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Tracing TOC concentration and SUVA254 in surface water, treated water and wasted aluminum sludge

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Abstract

Safe water production is the world's primary concern; however, organic pollution is a continuous threat to it. Egypt depends primarily on the Nile River to supply potable water. Organic pollution threatens freshwater, and it is reduced through effective conventional treatment, but using disinfectants generates harmful byproducts. This study aims to the evaluation of conventional treatment in eight WTPs in Cairo. Water Treatment Plants (WTPs) were chosen in greater Cairo to perform this study throughout the year 2018. Raw, tap water and sludge TOC was measured. Raw and tap waters $SUVA_{254}$ is calculated to determine the WTP's efficiencies to reduce DBPs formation probability. The maximum and minimum TOC obtained in winter and summer, respectively. $SUVA_{254}$ increased in Mostorod WTP and reduced in other WTPs. In conclusion, the Nile river organic matter is natural with a minimum amount of industrial origin, but the Ismailia canal suffers from industrial spills.

Keywords: Organic load, $SUVA_{254}$, TOC, Greater Cairo WTPs, Nile River, Ismailia Canal, Sharkawia Canal.

1. Introduction

Safe water supply and sanitation are significant life elements; communities could not live without it. So, it was set as a basic concept for policy formulation. Also, the United Nations stated in the 2030 agenda Sustainable Development Goals (SDGs) “goal number 6: clean water and sanitation”. That reflects how vital are the freshwater supply and safe wastewater handling and treatment. Drinking water production uses various resources including ground, surface, rain, and sea waters. Each water resource has its unique characteristics and nature. Every type of water also has its principal threats and pollutants and specific techniques for treatment and preparation for drinking and domestic uses (Lim et al., 2016; Talley et al., 2011).

Surface freshwater is the most used resource to produce drinking water in countries with fresh lakes, rivers, and waterways. Potable water supply is usually taking place through the conventional technique (when no exceptional pollution is reported). Conventional surface water treatment primarily includes coagulation, precipitation, filtration, and disinfection. Which targets safe drinking water through inactivating waterborne pathogens, reducing turbidity, and organic matter (García-Vaquero et al., 2014). The main waste from the conventional treatment is sludge which is the aluminum hydroxide mixed with the suspended, organic matter, pathogens and pollutants removed from the raw water (Moayedi et al., 2016).

Organic matter in the surface water is from natural and anthropogenic sources. The sources of natural organic

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matter in the raw water are the death of plants, planktons, fish, and other freshwater organisms. The anthropogenic sources of organic matter include a massive and wide variety of human activities that comprise pesticides drift, disposal of untreated wastewater, oils, and grease. The primary removal technique applied in the WTPs to reduce the organic matter in the coagulation/precipitation process (Keeley et al.,2014; Fouad et al., 2017a; 2018).

Although the natural and anthropogenic activities are the key sources of the presence and increase of organic constituents in raw water, the water management plan significantly affects the water quality (Wolsink, 2006). The surface water management plan includes but not limited to the water flow speed, quantity, reuse cycles, and dilution effect. All the mentioned parameters have a substantial impact on the persistence and composition of organic contents in the raw and tap water (Elarabawy et al., 2000).

The key deterministic parameter for measuring the organic content in water is the Total Organic Carbon (TOC), which is a reflection of the concentration of all the organic matter and compounds in the form of carbon. The organic matter often acts as a pH buffer and helps in minerals dissolution and precipitation. The organic matter reactivity, aromatic carbon content and the absorbance of UV light are essential indicators of DOC reactivity in several environmental processes (Weishaar et al., 2003).

Some research articles have described the organic matter composition, concentration, and treatment (Zhang et al., 2015). However, there is still a knowledge gap in describing the behavior, movement, and complexity throughout conventional treatment, particularly in Cairo governorate, Egypt. Especially the portion of organic matter discarded into the wasted sludge hence to freshwater bodies due to lack of probable handling and available budget. Water reuse is a primary non-traditional source of water in Egypt used to fulfill incremental needs, which requires significant attention to freshwater quality and in-deep study to the various wastes' disposal in it particularly the organic ones. Our study aims at determining the effect of the treatment process in eight WTPs in Cairo on diverse types and concentrations of organic matter.

2. Materials and Methods

2.1. Study area:

The study was done in Cairo governorate, which has a population of 19.5 million inhabitants (in October 2018) lives in 3085 Km2. Eight water treatment plants (WTPs) along the valley of the Nile River in 40 Km distance within Cairo were selected (table1).

All the eight WTPs intake from the Nile River except Mostorod and Shoubra El Kheima intake from Ismailia and Sharkawia canals respectively. The used doses of chlorine (range: 4.0 – 8.5 mg/l) and alum (range: 20 - 41 mg/l) which are varied according to the raw water quality and the amount of pollution. (Table 1, Figure1)

The eight WTPs are practicing the conventional treatment but using three distinct clarifiers models (circular, slurry recirculation, and pulsator). Both circular and return sludge clarifiers are similar in design but with a minor change in the latter, which is the slurry circulation to improve the flocculation process especially in case of reduced inlet turbidity. Typically, the clarifier performs three functions: coagulation, flocculation, and precipitation however, pulsator (sludge blanket) clarifier uses the sludge itself to filtrate the influent as an additional step to increase the quality of the effluent in the least occupied area (Crittenden et al., 2012).

Table 1: The eight Studied WTPs information

ID	WTP Name	Intake	Chlorine dose (mg/l)	Alum Dose (mg/l)	Design
1	El-Tebeen	Nile River	5.5 ±1	26 ± 3	Circular
2	Shamal Helwan	Nile River	5 ±1	30 ± 4	Pulsator
3	El-Fostat	Nile River	5.5 ±0.7	36 ± 2	Pulsator
4	El-Rawda	Nile River	5.5 ±2	25 ± 5	Circular
5	Shoubra El-Kheima	El Sharkawia canal	6 ±1.3	34 ± 2	Pulsator
6	Mostorod	Ismailia canal	4.5 ±0.5	36 ± 5	Pulsator
7	Embaba	Nile River	7 ±1.5	32 ± 6	Pulsator
8	Rod El-Farag	Nile River	5 ±0.5	34 ± 5	Return Sludge (Dorr Oliver)

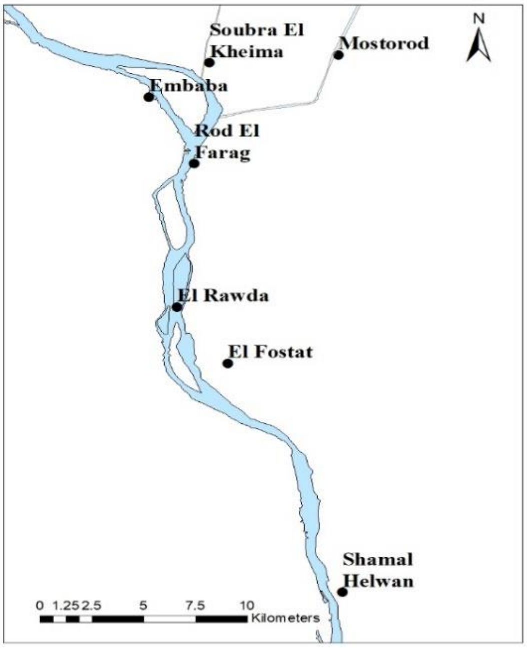

Figure 1: WTPs locations on the map

2.2. Characterization of raw, tap water and sludge:

Samples were collected from intake, produced water, sludge from clarifiers drainage site in the period from January 2018 to December 2018 to be analyzed for TOC, UVA254 using the methods in table 2. All samples were preserved according to each test method precautions and collected three times in each season (once a month), and the average of each season is drawn and discussed.

Table 2: The used test methods

No.	Parameter	Unit	Used method.	Reference
1	Total Organic Carbon (TOC).	mg/l	USEPA METHOD 415.3	(Potter and Wimsatt, 2005)
2	UV254 Absorbance.	Abs		
3	SUVA254	L mg^{-1} m^{-1}	(UVA254/ DOC) X 100	
4	TSS	mg/l	2540 D. Total Suspended Solids Dried at 103 –105°C	(Baird et al., 2012)

3. RESULTS AND DISCUSSION:

3.1. TOC survey analysis

TOC decreases significantly in the raw water showing the bottom value in the summer at Shamal Helwan WTP and the maximum during winter at Embaba WTP (Figure 2). That is due to the procedures obtained from the Egyptian ministry of water resources and irrigation, applying the national water management plan (NWMP) (Elarabawy et al., 2000). (NWMP) limited the amount of water flow and quantities during the period between December and February (in winter). That lets more amounts of the reused wastewaters to stream in the Nile reducing the dilution effect and causing the water quality to deteriorate.

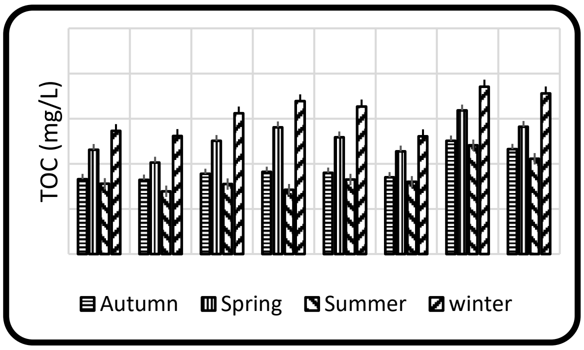

Figure 2: TOC Concentrations (mg/L) in raw water through the four seasons

That complies with Geriesh et al. (2008). They reported pollutants to increase in the Ismailia canal during winter due to closing the high dam gates in the period between January and February. On the contrary, pollutants decrease in summer because of the high quantity and flow of water in this season. TOC concentration is among several elements that are affected by the reduction of the quantity and flow of the surface water. Not only the decrease of fresh surface water quantity is the reason for the increased TOC concentrations in the winter but also the high percentage of the disposed of untreated wastewater including domestic, agricultural, and industrial effluents which reused during the minimum water flow (Wagdy, 2008). Water flow is also an extremely critical parameter in surface water TOC levels, causing it to elevate in low-flow and reduced in higher ones due to the aeration effect of the water movement. In summer, TOC recorded the minimum values if compared to other seasons because the increased amount of water allowed to stream in the Nile basin inside Egypt.

The raw water TOC in autumn and spring is showing moderate concentrations if compared to summer and winter. However, TOC concentrations in autumn are higher due to the low water passed in the Nile River during this period of the year. When the WTP location is in the north the low TOC concentration was detected and vice versa. Only Mostorod and Shoubra El-Kheima were not following this rule as they were treating the water from canals, not the Nile getting in mind that each canal has its unique conditions (Figures 1, 2).

Figure 3: Sources of pollution to Embaba WTP intake

These findings reveal the relative stability of TOC measurements and confirm the previous remarks. The maximum TOC concentration was in Embaba raw water and minimum in Shamal Helwan, which is evident in the satellite views of the two intakes in figures 3, and 4, respectively. Embaba WTP intake has potential sources of organic matter accumulation, release, and pollution upstream. On the other hand, in figure 4, Shamal Helwan WTP intake is clear from these kinds of pollution, organic matter sources, and dead zones.


Figure 4: Shamal Helwan WTP intake satellite view

Rod El-Farag WTP intake also showed high TOC concentration if compared with other intakes. That is well explained in figure 5 expressing satellite view for the location and potential pollution sources and signs like weeds and sediments which act as traps for organic contamination that concentrate and accumulate then released into water with relatively high concentrations.


Figure 5: Rod El-Farag WTP intake satellite view

On the other hand, TOC measured in tap water reflects the treatment process efficiency in each one of the selected eight WTPs as the main target is organic matter reduction and pathogen inactivation (Chen et al.,2007). Which infer, the treatment process removes only a certain amount of TOC and the rest escaped with the treated water. That explains the difference between the TOC values in the two figures, 2, and 6. Our results agree with Chen et al. (2007), who recorded a notable decrease in COD Mn due to the conventional treatment which considered an excellent highlight for the TOC reduction. Moreover, our findings are confirmed by Matilainen et al. (2010) reported a TOC decrease by conventional treatment.

The TOC in the sludge particles depends on the amount of organic matter detected in the raw water, the sludge retention time in the treatment, and the sludge disposal rate (Jarvis et al., 2005). The operational conditions are significant for the TOC concentrations per gram sludge. The little TOC concentration per g sludge the better will be its reuse options, especially as coagulants or adsorbents for environmental remediation and potable water production (Fouad et al., 2018).

The TOC per g sludge increases from the south to the north with the water flow (Figure 7), which confirms the results showed in the above two figures 2, 6 except for the results of Shamal Helwan WTPs. That is complying with the data published by (Geriesh et al.,2008; Mostafa, 2014) who studied TOC concentrations in eight WTPs along the Ismailia canal and recorded higher values downstream towards the north. Shamal Helwan raw and tap waters showed the most decreased TOC concentration, but that is not reflected on the sludge TOC due to insufficient disposing rate that causes the TOC accumulation in sludge. That is coping with the observations reported by Matilainen et al. (2010) reported the increase of organic carbon content in wasted sludge by not disposing of the wasted sludge frequently in the proper time according to lab studies.

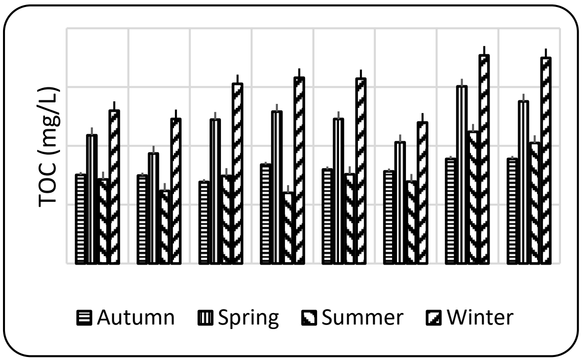

Figure 6: TOC Concentrations (mg/L) in tap water through the four seasons

TOC detected in Embaba and Rod El-Farag sludge samples show the maximum values. Embaba WTP is the maximum due to the operational conditions were not optimal during the sampling time, and the rate of sludge withdrawal and disposal was not efficient that led to excessive accumulation of organic compounds in the sludge. These observations and remarks are compatible with many articles include the previous work (Fouad et al., 2017a; b) and others' work

(Matilainen et al., 2010; Babatunde and Zhao, 2007). On the other hand, Rod El-Farag WTP design is using the slurry as a coagulant aid to enhance the treatment process. The continuous slurry circulation process accumulates organics and other pollutants in it, which infer that applying the SOPs in Embaba WTP could improve the quality of sludge regarding the organic matter. Unfortunately, the quality of the wasted sludge from Rod El-Farag WTP could not be improved as it is one of the design drawbacks of the sludge reuse.

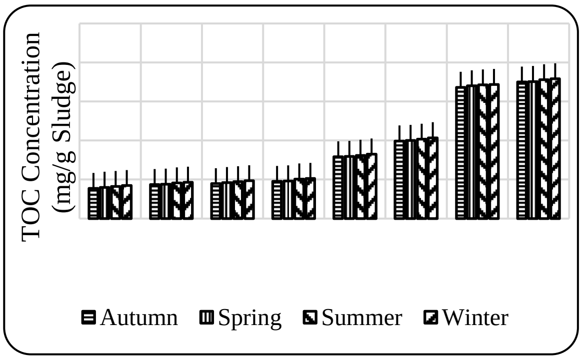

Figure 7: TOC Concentrations (mg/g) in wasted aluminum sludge through the four seasons

3.2. SUVA254 survey analysis for raw and tap waters.

Many research articles have reported the specific absorbance at the wavelength of 254 nm in the ultraviolet region to be a good indication for the type of organic matter (Weishaar et al., 2003; Wei-Bin et al., 2013; Özdemr,2014; Hua et al., 2015). A correlation between the SUVA254 and dissolved organic compounds was established to reflect the mass and aromaticity of organic compounds and their susceptibility to form disinfection byproducts (Kellerman et al., 2018). Raw and tap water absorbance at the wavelength 254 nm was measured and divided by the DOC concentration in mg/L to calculate SUVA254 (L/mg. m) (Figure 8)

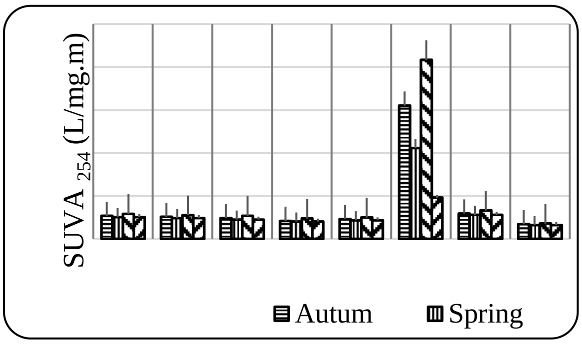

Figure 8: Annual SUVA254 (L/mg. m) for raw waters

There is a vast difference between the nature of organic constituents in raw water found in the Nile River and Ismailia canal which reflects the kinds of pollution added to the canal if compared to the Nile. Also, there are extreme values detected within the year in the Ismailia canal that confirms major spills or heavy pollution with high molecular weights and aromaticity of organic pollutants (Figure 8).

On the other side, raw waters of the Nile River show stable results and minimum extreme organic pollution and spills, which are the value of applying Egyptian protective regulations for WTP intakes and River Nile against potential organic pollution. By studying the satellite view of Mostorod and Rod El-Farag WTP intakes, figure 9 and figure 5, respectively no significant signs of industrial spills at Rod El-Farag intake. However, there are accumulations of weeds and sediments appear in figure 5 up and downstream for the intake of Rod El-Farag that may absorb and adsorb any potential industrial organic contamination. For the first time, it is a protective shield against pollution. However, it shows a potential accumulation site for the natural organic matter that would cause an increase in TOC concentration, as shown previously.

Figure 9: Mostorod WTP intake satellite view

On the other side, Mostorod intake showed less accumulation for sediments and weeds, but a sign of industrial spill was detected, and its flow was toward the intake. That confirms the previous discussion mentioned in the section of raw water TOC concentrations, and it was confirmed by the study conducted by Geriesh et al. (2008) which recorded industrial wastes polluting the Ismailia canal. These outcomes may also be accredited to the water velocity and flow which increase in River Nile due to the NWMP procedures and the difference in width between the Nile and Ismailia canal improves the self-purification process of the Nile if compared with Ismailia canal. Besides, the basin shape at the mentioned WTPs intakes influence the accumulation, or the washout of various pollution sources include organic compounds (Marsili-Libelli and Giusti, 2008). The SUVA254 increased values in Mostorod raw water would reflect on the used chemicals' doses and the quality of produced tap water, especially the disinfection byproducts.

On the other hand, Rod El-Farag tap water was the minimum value for SUVA254 (Figure 10), which is due to the reduced aromaticity and complexity of the organic matter. Also, the treatment process and design of Rod El-Farag WTP (Return sludge) are acting much more on circulating the wasted sludge to enhance the treatment and increase the removal of various potential pollution if compared with other designs.

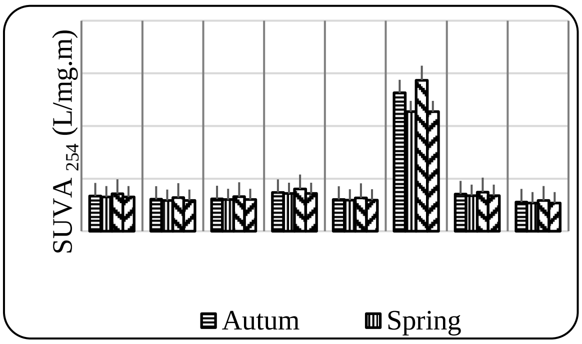

Figure 10: Annual SUVA254 (L/mg. m) for tap waters

It is evident from data in figures 8, 10 that conventional treatment reduces the molecular weight and aromaticity of organic compounds in the raw water. Our results comply with Chen et al. (2007), and Zhang et al. (2015) reported a reduction in SUVA254 values due to treatment with conventional treatment and combined treatment with the advanced oxidation process. There is a significant difference between the organic matter nature between the Ismailia canal and the Nile River due to industrial spills obtained at Mostorod WTP intake using

SUVA¬254. Also, the influence of that increase appeared through the raise in Mostorod tap water SUVA254 if compared with other tap waters. Our results agree with the study performed by Geriesh et al. (2008) who reported polluting Ismailia canal with industrial wastes.

As illustrated in figures 8, the amount of SUVA254 is the highest in summer if compared to other seasons, which reflect and indicate that industrial effluents are maximum in summer and the quantity of water flowing cannot dilute it. The winter is the best value for SUVA254, although the flowing water in the canal is minimum according to the records of the Egyptian ministry of water resources and irrigation (Wagdy, 2008).

As shown, the average TOC concentrations are rotating between 3.48 mg/L in Shamal Helwan WTP and 5.91 mg/L in Embaba WTP which infers that no extreme variation is recorded, and the raw water quality is stable (Figure 11). On the other hand, SUVA254 is showing a remarkable peak in Mostorod WTP raw water if compared with other WTPs which is attributed to the presence of heavy molecular weight and increased aromaticity of the organic content due to the uncontrolled industrial wastes monitored as confirmed previously. That means, however, there is no significant difference in TOC concentrations between Mostorod and other WTPs raw waters, but the nature of organic constituents is showing different properties. In conclusion, Mostorod WTP may face a challenge in treating high molecular weight organic compounds which increase the probability of DBPs formation (Kellerman et al., 2018).

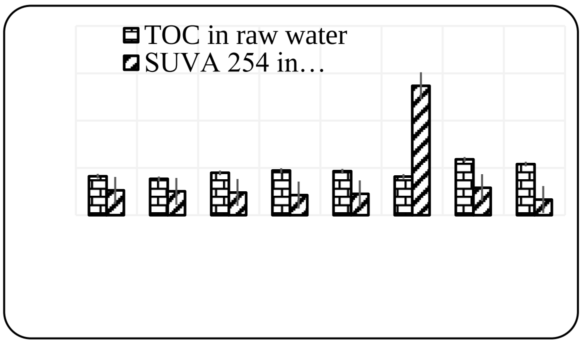

Figure 11: TOC (mg/l) and SUVA254 (L/mg. m) in raw water

Figure 12 copes with the data in figure 11, which tells that the treatment process nearly has a constant reduction in raw water TOC concentration. Moreover, SUVA254 is still showing the same response in Mostorod tap water, which confirms that the operational conditions, chemical dosing, treatment design could not change the nature of organic compounds detected in Mostorod raw water ultimately. In other words, the industrial effluents should not be disposed of in the Ismailia canal, especially near and upstream to Mostorod WTP intake and the Egyptian regulations for protecting WTPs intakes should be applied.

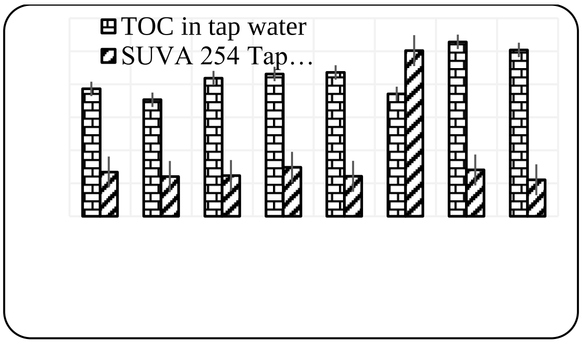

Figure 12: TOC (mg/l) and SUVA254 (L/mg. m) in tap water

Figures 11 and 12 are endorsing the effect of the treatment process, which is reducing the TOC concentrations from raw to tap water, as shown. SUVA254 values decreased by the treatment in all the studied WTPs except Mostorod WTPs. So, conventional treatment reduces TOC concentration found naturally in raw waters and high molecular weight aromatic organic compounds with little concentrations.

That is because of chlorine as a remarkable oxidant that oxidizes organic compounds and chlorinates it, forming less complicated organic compounds. Coagulation also has a notable effect on the structure and concentration of organic compounds released and detected in tap water through several mechanisms include adsorption, absorption, and electrostatic attraction. The reduction in organic matter and aromaticity in tap water is owed to the highly positive charge produced by hydrolyzed aluminum hydroxide which neutralizes the majority of organic compound that is negatively charged due to the presence of negatively charged functional groups (Golea et al., 2017; Sillanpää et al., 2018). Our findings are compatible with those published by Sillanpää et al. (2018) stating that coagulation using inorganic coagulants like aluminum sulfate decreases the TOC concentration and reduces the SUVA254 values.

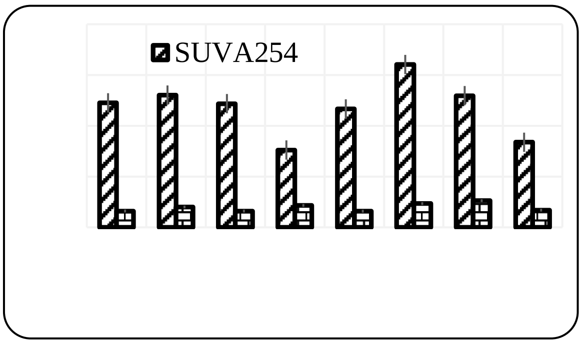

Figure 13: Removal efficiency of TOC and SUVA 254 in the studied WTPs

In the same context, figure13 shows that the treatment process has a significant effect on the SUVA254 values if compared to the efficiency of TOC removal. The minimum SUVA254 removal efficiency was in El-Rawda WTP; however, Mostorod shows the maximum reduction in SUVA254. That means operational conditions in Mostorod could reduce the overall molecular weight of organic matter in raw water, and El-Rawda was not able to do so due to the non-optimized treatment process. That is also reported by Sillanpää et al. (2018) who reviewed several articles discussing the effect of coagulation and precipitation on SUVA254 reduction and how vital the optimization of the controlling parameters is.

The previous findings tell that not only the amount of TOC is of profound influence on the water treatment plants but also the extent of its molecular weight and aromaticity is an immensely powerful factor. That is clear from the results of Mostorod WTPs if compared to other WTPs.

4. CONCLUSION

A survey analysis for TOC to raw, tap water and sludge is performed throughout the year 2018 from January to December, and the results showed that Nile River, Ismailia and El-Sharkawia canals exhibit stable readings of TOC with no extreme increase in the raw water. The TOC values show an increasing gradient from south to north and from summer to winter. Tap water and sludge samples showed fluctuated values depending on the efficiency of each WTPs and operational conditions. A remarkable increase in organic compounds was found in Mostorod WTP in raw and tap water due to industrial spills. The treatment process in Mostorod WTP reduced the SUVA 254 but it still more than other WTPs which means it still poses a threat to the consumers. Finally, more attention should be given toward the illegal industrial spills to fresh surface water.

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