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Thesis Review

Seasonal variation in drinking water disinfection by-products in Gharbia governorate, Egypt

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Abstract

Chlorine is the most common disinfectant used in drinking water treatment because it is cheap and has an efficient germicidal ability. However, chlorine and organic matter reacting trihalomethanes (THMs) are suspected carcinogens. The major groups of disinfection by-products (DBPs) are THMs, haloacetic acids (HAAs), haloacetonitriles (HANs), and halogenated ketones (HKs). Exposure to these by-products increases the risk of cancers, abortion, low birth weight, and congenital disabilities. The wastewater contents of organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), as the source of total organic carbon (TOC) compounds, are oxidized by chlorine to produce DBPs. This study aimed to monitor the seasonal levels of THMs in Egypt compared with international standards using capillary gas chromatography. Results revealed that THMs mean values vary between 9.26 to 35.86 μg/l, while dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA) mean values vary between 3.82 to 17.74 μg/l and 4.41 to 13.25 μg/l, respectively. The maximum THM and TCAA values were observed during the summer, probably due to high temperatures. While the maximum DCAA values were observed during the autumn due to the high levels of raw water TOC. In conclusion, continuous monitoring of THM and its species is highly recommended, taking into consideration how climate can influence THMs formation.

Keywords: Disinfection by-products, Surface water, Chlorination, Dangerous, THMs, DBPs

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Introduction

Controlling resistant pathogens in potable water requires efficient disinfectants and optimal design criteria to protect public health and minimize the risk of exposure to disinfectants by-products. Disinfection by-products (DBPs) are formed when the chemical disinfectant reacts with DBPs precursor. Natural organic matter, usually measured as total organic carbon (TOC), acts as the organic precursor, while the bromide ion (Br-) serves as the inorganic precursor (Bond et al., 2014). Therefore, DBP formation is affected by water quality (e.g., TOC, bromide ion, pH, temperature, ammonia concentration, and carbonate alkalinity) (Chen et al., 2010).

Also, treatment procedures, e.g. disinfectant amount, contact time, decrease natural organic matter (NOM) drop before disinfectant injection point, before adding disinfectant, affect the DBPs formation. The drinking water is polluted with wastewater pumped from domestic and industrial sources; therefore, increased pollutants in the River Nile are reported. Subsequently, the water quality and parameters are affected compared to the United States Environmental Protection Agency (US EPA) standard criteria. In Egypt, large amounts of agricultural waste drainage water are pumped into the River Nile without treatment in all governorates in the Delta region. The wastewater contents of organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs) as the source of TOC compounds are oxidized by chlorine to produce DBPs.

In 1979, EPA set the first regulatory standard for the annual average of total trihalomethanes (TTHMs) under the safe drinking water act (SDWA) as an interim maximum contaminant level (MCL) of 100 μg/l (Ngwenya et al., 2013). The World Health Organization (WHO) deploy drinking water criteria for a few DBPs, including THMs, haloacetic acids (HAAs), and haloacetonitriles (HANs) (WHO, 2017) by adding to individual THM criteria, THM 100, chloroform 300, dichlorobromoform 60, and bromoform 100 µg/l, which are also included in the national Egyptian standards.

Table 1: Sampling, handling, storage, and analysis

Parameter[1]	Preservatives; dechlorinating agents	Sampling bottle	Storage temp.	Max. hold period	Method
TOC	Each sample was adjusted to pH <2 using Phosphoric acid	Amber Glass	4°C	28 (days)	SM 5310 C[2]
THM	For each 40 ml bottle, 3 mg $Na_2S_2O_3$ were added and acidified using HCl to pH <2.0	Amber Glass	4°C	14 (days)	EPA 551.2[3]
HAAs	dechlorination: 0.1mg NH_4Cl/40ml of sample	Amber Glass	4°C	14 (days)	EPA 552.1[4]

[1]. Abbreviations: TOC; total organic carbon, THM; trihalomethanes, HAAS; haloacetic acids.

[2] Standard Methods for the Examination of Water and Wastewater, 21st edition (Gilcreas, 1967; Eaton et al., 2005).

[3] Munch et al. (1995).

[4] Munch and Hautman (1995).

Table 2: Capillary gas chromatography temperature programs for analyzing trihalomethanes and haloacetic acids

Chemical	Level	Ramping (°C/min)	Final Temp °C	Hold time (min)
Trihalomethanes	1	5	35	5
	2	5	75	10
Haloacetic acids	1	5	35	10
	2	5	75	17
	3	20C	200	1

Gharbiya governorate confined between major two-branches of the River Nile, i.e. the Damietta and Rashid branches. Hence, Gharbyia governorate has many industrial facilities that pump organic and inorganic waste containing NOM that react with chlorine and produce DBPs. In Gharbiya governorate, many sources pumped wastewater to the River Nile, such as El-Rahawy drain and Kafer El-Zayate industrial company. The current study was conducted to monitor the levels of THMs over the different seasons of the year (September 2013 to September 2013) in the drinking water plant in Gharbiya governorate, Egypt.

Study Methods

All chemical, reagents, and reference materials of THM, HAAs, and inorganic chemicals used were of appropriate purity grade. Chemicals were purchased from Acuu Standard, Riedel, Sigma Aldrich, and Fluka comapnies.

Sampling

All Samples were collected from the outlet of the drinking plant and at a depth of 35 cm from the surface of the raw water to ensure the homogeneity of the sample. The sampling site at the drinking water plant is located 2 miles before the site of Kafer El-Zayate and Salt and Soda industrial companies.

Capillary gas chromatography instrument set up

The capillary gas chromatography methods of chemical analysis, sample preservation, handling, and storage are provided in (Table 1). The instrument set up was as follow; injector 200° C, program oven (hold at 35°C for 10 min, ramp at 75°C for 5°C/min and hold for 17 min), detector 260, and conditioning at 350°C with nitrogen (N_2) as makeup and Helium as the carrier.

Determination of THM

The total THM compounds (trichloromethane, dichlorobromomethane, chlorodibromomethane, and tribromomethane) were detected according to EPA method 551 (Egbenya et al., 2015), the samples were collected in a 40 ml amber glass bottle with a screw cap. For gas chromatography, 25 ml of each sample were used, and the testing was performed under the following condition:

- Inlet condition: split mode, initial temperature 250°C, pressure 33 Pound per square inch (psi), split ratio 20:100.
- Oven condition: the oven thermal program was adjusted as shown in Table 2.

Determination of HAAs

The sample extraction was performed using methyl tertbutylether (MTBE) as the extraction solvent, the HAAs species (dichloroacetic acid, trichloroacetic acid) was measured according to EPA method 552.2 (Munch et al., 1995); and gas chromatography chromatography was performed under the condition explained in Table 2.

Table 3: Seasonal levels of disinfection byproducts levels in Kafr El-Zayat drinking water plant between September 2013 and September 2013

Season	$CHCl_3$ (μg/l)	BDCM (μg/l)	DBCM (μg/l)	$CHBr_3$ (μg/l)	THM (μg/l)	DCAA (μg/l)
Autumn 2012	4.87	3.44	0.95	0	9.26	17.74
Winter 2013	3.7	2.13	0.49	0	6.34	8.62
Spring 2013	13.73	10.86	2.26	0	26.85	3.82
Summer 2013	19.31	12.93	3.62	0	35.86	14.91
Maximum	19.31	12.93	3.62	0	35.86	17.74
Minimum	3.70	2.13	0.49	0	6.34	3.82
Average	10.40	7.34	1.83	0	19.58	11.27
SD	7.44	5.35	1.41	0	14.14	6.26

Abbreviations: $CHCl_3$; chloroform,BDCM; bromodichloromethane, DBCM; dibromochloromethane, $CHBr_3$; bromoform, THM; trihalomethanes, DCAA; dichloroacetic acid.

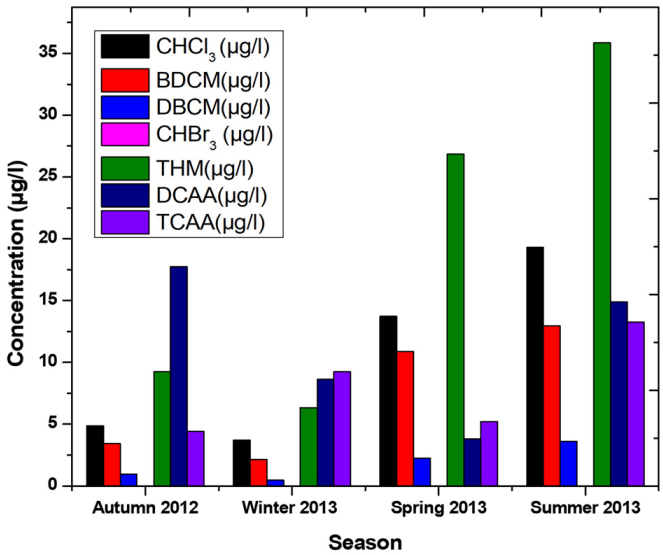

Figure 1: Trihalomethanes and haloacetic acid values for Kafr El-Zayat water plant for the studied four seasons. Abbreviations: $CHCl_3$; chloroform,BDCM; bromodichloromethane, DBCM; dibromochloromethane, $CHBr_3$; bromoform, THM; trihalomethanes, DCAA; dichloroacetic acid

Results and Discussion

To understand the existence of DBPs in the studied samples, this study performed a one-year survey of the seasonal variations of DBPs. Water samples were collected every week at a fixed location and time for one year. As a result, the THM and HAAs values were within the accepted limits according to the national Egyptian standard (ministerial decree No. 458/2007) (MOH, 2007)), the standards of EPA (EPA, 2012) and WHO (WHO, 2017) for drinking water.

The average DBPs concentrations during the surveyed seasons are shown in Figure 1. The average seasonal levels of chloroform ($CHCl_3$), Bromodichloromethane (BDCM), dibromochloromethane (DBCM), Bromoform ($CHBr_3$), THMs, DCAA, and TCAA in μg/l in the autumn 2012, winter, spring, and summer in 2013 are provided in Figure 1. The average seasonal levels of $CHCl_3$, BDCM, DBCM, $CHBr_3$, THMs, DCAA, and TCAA in (μg/l) in autumn 2012, winter, spring, and summer in 2013 are provided in Table 3.

The THMs mean values range between 9.26 to 35.86 μg/l, while DCAA and TCAA mean values range between 3.82 to 17.74 μg/l and 4.41 to 13.25 μg/l, respectively. The maximum THMs values and their species were observed during the summer seasons. The high temperatures during the summer usually result in high levels of free chlorine and other disinfectants byproducts. The THMs concentrations were found to be sensitive to water temperature, and the ratio of THMs in summer compared to winter was reported previously as 2.06 (Kim, 2009). Similar to previous studies, the maximum values of TCAA were observed during the summer (Wang et al., 2019), however, the maximum DCAA levels were observed during the autumn. Previous studies have shown that the raw water TOC levels are high during the autumn (Zhang et al., 2010). DCAA and TCAA are the main products of HAAs, and their concentrations, with THMs, increase with the increasing chlorine dosage (Niu et al., 2017).

Conclusion and recommendations

DBPs are formed during the chlorination of water containing organic substances. Changes in treatment conditions and temperatures in different seasons of the year directly impact THM levels in processed water. The study revealed increased levels of THMs and TCAA during the summer. However, DCAA values increased during the autumn. These findings indicate the increased chlorine dosages and other disinfectants by-products in the water in the Delta region. Therefore, it is highly recommended to continuously monitor water quality, especially the DBPs species in water treatment plant stages and distribution systems.

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