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Application of nanofiltration membrane for the River Nile water treatment in Egypt: Case study

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Abstract. In this manuscript, 35 m^3/d NF unit was designed and applied for surface water treatment of the River Nile water. Intake of Embaba drinking water treatment plant was selected to install that unit at since; it has the lowest water quality index value through the examined 6 sites in greater Cairo area. The optimized operating conditions were feed and permeate flow, 40 and 7 m^3/d, feed pressure 2.68 bar and flux rate 37.7 l/m^2h. The permeate water was drinkable according to Egyptian Ministerial decree 458/2007 for the tested parameters (physic-chemical, heavy metals, organic, algal, bacteriological and parasitological). Single and double sand filters were used as pretreatment for NF membranes but continuous clogging for sand filters moved us to use UF membrane as pretreatment for NF membrane.

Keywords: River Nile; NF membrane; pretreatment; water; treatment

1. Introduction

In Egypt, among drinking water sources, the River Nile is the main source (Jamil and Ali 2009). The River Nile is subjected to pollution in greater Cairo Area due to heavy industrial, commercial activities that may discharge their wastes to the river especially in the south of Cairo (Megahed *et al*. 2015). Most of water works in Egypt use conventional treatment technique (pre-chlorination, coagulation, flocculation, sedimentation, filtration and post chlorination) as shown in Fig. 1 with slight difference in their engineering parameters i.e., retention time of flocculation and sedimentation (Ali and Jamil 2008).

Needs for newer technology, among which membrane technology, to overcome the pollution embedded to the river became a most (Sanches 2013). Obviously, membrane filtration has unique property which is selecting specific membrane for removal specific components that is needed from the actual raw water (Shon *et al*. 2013). There is a great interest for NF technologies due to their potential in solving water shortage as well as water quality problems (Kheriji *et al*. 2016) although NF is an energy intensive process (Albert *et al*. 2016). Application of NF in water treatment is increased especially in suburb.

NF membranes are specifically used in separation of di- and tri-valent inorganic salts as well as small organic particles due to their high divalent and trivalenrt ions rejection compared to that of monovalent ions (Mohamed *et al*. 2015).

NF is a considerably complex process due to its dependence upon the interfacial and microhydrodynamic instabilities occur at the surface of the membrane and within the nanopores of the membrane. The main reason for NF membranes rejection is the combination of Donnan, dielectric, steric and transport effects (Oately-Radcliffe 2014).

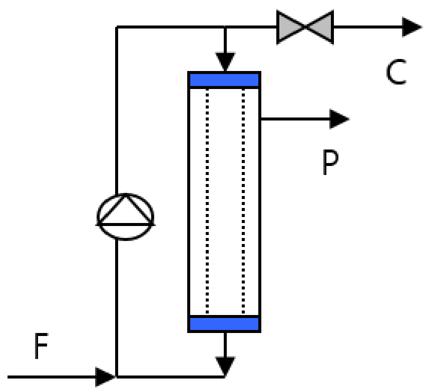

Fig. 1 Schematic diagram of semi dead end technique

The main purpose for using NF in surface water treatment is water softening as well as removal of Persistent Organic Pollutants (POPs) such as disinfection by-products (DBPs) and pesticide (Fang *et al*. 2013). Meanwhile, the removal of natural organic matter (NOM) and DBPs precursors produced after using chlorine in water treatment (Fang *et al*. 2014 and Martinez-Huitle 2008). Sentana *et al*. (2011) has been studied pressure, conductivity and pH influence on flow reduction and DBPs formation using NF45 and NF1000. However, drinking water treatment plants are not specifically designed to remove dissolved organic carbon (DOC) and there are few NF studies on DOC removal from surface water (Zwiener 2014, Radjenovic *et al*. 2008 and Garcia *et al*. 2013). Also, in Vergili work the performance of a flat sheet NF membrane was investigated using crossflow mode for filtration of

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spiked carbamazepine, diclofenac and ibuprofen spiked in water surface water.

The main aim of the manuscript is design and installation of pilot plant for surface water treatment in selected site according to water quality index and examining the water quality of the permeate against Egyptian standard.

2. Materials and methods

2.1 Survey of the River Nile water in Cairo

Six water samples were collected through greater Cairo area which represents the intake of six drinking water treatment plants (DWTPs) namely El-Tebeen, El-Maadi, El-Roda, Road El-Farag, Embaba and Shubra El Khaiyma.

2.2 Water analysis

Organic, inorganic, algal, microbiological and parasitological examinations were carried out according to APHA Standard Methods for the Examination of Water and Wastewater 22nd Edition, 2012. Bacterial counts were determined by pour plate technique and determination of MPN index for coliforms by multiple tube fermentation technique.

Organic micro pollutants were analyzed by HP6890 gas chromatography and Varian GC/MS 4000, heavy metals were analyzed by Agilent ICP 5100 and physicochemical parameters were analyzed by Cary 100 Agilent spectrophotometer, Concentration of phytoplankton present in water sample was performed by using the Sedwick-Rafter (S-R) Funnels.

2.3 Water quality index

Water quality index (WQI) provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience (Jamil *et al*. 2014).

In this study, Canadian Council of Ministers of the Environment Water Quality Index method (CCME WQI) was used which is based on developed formula of British Columbia Ministry of Environment according to the following equations.

1. Scope (the number of variables not meeting water quality objectives)

$$F1 = \frac{\text{Number of faild variables}}{\text{Total number of variables}} \text{ x } 100 \quad (1)$$

2. Frequency (the number of times these objectives are not met)

$$F2 = \frac{\text{Number of faild tests}}{\text{Total number of tests}} \text{ x } 100 \quad (2)$$

3. Amplitude (the amount by which the objectives are not met)

$$F2 = \frac{\text{Failed test value i}}{\text{Objective i}} \text{ x } 100 \quad (3)$$

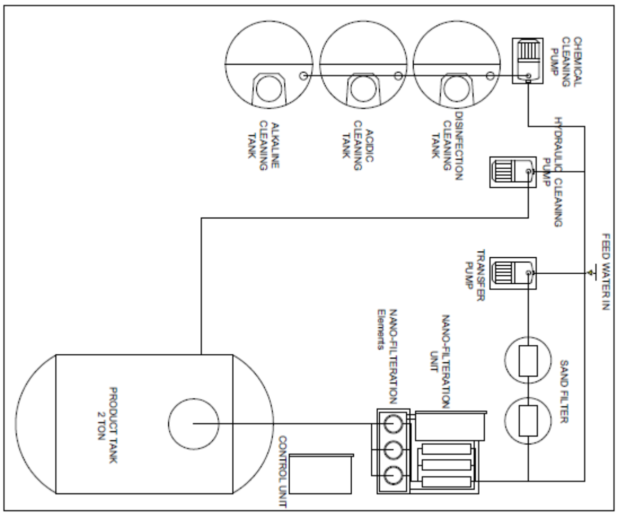

Fig. 2 Schematic diagram of the installed membrane unit

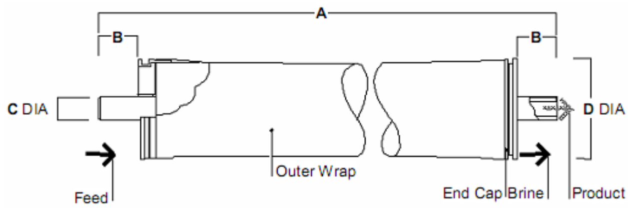

Fig. 3 Schematic diagram of membrane used

2.4 Design and construction of pilot plant unit for membrane applications

The membrane unit, which works under semi-dead end conditions (Fig. 2), is composed of feed pump, double sand filtration, nanofiltration modules, permeate tanks, hydraulic cleaning pump, chemical cleaning pump and tanks as shown in Fig. 3.

2.5 NF membrane specifications

The selected NF 270-4040 membrane with 1 meter height, 4 inches diameter is, 1 inch sheet thickness and diameter of permeate central tube is 0.75 inches (Fig 4). Membrane selection was according to characterization of water quality in the intake of Embaba DWTP and supplementary 2-6.

2.6 Rejection percent

Rejection can be calculated through equation 4

$$F2 = \frac{\text{concentration of pollutants after treatment}}{\text{concentration of pollutants before treatment}} \text{ x } 100 \quad (4)$$

3. Results and discussion

3.1 Selection of site to build NF unit

In this study, the water qualities at different locations in Greater Cairo were assessed from chemical (organic and inorganic), microbiological, parasitological and algal points

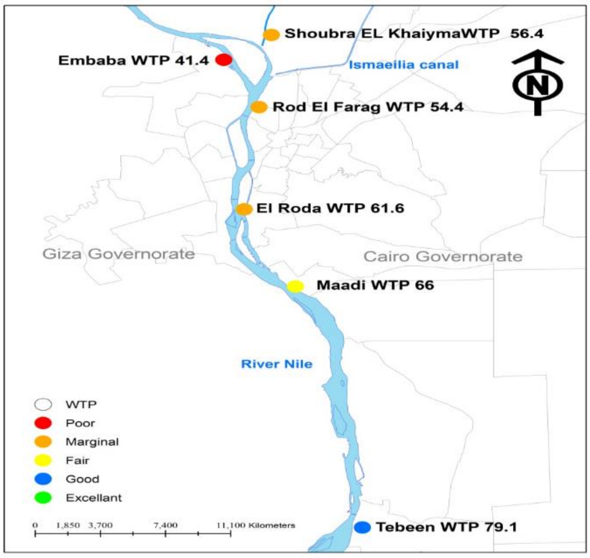

Fig. 4 Average WQI for the selected sites in Greater Cairo area

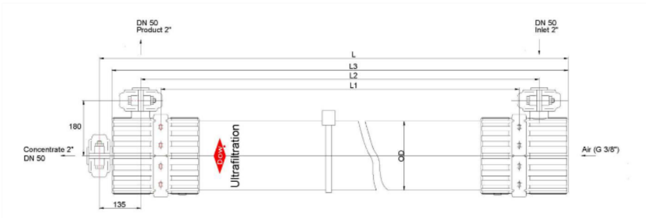

Fig. 5 Schematic diagram of UF membrane used

of view for a year (sample per month). The results were introduced to WQI equations to be simplified in one figure to judge the water quality and the result were inserted to the map shown in Fig. 5. It is clear that water quality of the River Nile in greater Cairo area is getting lower from south to north. Since, good water quality was recorded in the intake of El-Tebeen (79.1%) while water quality decreased and the intake of Embaba DWTP (41.1%) recorded the lowest water quality among the selected sites. So, The River Nile water at the intake of Embaba DWTP was selected to be treated by NF membrane unit.

3.2 Rejection test of the membrane

All membranes were examined by determination of the rejection percent for 2 g/L magnesium sulfate at room temperature and the related permeate flow rate for each membrane according to manufacturer's instruction. The results in Supplementary (1) showed that the all membranes have more than 97% rejection which reveals that there is no industrial problem according to the membrane specification.

3.3 Pre-treatment steps

3.3.1 Sand filtration

In this step several pre-treatment techniques were used in order to optimize the pre-treatment steps through which the lowest pollutant can be introduced to membrane unit in order to keep the membrane life as long as possible. Single sand filtration and double sand filtration were selected as pre-treatment steps in this study.

Slow sand filtration is a simple option for water treatment (Singh *et al*. 2016). Turbidity and suspended solids can be removed through sand filtration process because they can be attached to the sand grains (Nghiem and Fujiola 2016). Direct sand filtration is preferable than 1) coagulation - 2) sedimentation - 3) sand filtration processes since 1) coagulation - 2) sedimentation - 3) sand filtration is considered as double capital cost than direct sand filtration (Jamil *et al*. 2013).

These experiments were conducted for 6 weeks for each step (single sand filtration is one step and double sand filtration is another step) and a half weekly sample were withdrawn and analyzed. The results in Supplementary (7) represent that the mean and standard deviations for the collected samples of each step.

In single sand filtration, the treatment steps illustrated from physicochemical point of view that single barrier sand filter decreased turbidity by 50% but there is no removal for organic parameters such as COD, BOD, TOC and organic pesticides. On the other hand, algal examination showed removal for total algal counts by 18.2% which can be detailed by 15% removal of diatoms, 21.1% removal for green algae and 25.6% for removal of blue green algae. Meanwhile, several references (Chen *et al*. 2004) reported the possible problems created by algae. Algal growth in water results sand filter and screen clogging at the water treatment plants and release of toxic metabolites in water (Riungu *et al*. 2012, Lee *et al*. 2009 and Nghiem *et al*. 2004).

Also, microbiological examination showed that the sand filter affects negatively on the total bacterial count. However, it can remove Total Coliform, Faecal Coliform and Faecal Streptococcus efficiently. Since, total bacterial counts at 22°C and 37°C increased after single sand filter indicating that microorganisms accumulate on sand surface causing bacterial film that can be released to the water introduced to membrane unit (Lazar *et al*. 2014 and Rajesha *et al*. 2016). Also, Parasites present in the effluent of sand filter are introduced to NF membrane.

In the way to enhance the pre-treatment by sand filtration, two sand filters were set prior to membrane filtration unit. The performance of the treatment unit using two sand filters presented in Supplementary (7). It is clear that the presence of lower amount of microorganisms in the effluent of the second sand filter. Such microorganism can be introduced to NF membrane causing fouling. While lower algal count, bacteriological parameters as well as parasitological parameters were observed. Hence, algal parameters decreased by 64.1%, 36.3%, 66.0% for diatoms, green algae and blue green algae respectively making removal by 61.5% for total algal counts. Also, total bacterial counts were decreased by 39.8% and 40.5% at 37°C and 22°C. Also, parasitological parameters were decreased. But, microorganism still present and the availability of biofouling also present.

Also, Supplementary (7) showed the performance of the NF membrane treatment unit using single sand filter and double sand filter. The quality of permeate water is showed no significant.

Since, continuous clogging of sand filter hinders the

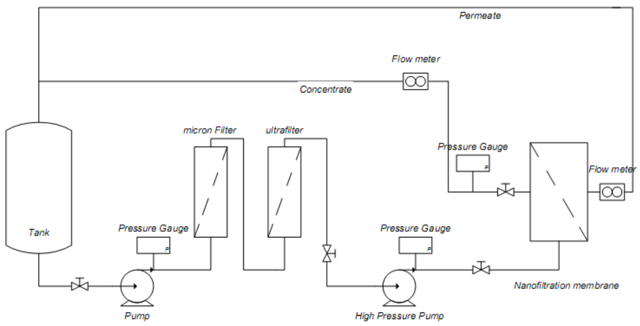

Fig. 6 Final schematic diagram for the unit

continuous water production from the membrane giving the chance for introducing UF as pre-treatment step for NF (Jamil *et al*. 2013).

3.3.2 UF as pre-treatment

77 m^3/d UF membrane unit was installed and used as pre-treatment for NF unit using UF membrane DOW shown in Fig. 6.

Parameters monitored after UF membrane addition were recorded in Table 1 since feed pressure was constant before and after UF (2.68 bar) and recovery percentages were increased from 15.5% to 17.5% per module by addition of UF membrane. Also, flux rate was increased by 0.6 l/h by addition of UF membrane.

There is a drastic decrease in energy consumption for NF membrane by addition of UF by 0.42 KW/m^3.

Also, permeate quality for some key parameters that may indicate the quality of UF are mentioned in Table 2. The results showed that UF membrane has no effect in removal of salts as expected since there is no significant change in TDS. On the other hand, parameters which have significant effect on fouling such as turbidity, total suspended solids and TOC showed high removal (97%, 91% and 56%) respectively. Also, parameters have direct effect on biofouling such as total bacterial counts and total algal counts, showed removal more than 98%. These results indicated lower organic loading as well as biological and microbiological loadings to NF which means higher membrane life time, lower fouling, lower cleaning time and higher production rate as well as higher recovery. The results are in accordance with the technical parameters for NF modules submitted in Table 1.

Fouling is an important factor related to the topic of the study in order to discuss the problems of clogging especially that the receiving environment is mixed with polluted water of industrial origin. Accordingly, fouling part will be published in the next study.

3.4 Permeate production rate

It is important to change permeate production rate to reach the highest recovery percent as well as the highest production capacity. Also, it is important to monitor some parameters feed pressure, permeate flow, flux rate value and energy consumption. During this experiment production rate was varied between 3-8 m^3/d. Also, some parameters were used to judge the quality of the permeate produced such as pH, turbidity, total dissolved solids, ammonia,

Table 1 Monitored parameters by variation of membrane designs

	Unit	Without UF	UF/NF
Feed Flow	m^3/d	39.4	40
Feed Pressure	bar	2.68	2.68
Permeate Flow	m^3/d	7.0	7.0
Recovery	%	15.5	17.5
flux rate	l/h	37.7	38.3
Energy	KW/m^3	0.6	0.18

Table 2 Permeate quality for some key parameters of UF

Parameter	Feed	Permeate of UF	% removal
pH	8.2	7.9	-
Turbidity	19.3	0.85	97.65
TDS	277	275	1.00
TSS	23	2	91.3
TOC	7.1	3.14	55.7
Total algal counts	6600	345	94.8
TBC at 37°C	2500	23	99.1
TBC at 22°C	910	17	98.1

potassium, sodium, magnesium, calcium, bicarbonate, chloride, sulfate and silica. Also, these parameters were determined in the concentrate in order to detect the availability of dumping that water to the River Nile. Since, if higher concentrations of salts detected then it is impossible to dump the concentrate to the River Nile because in that case it will increase salt and pollutants load to NF membrane and fast and higher fouling is expected.

In each experiment, the flux rate value was noticed till stability then the system left for 24 hours to ensure stability of the unit. Afterword, sampling was carried out and next flow rate or membrane design is performed. At optimum flow rate (7 m^3/d), after establishment, the system was continuously working for a week and 3 samples were collected giving the average in Table 3. Since feed pressure was increased from 1.18 bar to 2.68 bar and recovery percentages were increased from 10% to 15.5% by increasing the production rate from 3 m^3/d to 7 m^3/d. By increasing the production rate to 8 m^3/d, the system alarm was turned on because the maximum recovery percent (16%) was reached.

There is no significant difference between energy consumption showed by increasing production rate since energy consumption was increased by 90 Watt by increasing the permeate flow from 3 m^3/d to 8 m^3/d. Also, the pressure drop was more than one in 10 min indicating that the membrane needs to be hydraulically cleaned.

Also, permeate quality as well as concentrate composition are mentioned in Table 4. Low decrease in salt concentrations was noticed in the permeate by increasing the permeate flow rate. No significant changes in pH, turbidity, ammonia, potassium, sodium, chloride, sulfate and silica. On the other hand, there is significant decrease in the concentration of bicarbonate, calcium and magnesium resulting decrease in the total dissolved solids from

Table 3 Monitored parameters by variation of permeate production rate

	Unit	$3m^3/d$	$4m^3/d$	$7m^3/d$	$8m^3/d$
Feed Flow	m^3/d	30	33.7	39.4	45.7
Feed Pressure	Bar	1.18	1.56	2.68	3.12
Permeate Flow	m^3/d	3	4	7	8
Recovery	%	10	13	17.5	17.6
flux rate	l/h	16.41	21.88	37.7	43.8
Energy	KW/m^3	0.51	0.53	0.6	0.71

Table 4 Permeate and concentrate quality at various permeate production

Parameter	Feed	Permeate				Concentrate			
		$3\ m^3/d$	$4\ m^3/d$	$7\ m^3/d$	$8\ m^3/d$	$3\ m^3/d$	$4\ m^3/d$	$7\ m^3/d$	$8\ m^3/d$
pH	7.4	7.2	7.15	7.06	7.06	7.4	7.43	7.44	7.44
Turbidity	20.5	0.1	0.08	0.03	0.03	22.4	22.5	22.7	22.7
TDS	270	163	150	126	119	284	290	303	304
Ammonia	0.2	0.12	0.1	0.09	0.09	0.11	0.22	0.23	0.23
Potassium	4	3.24	3.1	2.8	2.7	4.08	4.1	4.2	4.3
Sodium	19.17	15.5	15	13.7	13.3	19.5	19.8	20.3	20.4
Magnesium	15.1	6.3	5.5	4.1	3.75	16.1	6.5	17.4	17.5
Calcium	32	19.6	18	15	14	33.4	34	35.7	35.9
Bicarbonate	140	82	75	61	56.5	146	150	157	158
Chloride	35	31.6	30	26.7	25.6	37.3	38	39.6	39.9
Sulfate	20	0.6	0.5	0.5	0.32	22.2	22.9	22.9	24.2
Silica	3.5	2.4	2.6	2.2	2	3.6	3.6	3.6	3.8

163 mg/L in case of 3 m^3/d to 126 mg/L in case of 7 m^3/d. The resulting TDS (126 mg/L) is acceptable for drinking.

In the same time, the characterization of concentrate showed low concentrations of the analyzed parameters indicating the availability of dumping it to the River Nile water. Accordingly, 7 m^3/d flow rate is chosen to be the optimum flow rate.

In this stage, the NF membrane unit is optimized and continuous processing reached using UF unit as pre-treatment and the schematic diagram of the final units is shown in Figure 6.

3.5 Determination of the retention for the water content of the permeate

Nanofiltration (NF) is one of promising technologies for the treatment of organic and inorganic pollutants in surface water (Singh *et al*. 2016). Since the surface water has low osmotic pressure, an ultra-low-pressure operation of nanofiltration is possible to apply for drinking water treatment. The rejection characteristics by capillary nanofiltration membranes are dependent on the molecular size as well as molecular charge of target solutes, because the membranes normally have charged properties, such as negative, positive or even neutral, in different pH condition (Chen *et al*. 2004). Moreover, the changing of capillary nanofiltration performances caused by membrane fouling due to long-term operation is an important key for such application. In this study, the performance of nanofiltration was examined.

Separation by NF membrane occurs primarily due to size exclusion and charge effect on electrostatic interactions (Mänttäri *et al*. 2006) namely, the rejection of uncharged molecules is dominated by size exclusion, while that of ionic species is influenced by size exclusion and electrostatic interaction. Electrostatic characteristics of NF membranes have been known as playing an important role in rejection anions, i.e., negative zeta potential on the membrane surface varies with different pH and concentration of an electrolyte solution (Lehi *et al*. 2017).

As shown in Table 5 for treatment of surface water using NF unit, it can conclude that NF showed good properties in removal of turbidity, color, sulfate, aluminum, iron, manganese, ammonia, nitrate, nitrite TOC, COD, BOD, organophosphorus, heavy metals, algal parameters, parasitological parameters and total bacterial count at 22°C and total bacterial count at 37°C, while the removal of phosphate, total hardness, calcium hardness, magnesium hardness, calcium and magnesium was moderate and the removal of alkalinity, potassium, sodium, bicarbonate, fluoride and chloride was poor.

Turbidity was almost totally removed. Also, removal of some cations (iron, manganese, calcium, magnesium and sodium) showed that the removal percent decreased with decreasing valence of cations. This may be attributed to decreasing the ionic radii accordingly, crystallite size of ions by decreasing its valence due to their presence in lower groups in periodic table leading to their easier passage through membrane holes causing lower removal. Also, trend for anions in Table 5 showed the same trend since, tri valence phosphate showed removal of 95% while, di valence nitrite and mono valence nitrate showed rejection of 80 and 71% removal respectively in permeate.

Organic analysis (Table 5) for permeate water showed very high removal of organic parameters (TOC, COD and BOD higher than 92.5%) and complete removal for organophosphorus pesticides which is in accordance with Chen *et al*. 2004 this may be attributed to one of the following mechanisms that can play a role in the mass transport of solutes through a membrane, which include solution-diffusion, convection (sieving), charge repulsion and dielectric exclusion (Nghiem *et al*. 2004).

Comparison between % removal of Ca^{2+} and TDS evaluated in this work and those obtained in the literature show that the performance of NF 270 nanofiltration to retentive Ca^{2+} is similar to NF200B (74%) and better than NanoMax50 (Ghizellaoui *et al*. 1998) (50%) and NF200B-400 (Costa and de Pinho 2006) (64%). The ability of this nanofiltration to retentive Mg^{2+} is 73% is lower than NF200B (Costa and de Pinho 2006) (greater than 86%). The results show that this nanofiltration can retain 73% of total hardness compared to those reported by Orecki *et al*. 2004, 85.2% and Galanakis *et al*. 2012, 70-76% taking in consideration that the previous works were working with diluted sea water and in other cases for wastewater (Ravazi *et al*. 2006) and industrial wastewater (Maddah and Cholge 2016).

The permeate of produced from the designed and

Table 5 rejection percent and water quality for permeate using sand filtration in pre-treatment prior to NF membrane

Parameter	`	Feed	Permeate	% Removal	Permissible limits
Physico-chemical analysis:					
Color	Pt/Co	15	0	100.0	<5
Turbidity	NTU	22.8	0.19	99.2	1
Temperature	°C	32	30	6.3	
pH	-	7.4	7.1	-	6.5-8.5
Electric Conductivity	µS/cm	518	170	67.2	
Total Dissolved Solids	mg/L	285	100	64.9	1000
Total Alkalinity as ($CaCO_3$)	mg/L	98	32	67.3	
Carbonate Alkalinity	mg/L	0	0	0	
Bicarbonate Alkalinity	mg/L	98	32	67.3	
Chlorides (Cl)	mg/L	46	32	30.4	250
Sulfates (SO_4)	mg/L	24.5	6	75.4	250
Phosphates (PO_4)	mg/L	0.2	0.01	95.0	
Total Hardness as ($CaCO_3$)	mg/L	152	46	69.7	500
Calcium Hardness	mg/L	90	28	68.9	350
Magnesium Hardness	mg/L	62	18	71.0	150
Calcium (Ca)	mg/L	36	11.2	68.9	
Magnesium (Mg)	mg/L	15.1	4.4	70.9	
Ammonia as (NH_3)	mg/L	0.2	0.04	80.0	
Nitrites as (NO_2)	mg/L	0.02	0.004	80.0	0.20
Nitrates as (NO_3)	mg/L	0.22	0.04	81.8	45
Silica (SiO_2)	mg/L	3.5	0.05	98.6	
Florides (F)	mg/L	0.21	0.1	52.4	
Cyanide (CN)	mg/L	N.D	N.D	N.D	Free
Sodium (Na)	mg/L	37	25	32.4	
Potasium (K)	mg/L	4	2.1	47.5	
Heavy Metal:					
Iron (Fe)	mg/L	0.7	0.02	97.1	0.30
Manganese (Mn)	mg/L	0.06	0.01	83.3	0.40
Alumenium (Al)	mg/L	0.56	0.01	98.2	0.30
Copper (Cu)	mg/L	0.018	< 0.01	100.0	2.0
Lead (Pb)	mg/L	0.007	< 0.01	100.0	0.01
Nickel (Ni)	mg/L	0.004	< 0.001	100.0	
Chromium (Cr)	mg/L	0.002	< 0.01	100.0	0.05
Zinc (Zn)	mg/L	0.019	< 0.01	100.0	
Organic Analysis:					
Chemical Oxygen Demand	mgO_2/L	36	2.7	92.5	
Biological Oxygen Demand	mgO_2/L	17	1.3	92.4	
Total Organic Carbon	mgC/L	9.1	0.48	94.7	
Organophosphorus pesticides	µg/L	60.1	N.D	100.0	20
Microbiological Examination:					
Total bacterial at 37 °C	Cell/ml	2700	8	99.7	50 cell/ml for 24 hrs
Total Plate Count at 22 °C	Cell/ml	2900	10	99.7	50 cell/ml for 48 hrs
Total Coliform	Cell/ml	7000	N.D	100.0	2 cell/100ml
Faecal Coliform	Cell/ml	5000	N.D	100.0	
Faecal Streptococcus	Cell/ml	5000	N.D	100.0	
Algal Examination:					
Diatoms	Org./ml	10900	6	99.9	Must be absent
Green Algae	Org./ml	1269	5	99.6	
Blue Green Algae	Org./ml	436	0	100.0	
Total Algae Count	Org./ml	12605	11	99.9	
Microcystin	Org./ml	0-0	0		
Parasitological Examination: Gastrointestinal helminth					
Nematodes	Ova/10L	3	N.D	100	N.D
Parasitic protozoa	Cyst⁄Oocyst⁄Spore per 10 L.	N.D.	N.D	100	N.D
Potentially pathogenic free-living amoebae					
At 22ºC	+ve/-ve	+ve	-ve	100	-ve
At 37º	+ve/-ve	+ve	-ve	100	-ve

constructed NF unit is drinkable and does not need any post treatment since, all parameters meet the Egyptian standards represented by Ministerial Decree 458/2007.

4. Conclusions

Six sites in the River Nile water were examined by full characterization and introduction of the results to Colombian water quality index to be treated by NF membrane. Among the examined sites, intake of Embaba drinking water treatment has the lowest value (41.4%). Single and double sand filtrations as well as UF were used as pre-treatment for NF unit. Sand filters were unacceptable as pretreatment step due to their continuous clogging. The quality of the permeate water was compared against Egyptian ministerial decree 458/2007 from the chemical, microbiological, algal and parasitological points. The results showed that permeate water is drinkable and meets all the requirements of the ministerial decree.

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Appendix: Supplementary 1-7

Supplementary 1 Rejection test of the membrane

Module Number	$MgSO_4$ rejection %	Permeate Flow Rate (m^3/d)
Module No. 1	98.8	9.8
Module No. 2	99.1	9.7
Module No. 3	97.9	10.0
Module No. 4	98.6	9.9

Supplementary 2 Average values* for physico-chemical characteristics of studied sites

Sampling sites / Parameters	Unit	Intake of El-Tebeen DWTP	Intake of El-Maadi DWTP	Intake of El-Roda DWTP	Intake of Road El-Farag DWTP	Intake of Embaba DWTP	Intake of Shubra DWTP
pH	-	8.27	8.17	8.20	8.03	8.03	8.1
Turbidity	NTU	8.93	8.06	10.15	9.13	11.20	8.5
Electrical Conductivity	µmho/cm	393	412	400	405	400	412
Total Dissolved Solids	mg/L	197	202	195	223	192	215
Total Hardness	mg/L	120	123	121	116	111	110
Calcium Hardness	mg/L	76	79	76	76	77	79
Magnesium Hardness	mg/L	44	44	45	40	37	31
Alkalinity	mg/L	154	149	147	143	139	140
Sulfate (SO_4^{--})	mg/L	15.4	18.4	17.1	23.0	16.2	18
Chloride (Cl^-)	mg/L	18.7	19.0	18.7	20.0	20.0	19
Nitrate (NO_3-N)	mg/L	0.04	0.03	0.05	0.10	0.08	0.01
Nitrite (NO_2-N)	mg/L	0.01	N.D	N.D	N.D	0.01	N.D
Phosphate (PO_4-P)	mg/L	0.02	0.02	0.03	0.01	0.03	0.01
Carbonate (as $CaCO_3$)	mg/L	0	0	0	0	0	0
Biarbonate (as $CaCO_3$)	mg/L	154	149	147	143	139	140
Hydroxide (as $CaCO_3$)	mg/L	0	0	0	0	0	0
Calcium	mg/L	30.5	31.5	30.4	30.7	30.9	30.4
Magnesium	mg/L	10.7	10.6	11.0	11.0	9.4	8.6
Sodium	mg/L	18.5	18.5	17.8	19.3	17.7	19.2
Potassium	mg/L	5.4	5.4	5.3	5.4	5.5	5.3

*The average values for eight samples

Supplementary 3 Average values* for heavy metals contents of studied sites

Sampling sites / Parameters	Unit	Intake of El-Tebeen DWTP	Intake of El-Maadi DWTP	Intake of El-Roda DWTP	Intake of Road El-Farag DWTP	Intake of Embaba DWTP	Intake of Shubra DWTP
Iron	mg/L	0.75	0.53	0.81	0.47	0.96	0.78
Manganese	mg/L	0.11	0.14	0.10	0.077	0.187	0.08
Copper	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Lead	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Zinc	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Chromium	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Cadmium	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

*The average values for eight samples

Supplementary 4 Average values* for organic contents of studied sites

Sampling sites / Parameters	Unit	Intake of El-Tebeen DWTP	Intake of El-Maadi DWTP	Intake of El-Roda DWTP	Intake of Road El-Farag DWTP	Intake of Embaba DWTP	Intake of Shubra DWTP
Phenol	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
COD	mgO_2/L	36.7	37.3	34.7	35.7	24.3	35.7
BOD	mgO_2/L	12.4	15.4	15.5	8.6	11.9	10.2
ΣPAHs	µg/L	1.68	1.35	3.03	2.70	5.11	0.68
ΣChlorinated pesticides	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
ΣOrganophosphorus pesticides	µg/L	159.94	60.19	69.92	195.02	25.35	60.79
Volatile Organic carbon	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
Total Hydrocarbons (as toluene)	µg/L	25.89	22.83	35.22	27.10	37.86	36.45

*The average values for eight samples

Supplementary 5 Average values* for algal contents of studied sites

Sampling sites / Parameters	Unit	Intake of El-Tebeen DWTP	Intake of El-Maadi DWTP	Intake of El-Roda DWTP	Intake of Road El-Farag DWTP	Intake of Embaba DWTP	Intake of Shubra DWTP
Phenol	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
COD	mgO_2/L	36.7	37.3	34.7	35.7	24.3	35.7
BOD	mgO_2/L	12.4	15.4	15.5	8.6	11.9	10.2
ΣPAHs	µg/L	1.68	1.35	3.03	2.70	5.11	0.68
ΣChlorinated pesticides	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
ΣOrganophosphorus pesticides	µg/L	159.94	60.19	69.92	195.02	25.35	60.79
Volatile Organic carbon	µg/L	N.D	N.D	N.D	N.D	N.D	N.D
Total Hydrocarbons (as toluene)	µg/L	25.89	22.83	35.22	27.10	37.86	36.45

*The average values for eight samples

Supplementary 6 Average values* for bacteriological examination of studied sites

Sampling sites / Parameters	Unit	Intake of El-Tebeen DWTP	Intake of El-Maadi DWTP	Intake of El-Roda DWTP	Intake of Road El-Farag DWTP	Intake of Embaba DWTP	Intake of Shubra DWTP
Total bacteria count at 37°C	CFU/ml	1.4×10^4	4.4×10^3	1.3×10^3	2.4×10^4	5.8×10^4	1.4×10^3
Total bacteria count at 22°C	CFU/ml	8.1×10^3	1.1×10^3	5.1×10^3	5.1×10^3	1.0×10^4	9.3×10^2
Total Coliforms	(MPN-index/100ml)	5.3×10^3	5.6×10^2	1.9×10^3	4.3×10^3	6.7×10^3	2.7×10^3
Fecal Coliforms	(MPN-index/100ml)	76. 7	3.2×10^2	3.9×10^2	4.3×10^2	5.1×10^2	1.6×10^3
Fecal Strepyococci	(MPN-index/100ml)	80	46.7	46.7	86. 7	140	40

*The average values for eight samples

Supplementary (7) characteristics of water samples collected from single and double sand filters

Parameter	Unit	Feed		Single sand filter		Double sand filter		Permeate	
		Range	Mean±stdev	Range	Mean±stdev	Range	Mean±stdev	Range	Mean±stdev
Physico-chemical analysis:									
Turbidity	NTU	23.4-27.8	25.5±2.20	12.2-12.6	12.4±0.20	6.3-6.5	6.4±0.10	0.12-0.18	0.15±0.03
pH	-	7.3-7.48	7.44±0.04	7.36-7.44	7.4±0.04	7.36-7.44	7.4±0.04	7.0-7.2	7.1±0.10
Electric Conductivity	µS/cm	440-462	450.7±11.02	345-355	350±5.00	345-355	350±5.00	185-195	190±5.00
Total Dissolved Solids (TDS)	mg/L	250-262	256.7±6.11	190-204	197±7.00	190-204	197±7.00	94-110	101.3±8.08
Total Suspended Solids (TSS)	mg/L	20-26	23±3.00	06-06	6±0.00	4.0-4.0	4±0.00	02-02	2±0.00
Total Solids (TS)	mg/L	274-288	281±7.00	209-217	213±4.00	209-217	213±4.00	96-112	103.3±8.08
Total Alkalinity as ($CaCO_3$)	mg/L	138-142	140±2.00	135-141	138±3.00	135-141	138±3.00	58-62	60±2.00
Carbonate Alkalinity	mg/L	0.00	0.00	0.00	-	0	0	0.00	-
Bicarbonate Alkalinity	mg/L	138-142	140±2.00	135-141	138±3.00	135-141	138±3.00	58-62	60±2.00
Chlorides (Cl)	mg/L	27-29	28±1.00	23-29	26±3.00	23-29	26±3.00	22-25	23.7±1.53
Sulfates (SO4)	mg/L	20-24	22±2.00	19-21	20±1.00	19-21	20±1.00	5.0-7.0	6±1.00
Phosphates (PO4)	mg/L	0.125-0.2	0.1625±0.05	0.00	-	0.00	-	0.00	-
Total Hardness as ($CaCO_3$)	mg/L	130-134	132±2.00	130-134	132±2.00	130-134	132±2.00	30-34	32±2.00
Calcium Hardness	mg/L	74-78	76±2.00	70-74	72±2.00	68-74	72±2.00	20-24	22±2.00
Magnesium Hardness	mg/L	54-58	56±2.00	58-62	60±2.00	60-62	60±2.00	9-10.8	9.9±0.90
Calcium (Ca)	mg/L	29.6-31.2	30.5±0.82	28.0-29.6	28.7±0.83	26.5-29.6	27.7±1.66	8.0-9.6	8.8±0.8
Magnesium (Mg)	mg/L	13.3-14.1	13.7±0.40	14.1-15.1	14.4±0.58	13.7-15.1	14.3±0.73	1.9-2.3	2.1±0.21
Ammonia as (NH_3)	mg/L	0.2-0.22	0.21±0.01	0.2-0.22	0.21±0.01	0.17-0.19	0.18±0.10	0.09-0.11	0.1±0.01
Nitrites as (NO_2)	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	0.22±0.02	N.D.	N.D.
Nitrates as (NO_3)	mg/L	0.21-0.27	0.24±0.03	0.20-0.24	0.22±0.02	0.15-0.18	0.16±0.15	0.02-0.04	0.03±0.01
Phenol	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Cyanide (CN)	mg/L	N.D.	N.D.	N.D.	N.D.	N.D.	-	N.D.	N.D.
Sodium (Na)	mg/L	18-23	20.3±2.52	17-21	19.3±2.08	17-21	18.7±2.0	12.7-14.1	14.4±0.7
Potasium (K)	mg/L	4-4	4.0±0.00	4-4	4.0±0.00	4-4	4.0±0.00	2.83-2.81	2.82±0.01
Iron (Fe)	mg/L	0.30-0.88	0.56±0.29	0.18-0.60	0.36±0.22	0.18-0.60	0.36±0.22	0.001-0.05	0.02±0.03
Manganese (Mn)	mg/L	0.02-0.10	0.06±0.04	0.014-0.007	0.04±0.03	0.014-0.007	0.04±0.03	0.00-0.001	0.0003 ±0.00
Alumenium (Al)	mg/L	0.2-1.1	0.6±0.26	0.15-0.89	0.59±0.39	0.15-0.89	0.59±0.39	N.D	-
Copper (Cu)	mg/L	0.005-0.015	0.01±0.005	0.005-0.015	0.01±0.005	0.005-0.015	0.01±0.005	N.D	-
Lead (Pb)	mg/L	0.008-0.008	0.008±0.00	0.008-0.008	0.008±0.00	0.008-0.008	0.008±0.00	N.D	-
Nickel (Ni)	mg/L	0.001-0.001	0.001±0.00	0.001-0.001	0.001±0.00	0.001-0.001	0.001±0.00	N.D	-
Chromium (Cr)	mg/L	0.002-0.002	0.002±0.00	0.002-0.002	0.002±0.00	0.002-0.002	0.002±0.00	N.D	-
Zinc (Zn)	mg/L	0.005-0.013	0.009±0.00	0.005-0.013	0.009±0.00	0.005-0.013	0.009±0.00	N.D	-
Organic Analysis									
Chemical Oxygen Demand	mgO_2/L	29.7±1.53	28-31	28.7±1.53	27-30	27-30	29±1.53	2.1±0.30	1.8-2.4
Biological Oxygen Demand	mgO_2/L	14.7±0.58	14-15	13.7±0.58	13-14	13-14	14±0.58	1.3±0.12	1.2-1.4
Total Organic Carbon	mgC/L	8.9±0.30	8.6-9.2	7.4±0.30	7.1-7.4	7.1-7.4	7.7±0.30	0.6±0.05	0.5-0.6
Organophosphorus pesticides	μg/L	54.1±5.03	50.2-59.8	54.1±5.03	50.2-59.8	50.2-59.8	52.4±5.03	ND	ND
Algal Examination									
Diatoms	Org./ml	10250-11350	10833.3±318.20	8970-9370	9173.3± 134.35	3100-3480	3293.3± 268.70	5.0-9.0	6.7±0.71

Supplementary (7) (continued)

Green Algae	Org./ml	1210-1322	1267.0±37.48	970-1028	999.0±20.51	600-670	636.7±49.50	0-0	0.0±0.00
Blue Green Algae	Org./ml	420-452	436.0±11.31	312-336	324.0±8.49	98-118	110.0±11.31	0-0	0.0±0.00
Total Algae Count	Org./ml	11880-12605	12536.3±366.99	10252-10734	10496.3±163.34	3814-4248	4040.0±306.88	5.0-9.0	6.7±0.71
Microbiological and parasitological examination									
Total bacterial at 37°C	Cell/100ml	1600-1900	1700.0±0.00	4100-4700	4433.3±424.26	2500-2900	2700.0±282.84	5.0-9.0	7.0±1.41
Total Plate Count at 22°C	Cell/100ml	1700-2100	1833.3±0.00	4900-5300	5100.0±282.84	2900-3200	3033.3±141.42	7.0-11	9.0±1.41
Total Coliform	Cell/100ml	9000-13000	11000.0±1414.21	9.0-11	9.0±2.83	5.0-7.0	6.0±1.41	ND	ND
Faecal Coliform	Cell/100ml	190-230	210.0±14.14	3.0-5.0	4.0±1.41	2.0-4.0	3.0±1.41	ND	ND
Faecal Streptococcus	Cell/100ml	90-110	96.7±0.00	3.0-5.0	4.0±0.71	2.0-4.0	3.0±0.71	ND	ND
Gastrointestinal helminth									
Nematodes	Ova/10L	4		5		3		N.D	
Parasitic protozoa	Cyst/Oocyst/Spore per 10 L	N.D		N.D		N.D		N.D	
Potentially pathogenic free-living amoebae									
At 22ºC	+ve/-ve	+ve		+ve		+ve		-ve	
At 37ºC	+ve/-ve	+ve		+ve		+ve		-ve	