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively. pH of the collected samples from all DWTPs were nearly constant within the treatment steps while alkalinity of the collected samples were decreased through the treatment steps by 20, 21.15, 13.14 and 20.47% in Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively.

Generally, the studied DWTPs were relatively not very effective in removal of total organic carbon (TOC), since the removal percentages of DOC in Embaba, El-Dahab Island, Fostat and Mostorod DWTPs were 32.41, 22.35, 22.64, and 14.63%, respectively. The DOC removal owed to reaction between chlorine used in disinfection and DOC and/or adsorption on sand filter. The low DOC percent removal indicates that water after passing through settling basins and filters was still loaded with organic matter. Such results are in agreement with that reported by Otson *et al.* (1982) where organic carbon values, upon treatment of raw water, slightly decreased or remained as the same. Sinsbaugh *et al.* (1986) indicated that ion metal coagulation is efficient for removing high molecular weight organic compounds whereas low weight organic species (<1000) are not effectively removed. Consequently, the latter compounds would contribute to increase the levels of THMs as the retention time is extended during the water treatment processes.

Ultraviolet absorption at 254 nm (UV_{254}) and specific Ultraviolet absorption at 254 nm ($SUVA_{254}$), which represents the ratio UVA_{254}/DOC and constitutes an indicator of carbon aromaticity in water, determinations were used in water treatment to obtain information about the nature of dissolved organic carbon (DOC) in water samples. In general, the results showed that average NOM contents in raw waters were 5.14, 4.43, 4.24 and 3.28 mgC/L with an average UVA_{254} of 0.1, 0.0947, 0.0948, 0.069 and 0.066 L/mg-M at Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively. In parallel, $SUVA_{254}$ values in all DWTPs were also in the low to medium range (1.62 - 2.54 L/mg-M) indicating that NOM in raw waters is of low molecular weight with hydrophobic and aromatic characteristics.

Table 1: Physico-chemical characteristics of water samples collected from Embaba DWTP.

Parameter	Unit	Inlet		Clarifier		Filter		Final Outlet	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Turbidity	NTU	2.31 - 9.54	5.09	1.18 - 2.31	1.77	0.56 - 0.87	0.76	0.61 - 0.42	0.506
pH	-	7.67 - 8.42	8.08	7.14 - 7.8	7.55	7.09 - 7.77	7.35	7.63 - 7.22	7.4892
Conductivity	$\mu s/cm$	533 - 483	508.6	350 - 453	376.6	349 - 429	394.2	411 - 341	376.8
Alkalinity	mg/L CaCO ₃	150 - 180	162.5	120 - 170	142.5	130 - 140	137.5	128 - 132	130
Total Hardness	mg/L CaCO ₃	115 - 128	120.3	110 - 116	112.5	90 - 118	107.0	90 - 118	104
Calcium Hardness	mg/L CaCO ₃	74 - 82	77.0	72 - 76	73.5	72 - 80	75.0	70 - 78	72.5
DOC	mg/L	4.36-5.9	5.14	3.81 - 5.21	4.36	3.17 - 4.89	3.83	3.08 - 4.12	3.474
UVA	cm ⁻¹	0.0712-0.1162	0.0947	0.0504 - 0.0775	0.07	0.0346 - 0.06	0.050	0.0341 - 0.0491	0.0441
$SUVA_{254}$	L/mg-M	1.46 - 2.17	1.85	1.16 - 1.98	1.54	1.07 - 1.71	1.31	1.01 - 1.59	1.282

Table 2: Physico-chemical characteristics of water samples collected from El-Dahab Island DWTP.

Parameter	Unit	Inlet		Clarifier		Filter		Final Outlet	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Turbidity	NTU	2.6 - 5.81	4.08	1.31 - 3.65	2.24	0.59-0.76	0.68	0.41-0.62	0.52
pH	-	7.67 - 8.36	7.98	6.99 - 7.93	7.35	6.99 - 7.65	7.27	6.88-7.62	7.28
Conductivity	$\mu s/cm$	458 - 513	497	458 - 492	476.0	431-465	446.8	398-438	418
Alkalinity	mg/L CaCO ₃	130 - 180	156	120 - 130	127.5	120-140	128.8	100-140	123
Total Hardness	mg/L CaCO ₃	110 - 136	118	104 - 118	109.3	102 - 118	112.0	101-122	111
Calcium Hardness	mg/L CaCO ₃	68 - 96	77.2	68 - 74	71.3	68-80	74.0	70-78	72.7
DOC	mg/L	3.81 - 5.48	4.43	3.7 - 3.91	3.81	3.34-3.78	3.50	2.26-3.59	3.44
UVA	cm ⁻¹	0.0714 - 0.1351	0.0948	0.0458 - 0.0623	0.06	0.0421-0.0608	0.05	0.0428-0.0528	0.05
$SUVA_{254}$	L/mg-M	1.72 - 2.46	2.13	1.63	1.50	1.26-1.61	1.39	1.31-1.47	1.37

Enumeration of phytoplankton with taxonomic identification:

Raw water at the different treatment plants showed various phytoplankton structures belonging to three main groups; diatoms, green algae and blue-green algae. The general distribution of algal taxa is revealed in Table 5. It is shown that diatoms and green algae were present through the examination period with 26 species. It may be seems that diatoms and green algae are equal in species number but actually diatoms represent the most abundant group in the count in all investigated water samples. The last group which is the blue green algae

was represented by 10 species. Such results are in agreement with that in a previous study by Shehata, et al (2008).

Table 3: Physico-chemical characteristics of water samples collected from Fostat DWTP.

Parameter	Unit	Inlet		Clarifier		Filter		Final Outlet	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Turbidity	NTU	2.65-3.62	3.56	1.55-1.67	1.56	0.37-0.76	0.43	0.24-0.42	0.33
pH	-	7.80-8.22	8.01	7.65-7.80	7.73	7.59-7.76	7.69	7.40-7.82	7.46
Conductivity	$\mu\text{s}/\text{cm}$	496-504	503	491-499	494	490-496	492	490-495	494
Alkalinity	mg/L CaCO ₃	148-180	175	156-170	149	128-160	142	124-152	152
Total Hardness	mg/L CaCO ₃	100-120	115	94-118	101	90-114	97	90-112	108
Calcium Hardness	mg/L CaCO ₃	70-88	88	66-86	75	64-82	73	64-80	78
DOC	mg/L	3.73-4.32	4.24	3.34-3.87	3.53	3.01-3.54	3.21	2.87-3.32	3.28
UVA	cm-1	0.064-0.074	0.069	0.0552-0.0454	0.0503	0.0337-0.0401	0.0346	0.0226-0.0377	0.0342
SUVA ₂₅₄	L/mg-M	1.53-1.76	1.62	1.22-1.65	1.44	0.99-1.18	1.09	0.79-1.16	1.04

Table 4: Physico-chemical characteristics of water samples collected from Mostorod DWTP.

Parameter	Unit	Inlet		Clarifier		Filter		Final Outlet	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Turbidity	NTU	2.64-6.34	3.79	1.23-2.97	1.77	0.57-0.77	0.66	0.41-0.56	0.46
pH	-	7.69-8.30	7.93	7.42-7.73	7.56	7.43-7.66	7.57	7.42-7.66	7.53
Conductivity	$\mu\text{s}/\text{cm}$	487-503	497	426-486	466	411-482	459	396-482	456
Alkalinity	mg/L CaCO ₃	165-180	171	140-145	141	136-140	139	130-140	136
Total Hardness	mg/L CaCO ₃	118-134	124	110-120	116	106-114	110	102-112	107
Calcium Hardness	mg/L CaCO ₃	82-86	85	76-84	79	68-78	74	62-72	70
DOC	mg/L	3.10-3.51	3.28	2.92-3.39	3.16	2.71-3.17	2.94	2.65-2.95	2.80
UVA	cm ⁻¹	0.041-0.094	0.066	0.031-0.070	0.054	0.029-0.061	0.048	0.028-0.054	0.041
SUVA ₂₅₄	L/mg-M	1.33-2.96	2.02	1.07-2.26	1.72	1.08-2.23	1.63	1.04-2.03	1.47

Table 5: Identified algal species in intake water of the studied water treatment plants.

Taxa		
<i>Diatoms</i>	<i>Green algae</i>	<i>Blue-green algae</i>
<i>Amphora ovalis</i>	<i>Actinastrum hantzschii</i>	<i>Anabaena constricta</i>
<i>Amphora coffeaeformis</i>	<i>Ankistrodesmus acicularis</i>	<i>Anabaena flos - aquae</i>
<i>Asterionella formosa</i>	<i>Ankistrodesmus falcatus</i>	<i>Chroococcus turgidus</i>
<i>Ceratium hlrundinella</i>	<i>Botryococcus braunii</i>	<i>Coelosphaerium kutezinglanum</i>
<i>Cocconies placentula</i>	<i>Chlamydomonas variabilis</i>	<i>Cylindrospermum stagnale</i>
<i>Cyclotella comta</i>	<i>Chodatella ciliata</i>	<i>Gomphosphaeria lacustris</i>
<i>Cyclotella glomerata</i>	<i>Closterium acutum</i>	<i>Merismopedia glauca</i>
<i>Cymbella cistula</i>	<i>Coelastrum microporum</i>	<i>Microcystis aeruginosa</i>
<i>Cymbella turgida</i>	<i>Crucigenia rectangularis</i>	<i>Oscillatoria limnetica</i>
<i>Diatoma elongatum</i>	<i>Dictyosphaerium ehrenbergianum</i>	<i>Oscillatoria chlorine</i>
<i>Fragilaria capucina</i>	<i>Eudorina elegans</i>	
<i>Fragilaria construens</i>	<i>Golenkinia radiata</i>	
<i>Gomphonema olivaceum</i>	<i>Kirchnerilla obesa</i>	
<i>Gryosigma attenuatum</i>	<i>Microactinium pusillum</i>	
<i>Melosira granulata</i>	<i>Oocystis parva</i>	
<i>Navicula gastrum</i>	<i>Oocystis solitaria</i>	
<i>Navicula mutica</i>	<i>Pediastrum clathratum</i>	
<i>Navicula pupula</i>	<i>Pediastrum duplex</i>	
<i>Nitzschia acicularis</i>	<i>Pediastrum simplex</i>	
<i>Nitzschia holisatica</i>	<i>Pediastrum tetras</i>	
<i>Nitzschia linearis</i>	<i>Scenedesmus obliquus</i>	
<i>Nitzschia palea</i>	<i>Scenedesmus quadricauda</i>	
<i>Pinnularia viridis</i>	<i>Staurastrum paradoxum</i>	
<i>Peridinium cinctum</i>	<i>Staurastrum polymorphum</i>	
<i>Stephanodisc asastrea</i>	<i>Sphaerocystis schroeteri</i>	
<i>Synedra ulna</i>	<i>Tetraedron minimum</i>	

In the raw water of all studied treatment plants, diatoms were the most dominant algal group which comprise 77 to 84.5% out of the bulk of finding taxa (Tables 6-9). The most dominant species of diatoms were *Diatoma elongatum*, *Cyclotella comta* and *Melosira granulata*. Green algae comprised 11.5 to 17.9% of the total bulk of found taxa and most dominant species were *Scenedesmus quadricauda*, *Actinastrum hantzschii* and *Ankistrodesmus acicularis*. Blue green algae were almost found in small percent and ranged from 3.9 to 5.1% of

the algal count and the most dominant species were represented *Merismopedia elegans* and *Gomphosphaeria lacustris*.

Due to Coagulation – flocculation and sedimentation processes, percentage of algal removal ranged between 77.7 to 84.8% of the total algal count of raw water samples as an average value between 4 different water treatment plants (Fig. 1). After clarifier, diatoms had been found with higher values than the other two taxonomic groups. According to Mouchet and Bonnely (1995) the removal rate of Nile water algae in clarified water at Cairo plants was 85% in absence of chlorine and 99 to 100% when prechlorination was carried out in combination with a well-adjusted coagulant dosage. Mean of percentage composition of algal species in raw water for the four DWTP amounted to 80.7, 14.9 and 4.4 for diatoms, green algae and blue- green algae. However, after clarifier the percentage composition of algal species showed a marked change where diatoms amounted to 68.9, the green-algae represented by 21.8 and blue-green algae amounted to 9.3 of the total algal counts. After sand filtration, percentage composition of algae was further changed. According to Abd El-Aty and El-Dib, (2005) algal composition of the treated water was subjected to wide variation after sedimentation and filtration processes and relative increase in algal composition of green and blue-green algae was recorded. Results given in Tables (6-9) indicated the abilities of algae to pass through the sand filter and diatoms represent the highest ratio in the outlet water compared to the other two algal groups. This may be attributed to the ability of diatoms to penetrate through the sand filter due to their spindle structure and their small size. The most dominant algal species in outlet water were *Diatoma elongatum*, *Cyclotella comta* (diatoms) *Scenedesmus quadricauda*, *Ankistrodesmus acicularis* (green algae) and *Merismopedia elegans* (blue- green algae).

Ma *et al.*, (2007) studied the effect of algae population characteristics on their removal efficiency during conventional water treatment processes. The results showed that the size, shape, surface structures and the activity of algal cells affected the algal removal efficiency. The smaller the size of algae cells was, the lower was the removal efficiency.

Table 6: Algal counts of water samples collected during treatment processes at El-Dahab island DWTP.

Algal Counts (Org./ml)	Raw Water (Inlet)		After Clarifier		After Filtration		Final Outlet	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Total diatoms	4070-5170	4591	634-704	673	88-517	297	99-132	121
% Composition		78.7		64		60.4		48.4
Total green algae	660-1320	961	121-429	254	33-187	103	44-110	70
% Composition		16.5		24.1		20.9		28
Total blue-green algae	198-352	286	55-198	125	66-132	92	22-88	59
% Composition		4.8		11.9		18.7		23.6
Total algal counts	5038-6270	5837	858-1331	1052	187--682	491	165-330	250

Table 7: Algal counts of water samples collected during treatment processes at Embaba DWTP.

Algal Counts (Org./ml)	Raw Water (Inlet)		After Clarifier		After Filtration		Final Outlet	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Total diatoms	4378-5214	4767	759-1188	939	154-462	268	66-209	132
% Composition		77		67.9		62.6		50
Total green algae	704-1474	1107	110-583	301	55-143	91	22-143	66
% Composition		17.9		21.8		21.3		25
Total blue-green algae	176-484	315	66-275	143	22-143	69	44-110	66
% Composition		5.1		10.3		16.1		25
Total algal counts	5258-7172	6189	935-2046	1382	231-583	428	132-347	264

Table 8: Algal counts of water samples collected during treatment processes at Fostat DWTP.

Algal Counts (Org./ml)	Raw Water (Inlet)		After Clarifier		After Filtration		Final Outlet	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Total diatoms	4664-5336	5020	726-748	737	132-440	242	55-253	128
% Composition		84.5		77		79.6		81
Total green algae	462-836	682	143-198	165	33-44	40	11-11	11
% Composition		11.5		17.2		13.2		7
Total blue-green algae	154-330	234	44-66	55	11-33	22	0.0-44	19
% Composition		3.9		5.8		7.2		12
Total algal counts	5280-6304	5936	935-968	957	198-506	304	99-264	158

Table 9: Algal counts of water samples collected during treatment processes at Mostorod DWTP.

Algal Counts (Org./ml)	Raw Water (Inlet)		After Clarifier		After Filtration		Final Outlet	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Total diatoms	5896-6270	6086	627-869	748	121-165	135	44-99	73
% Composition		82.5		66.7		52.7		54.1
Total green algae	836-1254	997	198-341	270	33-121	66	11-55	33
% Composition		13.5		24.1		25.8		24.4
Total blue-green algae	198-352	293	88-121	104	22-99	55	11-66	29
% Composition		4		9.2		21.5		21.5
Total algal counts	7062-7700	7376	1089-1155	1122	176-385	256	99-165	135

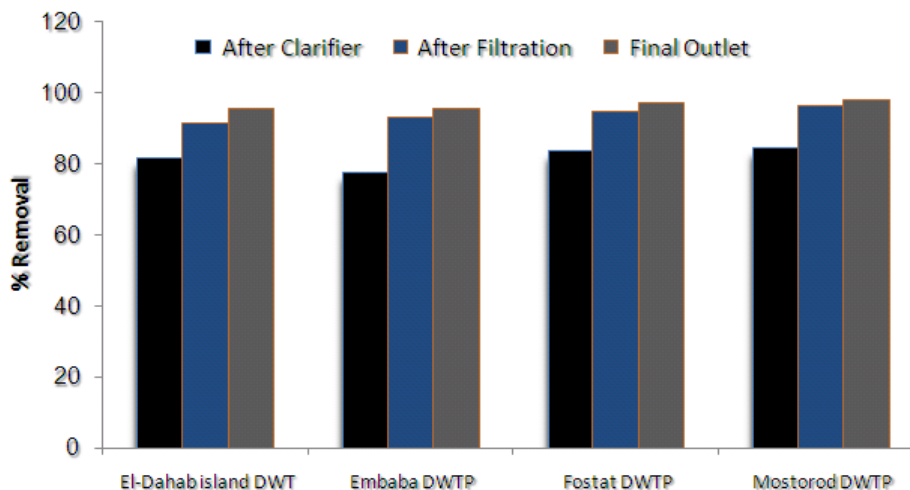


Fig. 1: Removal of total algal count through treatment steps in the studied treatment plant

Disinfection by-products (DBP) levels:

Trihalomethanes (THMs) and haloacetic acids (HAAs) are the most important groups of disinfection by-products (DBPs). The average concentrations of TTHMs were 64.38, 43.94, 52.41 and 51.72 $\mu\text{g/L}$ the outlet of Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively. While the corresponding average concentrations of HAAs were 57.64, 54.79, 36.38 and 61.52 $\mu\text{g/L}$ respectively. These values are lower than the values detected by Smith & El-Deen (2009), which indicated that in Summer 2005 event, the average for 20 tap water locations in Cairo City was 158 $\mu\text{g/L}$ TTHMs, well in excess of the U.S. EPA limit of 80 $\mu\text{g/L}$ and the current Egyptian standard of 100 $\mu\text{g/L}$; all 20 locations exceeded the 100 $\mu\text{g/L}$ limit. In the same time concentration of total THMs in the present studies are considerably higher than those recorded in five residential areas of Alexandria, Egypt more than ten years ago (45 \pm 16 ppb) (Hassan *et al.*, 1996). They are also higher than the values reported in a study from 1991–1993 for three treatment plant effluents in Cairo, where the highest values were in the range 40–50 ppb in May 1992 (El-Shahat *et al.*, 2001).

The ratio between maximum and minimum of total THMs during the period of study in 4 DWTPs were 1.41, 2.42, 1.89 and 1.86 $\mu\text{g/L}$ for El Dahab Island, Embaba, Fostat and Mostorod, respectively. The highest ratio was 3.29 which were noticed in Embaba DWTP, while the lowest value was 1.41 in Dahab Island DWTP. It was found that this ratio had varied depending on sites, raw water quality and treatment parameters. Previous studies indicated that the occurrence of DBPs in treated and distributed drinking water varies according to the quality of the water source and the operations carried out in the treatment plant. Generally speaking, the main influential factors are the nature and amount of natural organic matter (NOM) in particular humic substances, concentrations of bromide (which mainly impact the speciation of DBP species), pH of water, water temperature and residence time of water in the distribution system (Rodriguez and Sérodes, 2001, Ye *et al.*, 2009).

Consistent for both THMs and HAAs (Fig. 2), chlorinated species dominated over brominated ones for all waters as stated above. This is in agreement with a previous study (El-Dib & Ali, 1992), where chloroform and bromodichloromethane constitute well over 90% of TTHMs. Results in Fig. 2 show that chloroform was dominant in THMs while MCAA and DCAA (i.e., HAA2) were both dominant in HAA5. Singer and Reckhow (1999) reported that the fully chlorine-substituted forms such as chloroform, DCAA, and TCAA are dominant species in waters with low bromide concentration. Based on the survey of 500 large WTPs in the US, the fraction of chloroform in THMs was reported as 60.5% (Richardson *et al.*, 2007) which is higher than levels observed in this study but these percentages can significantly vary depending on raw water quality and operating conditions at DWTPs (Singer, 2002).

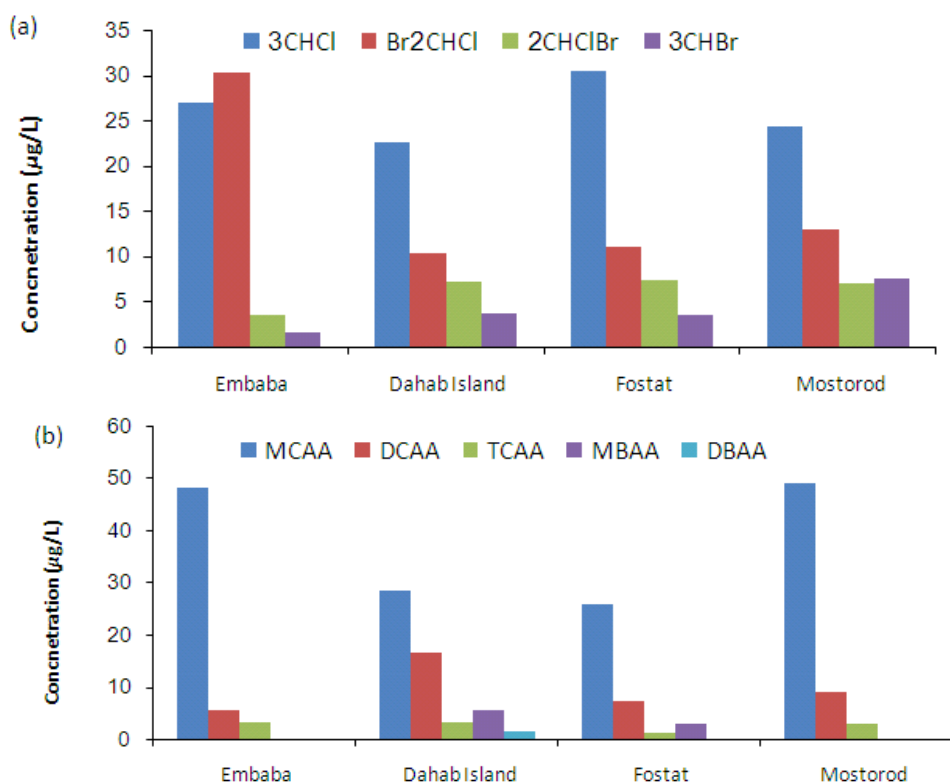


Fig. 2: Average DBPs recorded at the outlet of DWTPs; (a) THMs and (b) HAAs.

Conclusions:

The results of this study showed that average NOM contents in raw waters were 3.44, 5.14, 4.43, 4.24, 3.28 mgC/L with an average UVA_{254} of 0.0947, 0.0948, 0.069, 0.066 L/mg-M at Embaba, El-Dahab Island, Fostat and Mostorod DWTPs, respectively. In parallel, SUVA_{254} values in all DWTPs were also in the low to medium range (1.62 - 2.54 L/mg-M) indicating that NOM in raw waters is of low molecular weight with hydrophobic and aromatic characteristics. The studied DWTPs were relatively not very effective in removal of dissolved organic carbon (DOC) since the removal percentages of DOC in Embaba, El-Dahab Island, Fostat and Mostorod DWTPs were 32.41, 22.35, 22.64, 14.63%, respectively. Algal removal by conventional treatment processes is affected by variations in motility, morphological characteristics, specific density and negative surface charge, which make their removal is difficult than the inorganic particles. Treatment plants must modify the treatment processes according to number of algae to produce safe drinking water. The concentrations of THMs in the studied drinking water treatment plants were all below the Egyptian standards for Drinking Water Quality (100 $\mu\text{g/L}$). The proportion of chloroform (CF) to four THMs accounted for up to 50%, and the four THMs species were in the order of CF > DCBM > DBCM > BF. The highest concentration of THMs in drinking water was detected in water collected from Embaba DWTP. The average concentrations of studied HAAs in water samples collected from outlet of Embaba, El-Dahab Island, and Mostorod DWTPs exceeded the maximum contaminant level of 60 $\mu\text{g/L}$ proposed by the Disinfectant/Disinfection byproduct Rule (I) of US EPA (1998).

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