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RESEARCH

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The effect of sedimentation by chemical coagulants and the rapid sand filters on algal removal at drinking water treatment plants in Egypt

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Abstract

Background: The Nile River included diverse phytoplankton compositions belonging to five main phytoplankton categories. Algae have been classified and identified through comparative morphology.

Results: The Pyrrophyta, Charophyta, Cyanophyta, Chlorophyta, and Bacillariophyta were presented through the full period of investigation with 1, 3, 14, 23, and 28 species, respectively. Therefore, it may be important to note that diatoms were recorded as an abundant group in all investigated samples. The numbers of diatoms ranged between 1.45×10^6 and 1.18×10^7 Organism/l, this was followed by green algae that ranged from 7.0×10^5 to 1.22×10^6 Organism/l. While the lowest count of blue-green algae was ranged between 1.6×10^5 and 7.03×10^5 Organism/l. The treatment of Nile water using two chemical coagulants "aluminum sulfate ($Al_2(SO_4)_3{\cdot}16H_2O$) and aluminum oxide ($Al_2O_3$)" removed algae by about 85% and 90%, respectively. As for, the Cyanophyceae species, they were removed completely in treated water using the sedimentation, filtration, and chlorination process. The sedimentation basins removed from 20 to 100% of the total algal count while the rapid sand filters removed from 65 to 100% of the total algal count during the water treatment that depends on the species of algae.

Conclusions: This study concluded that the removal of algae from the Nile water may be more or less easy depending on the nature of the prevailing algal group. Water treatment plants must modify alum and chlorine doses in their water treatment processes according to the count and species of the algal groups, to provide an aesthetically acceptable and biologically safe water supply.

Keywords: Nile River, Algal count, Algal removal, Chemical coagulants, Water treatment

Background

The major source of drinking water supply in Egypt is the Nile River. It showed diverse Phytoplankton species that belong to three main groups: Chlorophyceae, Cyanophyceae, and Bacillariophyceae (Shehata et al. 2008; Ahmed 2016). Water quality and quantity are necessary to maintain the ecosystem integrity. The human consumption of water has a direct impact on human health and activities (El-Sheekh et al. 2017).

Securing drinking water plays a substantial role in preventing the outbreak of many water transmissible diseases. Algae especially those belonging to cyanobacteria are of interest in water treatment facilities because they produce taste, odor, and natural toxins secreted upon their exposure to certain environmental conditions (Ibrahim et al. 2015; APHA 2017; Djamel et al. 2017). Generally, diatoms produce clogging of water filters due to fractional silicon (Shehata et al. 2008; Khalil et al. 2013; APHA 2017). As mentioned before, it is of high priority

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that drinking water must not contain algae and must be free of toxins. Furthermore, it should be aesthetically acceptable in appearance, taste and odor properties in order to win the confidence of the consumers (Codony et al. 2003; Bui et al. 2019; Mohamed et al. 2020; Zhao et al. 2021).

Particular blue-green algae can manufacture toxins that are harmful to health (Sivonen 1996). These toxins may have deleterious effect on humans and can ultimately cause cancer (Rose et al. 1999). Some experimental studies proved that mutagenic and carcinogenic substances are produced by algae. Therefore, they are important because of their chronic impact on health and human physiology (Loper 1989; Monarca 1989; Ledra and Prosperi 1996; Khalil et al. 2013; Ahmed 2016; Djamel et al. 2017). Traditional drinking water treatment such as sedimentation, filtration, and disinfection can remove substantial amounts of algal toxins by removing the whole algal cell. Algae have been specified as beneficial indicators in the bio-monitoring of stream and river ecosystems (Hill et al. 2000; Bui et al. 2019). Recently, bio-monitoring has been utilized for water quality problems and diversity (Clark et al. 2003; Allam and El-Gemaizy 2015; Zhao et al. 2021). Algal populations provide an integrated measure of water quality, and they have several biological features that make them ideal for biological monitoring (Nevo and Wasser 2000; Allam and El-Gemaizy 2015; Delelegn et al. 2018; Mohamed et al. 2020).

Coagulants are rated based on two criteria: firstly, to choose the coagulant and chlorine dose in their best performance conditions; secondly, to ensure the convenient quality of the water. Therefore, the main objective of the present research is to monitor the change in algal abundance and community structure in the Nile river water. In addition, to estimate and evaluate the efficiency of traditional water treatment in removing the inconvenient algae.

Methods

Sampling sites

Water samples were collected monthly for a year from January to December 2019. This was at the inlet and outlet of Atfeeh, Al-Ayat, and Giza water treatment plants. Atfeeh is a rural region, about 75 km south of Giza governorate, east of the Nile River, while Al-Ayat is a rural region, about 55 km south of Giza governorate, west of the Nile River and Giza City. According to the Egyptian Ministry of Irrigation (2001), the annual average of Atfeeh, Al-Ayat, and Giza water treatment plants depths were 7.0 m, 6.9 m, and 6.8 m, respectively, and plants' discharges were 133,000 m^3/day, 133,000 m^3/day, and 65,000 m^3/day, respectively.

Physico-chemical characters and chlorine determination

They were carried out according to Standard methods, (APHA 2012).

Jar test

Coagulation and flocculation was conducted via the "Jar Test" procedure devised by Cohen (1957), Bulusu and Sharma (1967), and Zeta-Meter, Inc. (1993).

Phytoplankton analysis

Phytoplankton distribution and concentration were studied according to standard methods for water and wastewater examinations (APHA 2017).

Collecting samples

Algae samples were collected from midstream at a depth of 10–20 cm, below the water surface. In river, certain volume of water was collected from 1 to 2 m. A few drops of Lugol's solution were added to the water samples (Prescott 1971).

Identification of phytoplankton in water samples

The water samples were examined using a binocular light microscope (Olympus Denmark). Algae were recorded as absent (−) or present (+) in the different water sources for each category and the number of particular algae was recorded. A Sedgwick-Rafter counting chamber was used for the calculation. Therefore, comparative morphology and description were used for algal identification using pertinent textbooks, manuals, articles, and standard methods for water and waste-water examinations (Trégouboff and Maurice 1957; Compère 1977; Nguetsop et al. 2007; Bellinger and Siegee 2010; APHA 2012, 2017). Algae were classified according to the algal database.

Statistical analysis

The resulting data were the average of three replicates presenting intermediate values with the means standard deviation, the analysis of the data by the statistical package, Statgraphics (Statistical Graphics Corporation, Princeton USA) by functions of t-test, and ANOVA to assess significant differences between the means.

Results

Quantitative estimation of phytoplankton

The Nile River water demonstrated different phytoplankton compositions belonging to five major categories, namely Chlorophyta, Charophyta, Cyanophyta, Bacillariophyta, and Pyrrophyta. Generally, phytoplankton distribution is provided in Table 1. The green algae and diatoms were presented throughout the entire period of examination with 23 and 28 species, respectively. Diatoms were the most abundant group

Table 1 List of recorded species in the Nile River samples

Algal species	Occurrence	Algal species	Occurrence
Chlorophyta		*Microcystis aeruginosa* Kützing	+
Actinastrum hantzschii Lagerheim	+	*Oscillatoria limnetica* Lemmermann	+
Ankistrodesmus acicularis var. mirabilis	+	*Spirulina allansonii* Welsh	+
Botryococcus braunii Kützing	+	*Planktothrix rubescens* Anagnostidis & Komárek	+
Chodatella cilliata Lagerheim	+	Total Cyanophyta species	14
Chlamydomonas ehrenbergii Gorozhankin	+		
Chlorella regularis Oltmanns	+	Bacillariophyta	
Coelastrum microporum Nägeli	+	*Amphora ovalis* var. minor Kützing	+
Crucigenia rectangularis Nägeli	+	*Asterionella formosa* Hassall	+
Dictyosphaerium ehrenbergianum Nägeli	+	*Cocconeis placentula* f. major Cleve	
Golenkinia radiata Chodat	+	*Cyclotella comta* var. bodanica Grunow	+
Kirchneriella obesa var. contorta Schmidle	+	*Cyclotella catenata* Bachmann	+
Micractinium pusillum Fresenius	+	*Cymbella prostrata* Cleve	+
Nephrocytium lunatum West	+	*Diatoma elongata* Lyngbye	+
Oocystis parva West & G.S.West	+	*Diatoma vulgaris* var. producta Grunow	+
Oocystis solitaria f. major Wille	+	*Fragilaria capucina* var. familiaris	+
Pediastrum clathratum Lemmermann	+	*Gomphonema olivaceum* Brébisson	+
Pediastrum simplex Meyen	+	*Gyrosigma attenuatum* Rabenhorst	+
Cryptomonas erosa Ehrenberg	+	*Melosira granulata* Ralfs	+
Scenedesmus obliquus Turpin	+	*Navicula bacillum* Ehrenberg	+
Scenedesmus quadricauda Chodat	+	*Navicula cuspidata* var. alaskaensis Foged	+
Sphaerocystis schroeteri Chodat	+	*Navicula exigua* W.Gregory	+
Tetraedron minimum Hansgirg	+	*Navicula mutica* f. cohnii Cleve	+
Ulothrix subtilissima Rabenhorst	+	*Nitzschia acicularis* Kützing	+
Total Chlorophyta species	23	*Nitzschia closterium* f. minutissima Allen & Nelson	+
Charophyta		*Nitzschia constricta* var. major Grunow	+
Closterium acerosum Ehrenberg	+	*Nitzschia nana* Grunow	+
Spirogyra porticalis Dumortier	+	*Nitzschia sigmoidea* Nitzsch	+
Staurastrum paradoxum Meyen ex Ralfs	+	*Nitzschia hungarica* var. linearis Grunow	+
Total Charophyta species	3	*Nitzschia linearis* var. tenuis Grunow	+
Cyanophyta		*Peridinium cinctum* f. areolatum	+
Anabaena flos-aquae f. major Elenkin	+	*Pinnularia aequalis* Ehrenberg	+
Anabaena solitaria Klebahn	+	*Stephanodiscus astraea* Grunow	+
Anabaena planctonica Brunnthaler	+	*Synedra ulna* f. danica Hustedt	+
Anabaena circinalis filament	+	*Tabellaria fenestrata* var. asterionelloides Grunow	+
Anacystis marginata Meneghini	+	Total Bacillariophyta species	28
Aphanizomenon flos-aquae var. gracile Lemmermann	+	Pyrrhophyta	
Chroococcus turgidus Nägeli	+	*Ceratium hirundinella* Dujardin	+
Coelosphaerium kuetzingianum Nägeli	+	Total Pyrrhophyta species	1
Cylindrospermum stagnale Bornet & Flahault	+		
Merismopedia glauca Ehrenberg	+	Total No. of algal species	69

in all investigated samples, while blue-green algae were presented throughout the year with 14 species. These results are in agreement with Ibrahim et al. (2015) and Ahmed (2016) who found that the green algae and diatoms were presented during their full period of investigation with 22 and 24 species, respectively; however, blue-green algae were 7 species only.

Jar test depends on Alum coagulant doses (mg/l) and chlorine dose (4.0 mg/l) to reduce algal count in Nile River when the algal count was 5400 Organism/ml

The maximum algal count (700 Organism/ml) was recorded at 20 mg/l of alum doses, while the least algal count (650 Organism/ml) was obtained at 28 mg/l of alum doses. As a result, the optimal alum dose was detected at 28 mg/l, with an algal removal rate of 87.96%. The highest pH value (7.4) was observed at 20 mg/l alum doses, while the lowest pH value (7.2) was recorded at 30 mg/l alum doses. The largest turbidity (2.10 NTU) was recorded at 20 mg/l of alum doses, while the least turbidity (1.65 NTU) was reported at 28 mg/l of alum doses. The residual alum concentrations ranged from 0.16 to 0.21 mg/l (the normal range should not exceed 0.2 mg/l). Residual chlorine levels varied from 1.4 to 1.6 mg/l, which is within the acceptable range for drinking water. Table 2 demonstrates the alum's doses effect on the Nile River sample.

Effect of total alkalinity, pH, and temperature on the growth of algae in the Nile River

The highest total alkalinity was 156 mg/l in January and the least total alkalinity was 136 mg/l in July, in the other months, total alkalinity was ranged from 138 to 152 mg/l (Table 3). These results are agreement with Ahmed (2016). Total alkalinity as $CaCO_3$ (mg/l) is increased by dissolved CO_2 concentrations greater than those feasible from atmospheric CO_2. Water infiltrating soil and other formations accumulate CO_2 through root and microbial respiration, and hydrostatic pressure increases with depth in saturated subsurface formations, allowing water to hold more CO_2. Alkalinity levels in groundwater from limestone formations may be higher than those seen in surface waters. The decomposition of organic substances can also cause carbon dioxide to increase in surface waters Boyd et al. (2016).

The maximum pH value was 8.4 in December and the lowest pH value was 7.9 in July, while pH value was ranged from 8.0 to 8.3 in the other months (Table 3). The study indicates there were significant differences in the pH of water. The nature of the Earth's layers and

Table 2 Jar tests are based on alum doses and chlorine dose (4.0 mg/l) in Nile River samples

Parameters	Nile River sample	Alum doses (mg/l) + chlorine dose (4.0 mg/l)					
		20	22	24	26	28	30
Algalcount (Organism/ml)	5400	700	680	670	670	650	660
pH	8.1	7.4	7.3	7.3	7.3	7.3	7.2
Turbidity (NTU)	9.33	2.10	1.84	1.73	1.67	1.65	1.68
Residual Alum (mg/l)	0.07	0.16	0.17	0.18	0.19	0.20	0.21
Residual chlorine (mg/l)	–	1.4	1.4	1.5	1.5	1.5	1.6

Table 3 The influence of physio-chemical variables on the algal count in Nile river water

Months	Nile river water Algal count (Organism/ml)	Water physio-chemical parameters		
		Total alkalinity as $CaCO_3$ (mg/l)	pH	Temperature °C
Jan	6650	156 ± 6	8.4 ± 0.06	16.5 ± 0.5
Feb	4600	152 ± 6	8.3 ± 0.05	19.1 ± 0.8
March	4320	148 ± 4	8.3 ± 0.05	21.9 ± 1.0
April	4960	144 ± 4	8.2 ± 0.03	22.5 ± 1.0
May	5240	142 ± 2	8.1 ± 0.03	27.4 ± 0.6
June	4720	140 ± 2	8.1 ± 0.02	29.8 ± 0.7
July	2500	136 ± 2	7.9 ± 0.02	29.8 ± 0.5
Aug	3150	138 ± 2	8.0 ± 0.03	30.0 ± 0.5
Sept	7300	140 ± 2	8.2 ± 0.02	29.1 ± 0.5
Oct	9170	142 ± 4	8.3 ± 0.04	25.8 ± 0.6
Nov	13,800	146 ± 6	8.3 ± 0.05	22.9 ± 0.9
Dec	8500	150 ± 6	8.3 ± 0.05	18.7 ± 0.8

All data represented means of three replicates ± standard deviation (SD) composition of discharged water that was the river receives all influence the pH of the river. The pH of water is critical for aquatic life, and even small pH changes can affect species that are pH-sensitive Rashad et al. (2019). These results are agreement with Ahmed, (2016).

The maximum temperatures were 30 °C in August and the least temperatures were 16.5 °C in January, while temperatures was ranged from 18.7 to 29.8 °C in the other months (Table 3). Temperature observations revealed a wide range of temperatures; temperature varies greatly depending on several factors such as geographic location, shade, water supply, thermal discharges, water body size, and depth Rashad et al. (2019). It is significant because it has a direct impact on the amount of oxygen that can be dissolved in water, the rate of photosynthesis of algae and bigger aquatic plants, aquatic creature metabolic rates, and the sensitivity of organisms to toxic wastes, parasites, and illnesses. These results are in agreement with Rashad et al. (2019) and Mohamed et al. (2020). The current study indicated that total alkalinity, pH, and the temperature had an impact on the growth and number of algae in Nile river water (Table 3).

The removal rate of algae in the sedimentation basin and filters

Diatoms, green algae, and blue-green algae were present throughout the full examination period. In the sedimentation basin *Synedra*, *Asterionella*, *Melosira,* and *Fragilaria* (Diatoms) were removed with 40–90, 75–80, 80–90, and 85–100%, respectively; *Chlorella*, *Scenedesmus,* and *Pediastrum* (Green algae) were removed with 20–50, 25–60 and 80–95%, respectively; *Oscillatoria* and *Anabaena* (Blue-green algae) were removed with 40–50 and 50–70%, respectively (Table 4). In the current study, sedimentation basins in drinking water plants removed from 20 to 100% of the total algal count during the water treatment that depends on the species of algae, the use of the optimal coagulant dose, and the detention time of the clarifiers.

When using filters, *Synedra*, *Asterionella*, *Melosira,* and *Fragilaria* (Diatoms) were removed with 90–97, 90–98, 95–100, and 95–100% respectively; *Chlorella*, *Scenedesmus,* and *Pediastrum* (Green algae) were removed with 70–96, 65–95 and 92–98% respectively; *Oscillatoria* and *Anabaena* (Blue-green algae) were removed with 99–100 and 99–100% respectively. Diatoms represented the most abundant category in all investigated samples (Table 5). An ongoing global problem for the drinking water treatment industry is the presence of algae in the water source. Algae in the drinking water supply can cause major disturbances including taste, odor, production of secondary product, coagulation impairment, filters clogging, and absorbable organic carbon for the biofilm growth. Therefore, conventional treatment of drinking water that includes sedimentation basins and rapid sand filters is satisfactory and suitable for removing algae under normal conditions (Badiaa et al. 2010). In the present study, rapid sand filters in drinking water plants removed from 65 to 100% of the total algal count during the water treatment depending on the species of algae, sedimentation efficiency, the efficiency of the filters (filter medium) and the filters discharge rate m^3/hour.

Phytoplankton occurrence and abundance in drinking water

The most abundant phylum was Bacillariophyta. The occurrences of these algae were variable among groups and sites. The mean counts of Bacillariophyta species per-site were 14, 13, and 13 for Atfeeh, Al-Ayat and Giza, respectively. The second dominant phylum was Chlorophyta. Its occurrences were not uniform among groups and sites. The mean counts of Chlorophyta species per-site were 3, 5, and 6 for Atfeeh, Al-Ayat and Giza,

Table 4 Removal rate for algae in sedimentation basin

Algae type	Algal genera	Removal rate %
Diatoms	*Synedra*	40–90
	Asterionella	75–80
	Melosira	80–90
	Fragilaria	85–100
Green algae	*Chlorella*	20–50
	Scenedesmus	25–60
	Pediastrum	80–95
Blue green algae	*Oscillatoria*	40–50
	Anabaena	50–70

Table 5 Removal rate for algae after filtration

Algae type	Algal genera	Removal rate %
Diatoms	*Synedra*	90–97
	Asterionella	90–98
	Melosira	95–100
	Fragilaria	95–100
Green algae	*Chlorella*	70–96
	Scenedesmus	65–95
	Pediastrum	92–98
Blue green algae	*Oscillatoria*	99–100
	Anabaena	99–100

respectively. While Charophyta species counts per-site were 1, 1 and 2 for Atfeeh, Al-Ayat and Giza, respectively. The total number of species in drinking water was 18, 19, and 21 for Atfeeh, Al-Ayat and Giza, respectively (Table 6).

Changes into algal abundance in Nile River and tap water samples

In the present study, the algal count was used as biological monitoring for the detection of the optimal dose in water treatment. Algal counts (Organism/ml) in Atfeeh, Al-Ayat, and Giza sites are recorded in Fig. 2. To protect consumers from water-borne diseases, the distributed water should be completely free of pathogenic algae (Mohamed et al. 2014; Mohamed et al. 2020). Diatoms and green algae were recorded in all investigated samples, but Cyanophyceae (pathogenic algae) were not recorded in all outlet samples of water treatment plants and this is conforms to the Egyptian standard specifications.

For the Nile River water samples, the highest algal count was recorded during November as 13,800 Organism/ml, while the lowest count was recorded during July as 2500 Organism/ml. During the other months, the counts were between 3150 and 8500 Organism/ml (Fig. 1). These results are in agreement with Ahmed (2016) and Mohamed et al. (2020) who stated that the counts of algae were between 2670 and 8110 Organism/ml.

At Atfeeh site, tap water samples had the highest count that was recorded during November as 60 Organism/ml, while the lowest count was recorded during other months (10–50 Organism/ml). At Al-Ayat site, tap water samples had the highest count that was recorded during December as 50 Organism/ml, while the lowest count was recorded during other months (10–40 Organism/ml). At Giza site, the highest count in tap water samples was recorded during November as 50 Organism/ml, while the lowest count was recorded during other months (10–40 Organism/ml) (Fig. 2). These results are

Table 6 Algal species occurrence in the drinking water samples

No	Species	Family	Phylum	Site of plants		
				Atfeeh	Al-Ayat	Giza
1	*Actinastrum hantzschii* Lagerheim	Scenedesmaceae	Chlorophyta	−	−	+
	Ankistrodesmus acicularis var. mirabilis	Selenastraceae	Chlorophyta	−	+	+
3	*Chlorella regularis Oltmanns*	Chlorellaceae	Chlorophyta	+	+	+
4	*Scenedesmus quadricauda* Chodat	Scenedesmaceae	Chlorophyta	+	+	+
5	*Sphaerocystis schroeteri* Chodat	Sphaerocystidaceae	Chlorophyta	+	+	+
6	*Tetraedron minimum* Hansgirg	Hydrodictyaceae	Chlorophyta	−	+	+
7	*Closterium acerosum* Ehrenberg	Closteriaceae	Charophyta	−	−	+
8	*Staurastrum paradoxum* Meyen ex Ralfs	Desmidiales	Charophyta	+	+	+
9	*Asterionella formosa* Hassall	Fragilariophyceae	Bacillariophyta	+	+	+
10	*Cocconeis placentula* f. major Cleve	Cocconeidaceae	Bacillariophyta	+	−	−
11	*Cyclotella catenata* Bachmann	Stephanodiscaceae	Bacillariophyta	+	+	+
12	*Cymbella prostrata* Cleve	Cymbellaceae	Bacillariophyta	+	+	+
13	*Diatoma elongata* Lyngbye	Tabellariaceae	Bacillariophyta	+	+	+
14	*Diatoma vulgaris* var. producta Grunow	Tabellariaceae	Bacillariophyta	+	+	+
15	*Navicula cuspidata* var. alaskaensis Foged	Naviculaceae	Bacillariophyta	+	+	+
16	*Navicula bacillum* Ehrenberg	Naviculaceae	Bacillariophyta	+	+	+
17	*Nitzschia closterium* f. minutissima Allen & Nelson	Bacillariaceae	Bacillariophyta	+	+	+
18	*Nitzschia constricta* var. major Grunow	Bacillariaceae	Bacillariophyta	+	+	+
19	*Navicula mutica* f. cohnii Cleve	Bacillariaceae	Bacillariophyta	+	+	+
20	*Nitzschia linearis* var. tenuis Grunow	Bacillariaceae	Bacillariophyta	+	+	+
21	*Nitzschia acicularis* Kützing	Bacillariaceae	Bacillariophyta	+	+	+
22	*Synedra ulna* f. danica Hustedt	Fragilariaceae	Bacillariophyta	+	+	+
	Total of Bacillariophyta species			14	13	13
	Total of Chlorophyta species			3	5	6
	Total of Charophyta species			1	1	2
	Total of species			18	19	21

Absent (−) Present (+)

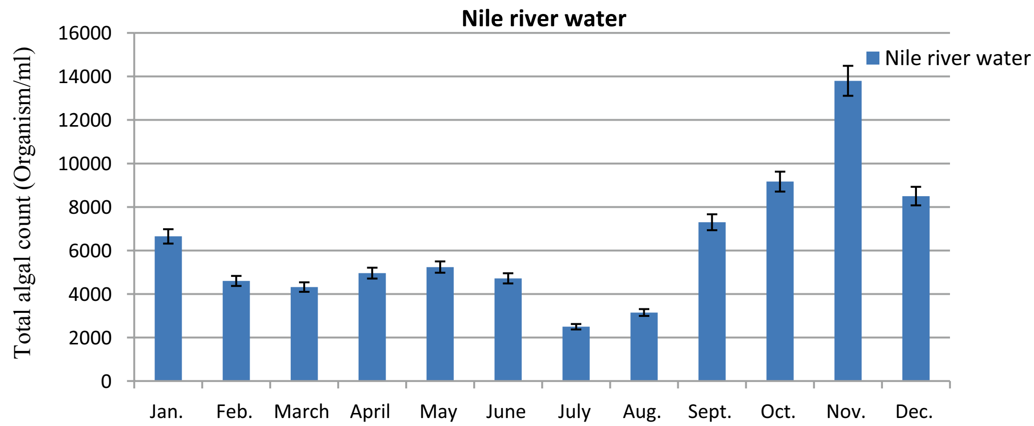

Fig. 1 Total algal count (Organism/ml) in Nile river water samples

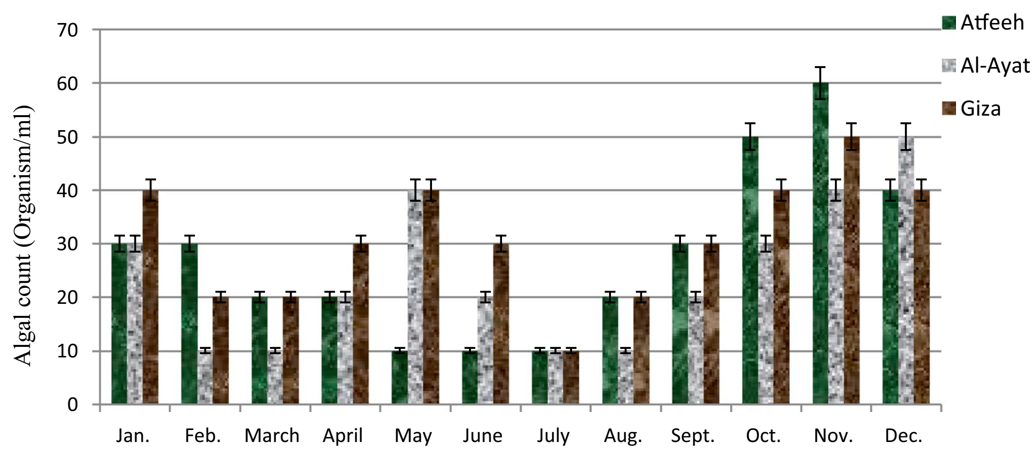

Fig. 2 Algal count (Organism/ml) in the treated water sample

in agreement with Ahmed (2016) who stated that the counts of algae were between 10 and 60 Organism/ml in outlet samples of water treatment plants.

Discussion

Different phytoplankton groups such as green algae, blue-green algae, and diatoms were different in their numbers during the full duration of investigation in the waters of the Nile River. Diatoms count exceeded the other two groups, in all months. Diatoms count ranged from 1.45×10^6 to 1.18×10^7 Organism/l. This was followed by green algae, which ranged from 7.0×10^5 to 1.22×10^6 Organism/l, while the lowest number was observed for blue-green algae, which ranged from 1.6×10^5 to 7.03×10^5 Organism/l. This is due to the changes in flow rate and turbidity levels of the water (Ramadan and Shehata 1976; Shehata et al. 1997). These results are in agreement with Shehata et al. (2008) and Ibrahim et al. (2015) who reported that the abundance of green algae, blue-green algae, and diatoms was variable, and diatoms represented the most abundant category in all investigated samples.

In conventional treatment (pre-chlorination and coagulation), as processes for removing freshwater algae, two forms of alum ($Al_2 (SO_4)_3 \cdot 16H_2O$ and Al_2O_3) were used. The results showed that blue-green algae were the most sensitive algal group for the water treatment process and that they were completely removed from the water by both the two alum formulas. Moreover, the response of the other two algal groups, green algae and diatoms, was relatively high. However, the removal of the total algal count was between 85% for aluminum sulfate and 90% for aluminum oxide. These results are in agreement with Al-Layla et al. (1974), Shehata et al. (2008), Ibrahim et al. (2015), and Mohamed et al. (2020) who stated that the removal of the total count of algae in surface water treatment was 85% for aluminum sulfate and 90% for aluminum oxide treatment.

Turbidity is caused by dissolved substances and negative charges (i.e., algae) that require more positive charges (i.e., H^+ and $Al_3{}^+$) to pass from the dissolved state to the solid-state during the coagulation phase before their sedimentation through the flocculation phase. In the present study, two types of aluminum were introduced and the following coagulation mechanisms were suggested: (1) protons donate H^+ ions in less than 1 s, (2) CN release cationic aluminum species in less than 7 s, and (3) coagulation process is produced by aluminum hydroxide precipitation in 7 s. Protons here mean acidification that acts more quickly than cationic aluminum because the hydrogen ion is smaller than the metal. $Al(OH)_3$ carries a positive charge to indicate that aluminum flocs are positively charged. Indeed, Dempsey (1987) has found that the flocs generated in any conventional technology for water treatment were positively charged. The point of zero charges (PZC) of $Al(OH)_3$ is ~8.5. The colloids for clay minerals that are frequently observed in water are negatively charged. As an example, the PZC of silica and kaolin is ~2 and 4, respectively. Thus, the colloids are electrostatically fixed to the flocs in the neutral pH water. The typical pH ranges from 6.0 to 7.5 in coagulation processes (Ghernaout and Ghernaout 2012; Ghernaout et al. 2017).

Water treated for human use should be free from algal toxic substances (WHO 2005; Desta Kassa 2009). Based on the species, the presence of algae may results in greenish discoloration of water, due to high concentration of suspended cells in some conditions and the formation of foams on the surface, such as cells aggregations that may lead to high concentrations of toxin (WHO 2006; APHA 2017). In terms of public health impact, a range of blue-green algae species can produce toxins; therefore, drinking water should be free from cyanobacteria (WHO 2006).

Conclusions

This study concluded that the removal of algae from the Nile water may be more or less easy depending on the nature of the prevailing algal group. Water treatment plants must modify alum and chlorine doses in their water treatment processes according to the count and species of the algal groups, to provide an aesthetically acceptable and biologically safe water supply. Furthermore, it is recommended to apply algal count as a biological monitor to determine the drinking water quality, because drinking water must be free from blue-green algae, pathogenic algae, and their toxic substances. Traditional water treatment plants in Egypt are suitable for algal removal and their toxins, but alum coagulant and chlorine doses should be adequate for algal removal. Finally, rapid sand filters are efficient in the removal of pathogenic algae at surface water treatment plants.

Abbreviations

APHA: American Public Health Association; Alum: Aluminium sulphate; NTU: Nephelometric turbidity unites; WHO: World Health Organization.

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Authors' contributions

AH and HH have done the writing of the final manuscript. The work plan and implementation of the research, as well as the analysis of the results, were all contributed to by all authors, who were also in charge of the general direction and design. Before submitting the work, all authors have read and approved manuscript and ensure that this is the case.

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This study did not require ethical approval or consent for participation.

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Competing interests

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