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Algal control and enhanced removal in drinking waters in Cairo, Egypt: A case study

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ABSTRACT

Incidents of algal blooms targeting the major water treatment plants within the capital region have been reported by the Egyptian media since 2006. While previous studies focused upon the identification of algal types and its correlation to the disinfection byproducts formed, no correlation between the change in raw water quality and this phenomenon was explored. For this purpose, a survey of the Nile water quality parameters at one of the major water intakes at El-Maadi, South of Greater Cairo Urban Region was conducted during the period Dec 2011- Nov 2012. Bench-scale experiments were conducted to evaluate the effectivity of the conventional chloride/alum treatment relative to a combined Cl/permanganate preoxidation with Al and Fe coagulants during the algae outbreak period. The results showed that the addition of a permanganate dose of 0.5 mg/L significantly reduced the chlorine demand, the applied coagulant dose as well as the residual metal (aluminum/iron) concentration in the treated water. Multivariate analysis was used to identify the raw water parameters that contributed towards the reported algal population as well as to explain the impact of chemicals coagulants added upon the final water quality parameters.

KEYWORDS

Nile raw water;
Permanganate/chloride;
Algal reduction;
MVS.

INTRODUCTION

In Egypt, the majority of the population depends upon the river Nile as the main source for drinking water and for industrial and agricultural activities. However, after the completion of the Aswan High Dam (AHD) in 1966, stream flow-regulation has caused significant changes to the Nile aquatic ecosystem and waterway environment[27,18,44]. This change in flow lead to the retention of water masses at reservoirs behind dams and barrages in some regions within the Nile system, which provided favorable conditions and abundant time for phytoplankton development. Subsequently, this altered the aquatic vegetation which is a source of nutrients for phytoplankton and algae utilization.

Evidently and since 2006 - specifically in September /October, incidents of algal blooms targeting the major water treatment plants all over the country were reported by the Egyptian media. The increase in algal growth was attributed to the extended storage time of raw water on site before treatment as well as the lack of regular maintenance and pipe cleansing, an event scheduled every 6 months (Al Ahram Newspaper, 28 September 2006). As well, the prolonged residence time of water masses in the distribution system was reported to promote unexpected algal growth and microbial re-growth. Eventually, this caused an increase in algal toxins within the water distribution system during this period that was reflected by reports of at least 85 sick and one documented death in 2006 (Egyptian Minister of Health- 15 October 2006).

Generally, algae are widely dispersed throughout lakes and rivers at relatively low population densities; however, its population is liable to rapidly grow with the increase in nutrients in surface waters[24]. This may result in dissolved oxygen depletion, high water turbidity and eventually, the degradation of aquatic ecosystem[32,1,41,49]. As well, this may cause acute disturbance in taste, odor and induce toxins under stressful environmental conditions[40,25,41]. In a conventional water treatment plant, uncontrolled algae blooms may clog screens and rapid sand filters and hinder the drinking water supply system[5, 52]. On the other hand and due to their microscopic size, algae may penetrate filters and reside within the domestic drinking water supply storage systems and excrete extra-cellular organic products that may lead to an increase in the coagulant demand, impair the final water disinfection process and promote microbial re-growth in the water distribution systems[30,5,52]. Subsequently, reduction of surface water algae during the initial stages of treatment is preferred to maintain acceptable final water quality[28,24,5,52]. This is mainly because the removal of algal cells as suspended solids may reduce the associated soluble toxins that may impair the physicochemical water treatment systems.

The general techniques applied for algal-control in drinking water treatment systems were discussed elsewhere [24,22,5,4,52,12]. Of these operations, coagulation/ flocculation is regarded as the main process for algae removal as it has the ability to remove suspended solids through particle destabilization while flocculation allows for solid separation either through settling or flotation, and filtration[28,24,22,41,12]. However, due to its small size and low specific gravity, algae removal may not be effectively achieved through using chemical coagulation alone[12]. Therefore, chemical pre-oxidants (such as ozone, chlorine dioxide, chlorine, or permanganate) are required to enhance coagulation as they have the capacity to inactivate algal cell[30,10,24,40,25,22]. Overall, chlorine is the preferred pre-oxidant because it is a powerful water disinfectant that is safer to apply; is more economical than other algaecides and is less time-consuming in application[41]. Nevertheless, it was reported that algae may consume large quantities of chlorine and thus reduce the free chlorine available to control bacteria if they persist after treatment[41].On the other hand, it was reported that overdosing of preoxidants must be avoided as it can cause algal cell lyses and release undesirable toxins or offensive taste and odor associated compounds[24, 25].

In Egypt, a typical drinking water treatment system comprises stages of pre-chlorination, flocculation/coagulation with alum, filtration (14 sand and carbon filters), post-chlorination and settling in distribution tanks[13]. In this set-up, pre-chlorination is regarded as the most important stage for the control of bacteria and algal growth[18,13,6]. In this respect, a number of studies were conducted to investigate the contribution of this stage towards the formation of disinfection by-products in the final treated waters and to set recommendations for its application[18,13,6]. Nonetheless, in a review by Donia (2007), it was speculated that there was a need to upgrade the current treatment technologies in Egypt in order to efficiently handle the recent added loads of chemical and biological pollutants transported through surface and drinking water systems. However, there has been no investigation exploring the relationship between the raw water quality parameters and the noted algal surges. As well, no study was conducted to evaluate the impact of the current applied treatment procedures upon the final treated water parameters in case a combined pre-oxidation stage was applied.

Thus, the aim of the current study is to survey of the water quality parameters of Nile surface water at El-Maadi, South of Greater Cairo Urban Region Figure 1 during the period of Dec 2011- Nov 2012. Multivariate statistical analysis was applied to identify the contribution of the measured parameters towards such an occurrence. As well, during this work, an investigation of methods to improve the efficiency of the current applied pre-oxidation/coagulation procedure through use of a combined preoxidation (permanganate and chlorine) and the use of the different coagulants (alum, ferric chloride and ferric sulfate) was undertaken during the algae outbreak period. As a final step, the effect of this combined pretreatment/ coagulation upon the final main water parameters and the residual metal (aluminum/iron) concentration in the treated water was assessed using multivariate statistical analysis.

MATERIALS AND METHODS

Sampling site

The sampling site is located at El-Maadi district Figure 1, south of the Greater Cairo Urban Region, Egypt (Latitude: 29˚56’53.3’’N and Longitude: 31˚15’24.6’’E). The area is bound from the north and east by residential areas and to the west and south, the predominant activity is agriculture.

Physical and chemical analysis of water

Ample water samples were collected twice/ month from Dec. 2011 to Nov. 2012. Both temperature and pH of the samples was measured on site. The samples were transferred immediately to the lab for physical and chemical characterization according to APHA (2005). The measured parameters included: Turbidity: Nephelometric method; TDS: EC electrical conductivity; Total alkalinity: titrimetrically (pH 4.5); (Ca^{2+}) and (Mg^{2+}): Na_2EDTA titrimetric method; Chlorides: Argentometric method; (SO_4^{2-}); Barium Chloride spectrophotometric method; PO_4^{3-}: Stannous Chloride colorimetric method; TOC: Persulfate-Ultraviolet or Heated-Persulfate Oxidation Method; Silicates: Silicomolybdate Method. Nitrates were determined using the sodium salicylate method for nitrates determination in drinking waters[38]. Algae count was determined using Sedgwick – Rafter method Counting cell[4]. Residual elements (Al, Fe and Mn content) in the final treated waters were determined by Eriochrome Cyanine R Method; Phenanthroline Method, and the Persulfate Method, respectively[4].

Jar test- experiments: Pre-oxidation and settling tests

Jar tests were conducted to evaluate algal re-

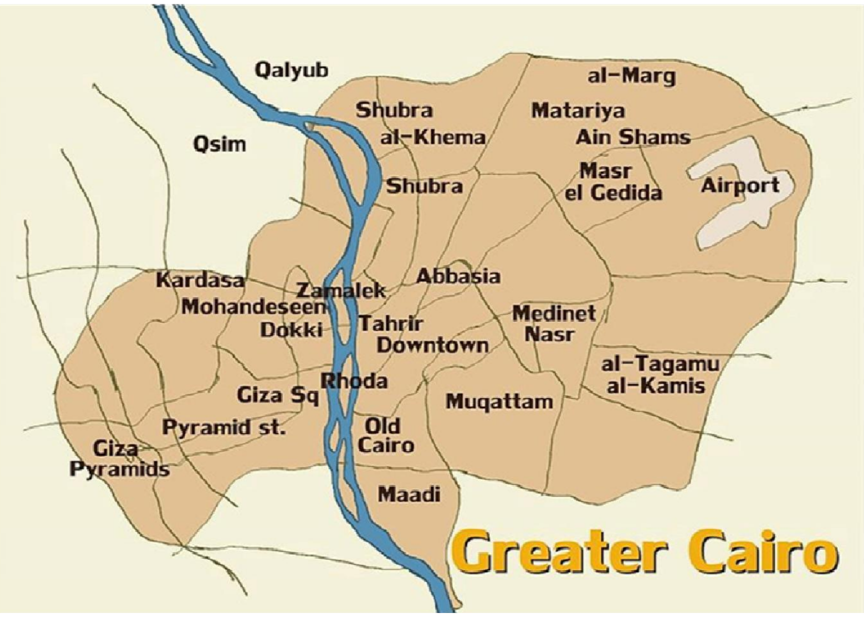

Figure 1 : A map of Greater Cairo Urban Region indicating the Location of sampling site along the River Nile at El-Maadi district.(■)

TABLE 1 : Monthly mean variation of Nile raw water physical and chemical parameters (Algae count, Turbidity, temp, pH, TDS, TOC, Total alkalinity, calcium, manganese, chloride, sulfate, phosphate and nitrate contents) during the period from Dec. 2011- Nov. 2012

Month	Algae (unit/mL)	Turbidity (NTU)	Temp (°C)	pH	TDS (mg/L)	Silica (mgSiO$_2$/L	TOC (mg/L)	Total Alkalinity (mg CaCO$_3$/L)	Ca^{++} (mg/L)	Mg^{++} (mg/L)	Cl$^-$ (mg/L)	SO$_4^{2-}$ (mg/L)	PO$_4^{3-}$ (µg/L)	NO$_3^-$ (x10^{-2}) (mg N/L)
Dec	5200	6.3	15.30	7.9	314	1.58	3.84	162	32.0	18.0	36.0	40.0	23.0	7.00
Jan	4350	6.0	13.40	7.9	288	1.96	4.52	144	38.0	19.5	37.2	40.6	8.0	5.00
Feb	3300	4.6	14.00	7.9	268	2.63	4.64	134	34.4	17.0	32.0	42.0	7.3	3.00
Mar	4000	4.3	16.30	8.2	254	3.67	5.69	140	30.0	15.8	27.7	33.0	9.0	3.70
Apr	3800	4.4	22.00	8.3	253	2.56	4.89	141	29.5	15.0	28.0	32.0	10.0	3.50
May	3100	4.9	25.70	8.2	240	3.33	6.99	142	28.0	14.3	24.5	29.8	8.0	5.00
Jun	2330	4.5	27.00	7.9	221	3.74	5.36	118	26.0	12.0	20.0	23.8	6.0	2.40
Jul	2500	3.4	29.20	7.9	223	4.88	4.30	124	25.7	10.2	19.7	24.0	5.0	2.70
Aug	3150	4.2	29.70	7.8	230	4.03	3.95	136	24.0	9.6	21.2	25.7	9.0	4.00
Sep	6300	6.5	27.70	8.0	257	4.4	4.37	142	26.4	11.2	23.5	28.6	16.0	7.00
Oct	7100	6.7	25.50	8.0	269	2.09	3.76	152	27.0	14.6	27.5	39.6	17.0	7.50
Nov	8300	6.4	22.20	8.1	277	2.6	4.74	154	30.0	17.3	31.0	36.4	20.0	9.00

- **The monthly data represents the mean value of 4 weeks determinations that were repeated in triplicates.**

moval by pre-oxidation followed by coagulation using a six-paddle stirrer (JLT 6- VELP Scientifica) on surface water samples at room temperature (about 20°C). This method was used to determine the optimal oxidant as well as the coagulant demand/dose[4].

Statistical analysis of data

Cluster analysis was performed using Ward's method for minimum variance and the similarity coefficient used was the Square Euclidean distance function using 'StatistiXL 1.8' incorporated within the Microsoft Excel 2007 (Microsoft® Windows 2007) software program. Hierarchal clustering was performed for the water chemical and physical characteristics before and after treatment and the results obtained included the distance matrix, clustering strategy report and dendogram were utilized in data interpretation accordingly.

RESULTS AND DISCUSSION

Nile water quality and algae types present in raw Nile waters

TABLE 1 shows the mean monthly chemical and physical water quality parameters obtained during Dec 2011 – Nov. 2012. The data revealed that a higher algal count was obtained during the period from Sept. to Nov. 2012. This increase may be attributed to agricultural wastewater discharge and the accumulation of pollutants and nutrients south of the sampling point[13]. The TDS ranged from 221- 314 mg/L with the highest in the winter season while the lowest in June 2012, which is similar to that reported by Amer and Abd El-Gawad (2012) within the vicinity of the selected site in 2010. Generally, it was reported that the salinity of Nile water increased going from Aswan High Dam (160 mg/L) to Cairo (around 260 mg/L)[48,44]. This was attributed to the release of agricultural wastewaters containing excess chemicals along the river. As well, it was reported that higher TDS recorded during winter for the Nile waters was attributed to the dam closure period in which the amount of water released from the behind the dam was less than that in summer. On the other hand, a decrease in TDS within the Nile system was related to the increase in suspended particles during the flooding period as these particles may adsorb the dissolved solids onto it and subsequently reduce the TDS by sedimentation[2]. The data also revealed that the highest water turbidity was observed during the winter period whilst the lowest was during the summer season, an event that was

TABLE 2 : Monthly mean variation in algae count (unit/ mL) and the count of the different types of algae identified in these raw waters and their relative percent with respect to the total Algae count during the period from Dec. 2011- Nov. 2012

Months	Total algae count unit/ml	Diatoms	Diatoms %	Chlorophyta	Chlorophyta %	Cyanophyta	Cyanophyta%	Euglenophyta	Euglenophyta %
Jan	4350	2300	52.9	1400	32.2	500	11.5	150	3.4
Feb	3300	1750	53	1000	30.3	400	12.1	150	4.7
March	4000	1980	49	1400	35	500	12.5	100	3.5
April	3800	1900	50	1100	28.9	700	18.4	100	2.7
May	3100	1500	48.4	1050	33.9	500	16.1	50	1.6
June	2350	1150	48.9	800	34	350	14.9	50	2.2
July	2500	1100	44	850	34	500	20	50	2
Aug	3150	1400	44.4	1150	36.5	700	22.2	100	2.5
Sep	6300	2900	46	2450	38.9	1000	15.9	150	2.5
Oct	7100	3750	52.8	2650	37.3	650	9.2	150	0.8
Nov	8300	4300	51.8	3150	37.9	700	8.4	150	1.8
Dec	5200	2700	51.9	1850	35.6	550	10.6	100	2

attributed to the winter closure period[19]. High turbidity of the Nile stream was attributed to the increase in water nutrient content[3], which is in agreement with the current findings.

Generally, it was reported that Nile water temperatures varied from 13°C in winter to H” 30°C in summer[44,2]. This variation in temperature was reported to be an indicator of water transparency which had a direct impact upon regulating algal/phytoplankton population in these waters[2]. As well, higher temperatures were reported to accelerate the metabolic rate of microalgae[41]. The presence of carbonates in these waters was reported to be dependent upon both the pH and salinity (TDS)[17]. In addition, the increase in alkalinity ($CaCO_3$) of these raw waters was reported to promote phytoplankton growth[2] as a results of algal utilization of dissolved CO_2 and HCO_3 in biomass formation[32].

Overall, it was observed that there was an increase in Ca, Mg, SO_4, Cl, PO_4 and NO_3 content during the winter period, which is in accordance with the findings of Emara et al. (2012). The phosphates and nitrates contents of these waters showed a similar pattern of increase and decrease during the study period. This may be attributed to the discharge of agricultural drainage[17,27,48,6] as well as from surrounding industrial and urban sources[15]. Finally, the silica content of these waters ranged between 1.58-4.88 mgSiO_2/L with the highest in July and the lowest in December. Shehata et al. (2008) reported that low silica levels were associated with the increase in diatoms present in these waters. This variation in silicates was also attributed to the fact that diatoms utilized dissolved silicates for the formation of skeletal materials during algal productivity[8].

Concerning the class and types of algae present in these waters, the data obtained TABLE 2 shows the predominance of diatoms over Chloropyta, Cyanophyta and Euglenophyta. This is accordance with the findings of Abd El-Hady (2014) who indicated that phytoplankton in the Nile system were dominated by Bacillariophyta (diatoms) all year round. As well, the prevalence of diatoms within the river Nile was attributed to the presence of iron and dissolved silica[40]. On the other hand, while the predominance of diatom is regarded as a water good quality indicator under low stress conditions, the increase in Chlorophyceae and Cyanophyceae is considered an indication of organic pollution and nutrient accumulation in surface waters[31].

MVS analysis of raw water data and its correlation with algal types

Generally, it was reported that the important factors controlling algal growth are light, temperature, the chemical composition of water and its acidity or alkalinity[41]. However, to better explain the dependency of the algal content of these waters upon the measured parameters, Hierarchal Cluster analysis was performed using the analytical data obtained for the raw waters and the identified types of algae present and the result is depicted in a dendogram Figure 2. The dendogram indicated the split up of the data into 17 clusters that were grouped into 2 main groups. The first of the multi-cluster groups indicated that the Euglenophyta content was strongly dependent upon the total alkalinity ($CaCO_3$) and the TDS of these waters. This may be attributed to the fact that Euglenophyta may utilize these contents as nutrients during its growth period[36]. Cyanophyta also showed a strong dependency upon all chemical parameters measured as well as on Euglenophyta in these waters. This may be attributed to the fact that Cyanophyta is a photosynthetic nitrogen fixing group that thrives upon the increase in nutrient content[36]. The second group indicated that both the Chlorophyta and Diatoms contents were the major contributors towards the measured Total algal count. Even though this was attributed to the pH of raw waters, the abundance of these types of algae may be attributed to the increase in nutrients[36]. Overall, the data revealed that these two groups of algae were also affected by the presence of Euglenophyta and the water TDS. There is significant correlation revealed between phosphates and nitrates contents as well as for the turbidity, TOC and SiO_2 content, both of which were found to be affected by the pH of these waters. This may signify the role that these contents play in the formation of algae and its growth as their abundance was related to slightly alkaline pH waters[8]. On the other hand, it was reported that the significant correlation between nitrate and phosphate may be indicative of their assimilative origin, i.e. agricultural sources[36].

Evaluating the efficiency of the chlorine/alum water treatment process upon algal removal and residual turbidity

Overall, the efficiency of the pre-chlorination stage is governed by two indicators, namely: the chlorine demand and residual chlorine content. The chlorine demand determines the chlorine dose applied during the pre-chlorination /disinfection process and the residual chlorine signifies that sufficient amount of chlorine has been added to inactivate bacteria and some viruses that may cause diarrheal disease in drinking water[51]. Technically, a minimum of 0.5 mg/L residual chlorine must be maintained to ensure water protection from recontamina-

Figure 2 : Dendogram depicting Hierarchal Clustering strategy and distance between the mean measured monthly Nile water chemical and physical variables and the type of algae identified within these waters using Ward's methods for minimum variance

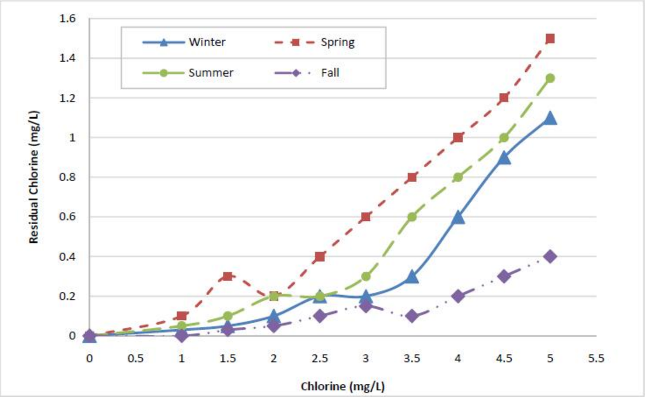

Figure 3 : Seasonal variation in Chlorine demand (mg/L) for the mean seasonal algae count (units /mL) of (winter = 4000, spring= 3000, summer= 3200 and fall= 7000) and the resulting residual chlorine (mg/L) (Dec 2011- Nov 2012)

tion during storage and that residual chlorine levels between 0.2 and 0.5 mg/L at the consumer outlet water given the extremities of the supply network[51]. Figure 3 shows the seasonal variation in chlorine oxidant demand and the corresponding residual chlorine. It was noted that as the algal count increased from 3000 to 7000 units/mL (spring and winter), the chlorine dose breakpoint increased from 2.0 to 3.5 mg/L. As well, in order to achieve the required residual chlorine of 0.2-0.5 mg/L, the optimal chlorine dose applied was 3.7, 2.7, 3.3 and 5.5 mg/L for the winter, spring, summer and fall algal count, respectively.

Generally, chlorine disinfection effectivity depends on the applied dose and contact time[9]. Previous work by El-Dib and Ali (1995) recommended, as a precaution, to monitor the applied dose and not to exceed the chlorine contact time over 30 min for Nile waters. This was based upon their findings that the concentration of THMs formed increased progressively as the contact time extended from 30 min to 240 min. As well, low chlorine dose may readily aid in the formation of chloro-substituted by-products, while higher chlorine doses may lead to the oxidation and cleavage NOM products and THMs.

Generally, the hydrated form of $Al_2(SO_4)_3$ ($Al_2(SO_4)_3.nH_2O$, where n=14-18) is widely used as a coagulant in drinking water treatment[33,5,51,2]. Of the advantages of using alum is the fact that it does not damage algal cells[5] as well as it removes a large portion of natural organic matter (NOM) that has a slower reaction rate with chlorine[21]. Technically, it was reported that a typical alum dose between 5-50 mg alum/L was effective for turbidity reduction in most waters[2]. Figure 4 shows the variation in algal removal % using an alum dose ranging from 5- 30 mg/L in pre-chlorinated waters. It was observed that applying 5 mg alum/L to the pre-chlorinated waters achieved an initial algal removal efficiency of 60% and 80% for the lowest and highest algal count, respectively. However, in order to achieve the 1.0 NTU WHO limit target, a higher alum dose of 30 and 25mg/L was applied for 15 min. and 30 min contact time, respectively. Accordingly, this achieved 86% and 89% reduction in final water turbidity for the respective contact times. In addition, in the current study, these reduction obtained for unbuffered waters may benefit from the fact that alum addition to alkaline raw waters decreased the pH to the acidic range for an efficient coagulation and for better THM removal[11,6,2]. However, although alum is effective in removing turbidity, it is always- applied in excess which may result in high residual Al[51]. Explicitly, it was reported that about 11% of the Al input remains in treated waters and may produce a residual concentration of 0.003 to 1.6 mg/L, which may exceed the acceptable limits.

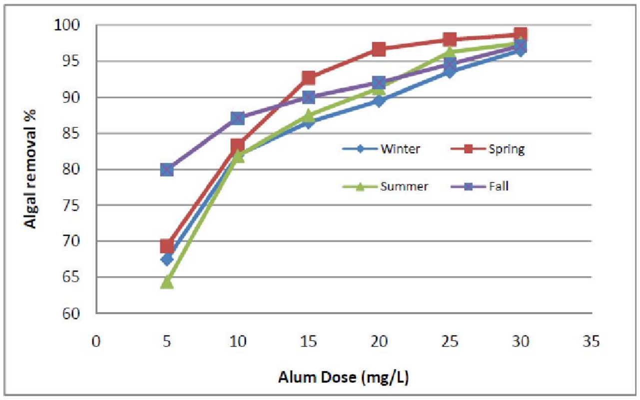

Figure 4 : Mean Algal removal % vs the applied alum dose (mg/L) for the mean seasonal algae count (units / mL) of (winter = 4000, spring= 3000, summer= 3200 and fall= 7000) and using the chlorine dose (mg/L) for (winter = 3.7, spring= 2.7, summer= 3.3 and fall= 5.5) (Dec 2011- Nov 2012)

Enhanced algal control and removal using combined chlorine/permanganate preoxidation

As indicated previously, while the major concern for the use of chlorine and its derivatives in water disinfection is the formation of chlorinated by-products, the application of $KMnO_4$, was reported to remove soluble manganese and iron that are frequently associated with the presence of cyanobacteria in raw water[20]. As well, $KMnO_4$ may serve as an alternative to pre-chlorination or other oxidants for the control of color, taste and odor, and algae and for the further control of biological growth in treatment plants. In addition, previous studies have indicated that combining chlorine with permanganate during the pre-oxidation stage has a synergistic effect upon water disinfection[25].

Previous studies have recommended the use of permanganate dose between 0.5–3 mg/L for enhanced algal removal by alum coagulation[10,25]. Heng et al. (2008) indicated that a 0.5 mg/L permanganate dose in combination with chlorine attained the best reduction efficiencies in turbidity and COD_{Mn} in raw surface waters. In the current study, the effect of adding an optimal constant dose of 0.5 mg/L $KMnO_4$ upon the water chlorine demand was studied and the results are depicted in Figure 5. It is evident from the results that the applied permanganate dose effectively reduced the chlorine demand and the resulting waters did maintain acceptable residual chlorine content required for bacterial growth control in water supply delivery system. This may be explained by the synergistic inactivating effect and strong adsorptive capacity of the permanganate reduced product/intermediate (MnO_2) [41]. As well, the combination of permanganate/ chlorine during the pre-oxidation stage may enhance the inactivation of algal cells and its removal through coagulation, an event that may control the production of THMs[47,11]. Nonetheless, overdosing with permanganate must be avoided since a residual 0.05 mg/L $KMnO_4$ or greater may result in a pink taint in the drinking water. Nonetheless, Fan et al. (2013) indicated that the application of a 1 mg/L dose $KMnO_4$ may lead to a $KMnO_4$ residual of 0.2 mg/L which becomes non detectable after 1-2 hours of treatment.

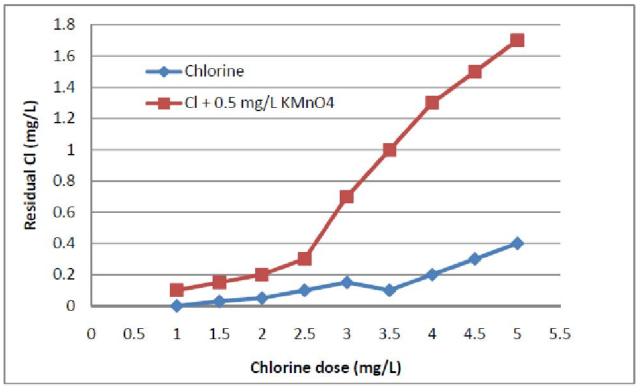

Figure 5 : The effect of using $KMnO_4$ (0.5 mg/L) upon the reduction in Chlorine demand dose (mg/L) and the residual chlorine (mg/L) after the application to raw surface water (initial mean algal count 7000 units /mL – during algal peak period)

The effect of the combined chlorine/permanganate pre-oxidation upon the use of al and fe coagulant salts

Aluminum sulfate, ferric chloride and ferric sulfate are the most common coagulants used in drinking water treatment[29,33,39]. The main purpose for the use of these metal coagulants is to reduce NOM which may interfere with the removal of other contaminants that cause membrane fouling, contribute to piping corrosion and act as a substrate for bacterial growth in the distribution system[33]. However, it is important to note that the action of aluminum and ferric salts depends upon their hydrolyzed form and their soluble complex that posses high positive charge as well as upon an acidic pH range

To attest the effectivity of these metal salts coagulation using the combined permanganate /chlorine pre-oxidation, the residual turbidity and algal removal% of the raw and final treated waters were

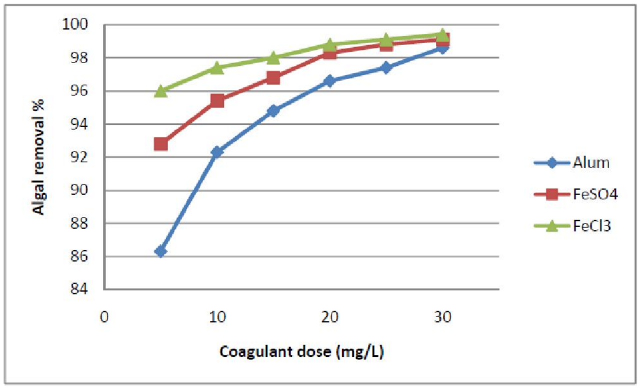

Figure 6 : The effect of varying coagulant (alum, ferric chloride and ferric sulfate) doses upon the Algal removal % in waters pretreated with a combined peroxidant dose of chlorine (2.7 mg/L) / permanganate (0.5 mg/L) during algal peak period

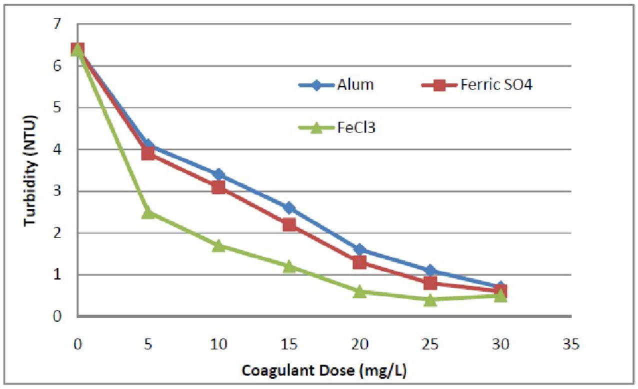

Figure 7 : The effect of varying coagulant (alum, ferric chloride and ferric sulfate) doses upon the final turbidity of water pretreated with a combined peroxidant dose of chlorine (2.7 mg/L) / permanganate (0.5 mg/L) during algal peak period

monitored after applying the coagulant doses (5-30 mg/L) these waters. Figure 6 shows that the application of these metal salts to Cl/KMnO$_4$ pretreated raw waters achieved algal removals of over 90% at a dose as low as 10 mg/L. Figure 7 indicates that the maximum algal removal% and lowest residual turbidity was achieved using alum, ferric chloride and ferric sulfate doses ranging between 25-28 mg/L, 15-20 mg/L and 20-25 mg/L, respectively. Nonetheless, Al salts were reported to have a better capacity for turbidity removal and be more effective at lower doses than ferric salts, while ferric salts are more effective in NOM removal and are not sensitive to temperature changes as alum[33].

TABLE 3 provides a summary of the finished water quality after the application of the combined pre-oxidation treatment for the raw water. Chen et al. (2009) reported that the presence of low calcium carbonate content (240 mg/L) in raw water was an important factor in the performance of the KMnO$_4$/ alum system provided that the pH remained near alkaline. As well, in neutral pH range, it was reported that the surfaces of MnO$_2$ and algae cells developed a negative charge and that calcium ions in water served to bridge and hold these negatively charged surfaces together into algae flocs[11]. As well, it can be seen from the data that ferric chloride and ferric sulfate provided slightly better finished water quality characteristics. However, the use of ferric chloride increased the final Cl as well as the use of alum and ferric sulfate increased the residual sulfates. Basiouny et al. (2008) studied the effect of potassium permanganate pre-oxidation alone upon the coagulation of raw Nile water. They found that an optimum KMnO$_4$ dose of 6 mg/L applied to Nile water resulted in a 35% turbidity removal. However, this required the an alum dose between 40-60 mg/L and a ferric sulfate dose of 85-105 mg/L to achieve a turbidity reduction of 58% and 20%, respectively, with no pH adjustment.

Regarding the residual metal in final treated waters, an account of the health effects and efficacy of using both Al and ferric salts in water treatment was presented elsewhere[43,33]. However, the use of alum as coagulant may lead to a high residual con-

TABLE 3 : The effect of using different coagulants (Alum, Ferric Sulfate and Ferric Chloride) optimal dose and the combined Cl$_2$/ KMnO$_4$ (2.7 mg/L + 0.5 mg/L) upon finished water quality parameters (pH, turbidity, chloride, sulfates, TOC and residual Al, Fe and Mn).

Water Quality parameters	Pre-oxidation with 5.5 mg Cl$_2$/L + 30 mg/L Alum	Combined Pre-oxidation = Cl$_2$ (2.7 mg/L) and KMnO$_4$ (0.5 mg/L)		
Coagulant		28 mg/L Alum	25 mg/L Ferric Sulfate	20 mg/L Ferric Chloride
pH	7.3	7.3	7.25	7.2
Turbidity (NTU)	0.33	0.3	0.3	0.25
Residual Al (mg/L)	0.23	0.17	0.05	0.05
Residual Mn (mg/L)	0.02	0.10	0.11	0.10
Residual Fe (mg/L)	0.07	0.00	0.14	0.13
Chloride (mg/L)	35	35	35	43
Sulfates (mg/L)	52	49.5	51.7	37
TOC (mg/L)	7.0	6.8	6.6	6.5
Algal Count (unit/mL)	200	100	80	80

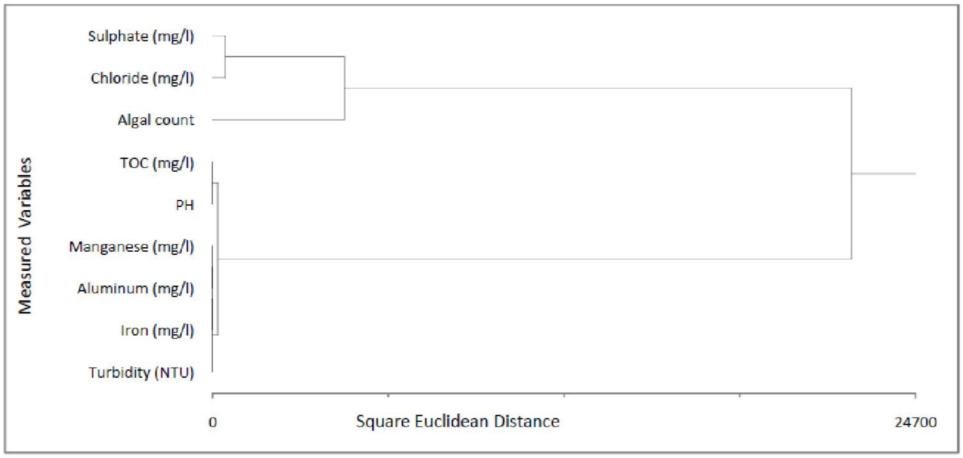

Figure 8 : Dendogram depicting Hierarchal Clustering strategy and distance between the average chemical and physical parameters of the final treated waters using Ward's methods for minimum variance

tent as well as it may form micro-flocs in the distribution networks that provide nutrients for microbial growth[29,33, 42]. On the other hand, it was reported that utilizing $KMnO_4$/alum in combination did reduce the amount of residual alum in the finished waters[46]. Ferric salts are also favored because of being more robust operationally and insensitive to the coagulation pH[49]. However, ferric salts were reported to induce high alkalinity consumption plus the residual sulfates or chloride in finished water may increase its corrosivity[33] As well, high residual iron content in drinking water may be responsible for the disinfectant neutralization, the coloration of water and the metallic taste in water[42]. ferric chloride, on the other hand, is a corrosive compound that could rapidly attack metals and in a treatment plant, thus, using ferric chloride as coagulant may necessitate major modifications in dosage equipments and system (storage tanks, pumps, piping, valves and accessories)[35]. In addition, the use of ferric sulfate in drinking water treatment may incur higher operational costs than using alum; however it offers a higher satisfaction to the consumer[35].

Hierarchal cluster analysis was performed on the final treated water main parameters and the results are depicted in the dendogram Figure 8. From this figure, it can be seen that the reduction in algal count was dependent upon the sulfates and chloride content of the final treated waters. In addition, the reduction in TOC is strongly dependent upon the pH while the reduction in turbidity is more directly related to the hydrolyzed metal ions.

CONCLUSION

In the current study, an investigation of relationship between the Nile surface waters quality measured parameters and the occurrence of algae was investigated using multivariate statistical analysis. The data revealed that Chlorophyta and Diatoms contents were the major contributors towards the measured Total algal count and that the Euglenophyta content was strongly dependent upon the total alkalinity ($CaCO_3$) and the TDS of these waters. Cyanophyta also showed a strong dependency upon all chemical parameters measured as well as on Euglenophyta in these waters. As well, the effectivity of the current treatment procedure using pre-chlorination/alum upon the clarification of the final treated water was investigated relative to the application of a combined $KMnO_4$ /chlorine / coagulant stage. The results indicated that this application of $KMnO_4$ was effective in reducing the required chlorine demand while maintaining an acceptable residual content. As well, the use of the combined chlorine/permanganate pretreatment using alum, ferric chloride and ferric sulfate improved residual turbidity of the treated waters and enhanced algal removal%. Moreover, the finished water quality after the application of the combined pre-oxidation treatment for the raw water indicated favored the application of ferric chloride and ferric sulfate. The study also revealed that the sulfates and chlorides ions contents were more responsible for the reduction in total algal count while the hydrolyzed metal ion was effective in the reduction of the final water turbidity.

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