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Assessment of some drinking water purification plants efficiency at Great Cairo in Egypt

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ABSTRACT

This study was conducted to investigate the quality of water from entries and exits of six drinking water purification plants at Great Cairo in Egypt. Results obtained from four seasons trips (December 2014 through November 2015) revealed variation in chemical, physical and microbiological properties of River Nile (raw water source). Some intakes (El-Qanater, Embaba, and El-Hawamdeya) recorded high concentrations of ammonia, biological oxygen demand, chemical oxygen demand, and depletion in dissolved oxygen. Total coliforms, fecal coliforms and fecal streptococci exceeded permissible limits for drinking water intakes. Meanwhile, water produced from purification plants were suffering from high turbidity and unsatisfactory residual chlorine levels. The water quality index (WQI) categorized the plants entries (River Nile) as being medium-good, while that of plants exits as being good but not excellent. The study recommends the protection of raw water resources from pollution (River Nile and its branches) by enforcement of actual applying of LAW 48⁄1982. Such step should be coupled with rising the efficiency of water purification plants especially filtration and disinfection stages to ensure safe drinking water free of disease-causing agents, and prevent bacterial re-growth in distribution systems which travel for long distances to reach consumers' taps.

Key words: Drinking water, Water purification plants, River Nile, Physico-chemical analysis, Microbiological analysis.

Introduction

The main source of drinking water in Egypt is the River Nile which receipts wastewater and drainage generated by different activities (El-Sadek, 2007). World leaders increasingly recognize safe drinking water as a critical building block of sustainable development. The sanitary risk for man linked to the presence of pathogens depends on the use of water (Drinking, recreational activities, bathing, irrigation, shellfish harvesting) and on the pathogen concentration in water (Garcia- Armisen *et al*., 2007). Fecal indicator bacteria provide an estimation of the amount of feces, and indirectly, the presence and quantity of fecal pathogens in the water (Reynolds *et al*., 2008).

Drinking water should meet specific standards and criteria for good public health and being free from disease-causing bacteria. The drinking water purification plants are designed specifically to eliminate chemical and microbiological pollution in raw source water through treatment stages, especially disinfection stage in which bacteria and pathogens which cause water born diseases are killed by adding chlorine. The presence of bacteria in drinking water seriously affects public health and it is an emerging issue in drinking water industry. Potable water, particularly hospital water supplies, can support the growth of these bacteria, which may be linked to nosocomial infections (Bitton, 1994).

The treatment and distribution of water for safe use is one of the greatest achievements of the twentieth century. Clean, safe drinking water is essential for good public health. Achieving the goal of clean, safe drinking water requires a multi-barrier approach that includes: protecting raw source water from contamination, appropriately treating raw water, and ensuring safe distribution of treated drinking water to consumers' taps. The water sources must be protected from contamination by human and

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animal wastes which contain a variety of bacterial, viral, protozoan pathogens and helminthes parasites. Failure to provide adequate protection and effective treatment will expose the community to the risk of outbreaks of intestinal and other infectious diseases. The drinking water microbiological parameters are very important and should not exceed the limits specified in the water quality guidelines as they indicate the potential of waterborne disease. LeChevallier (2003) and Rifaat (2007) showed that water contaminated with microbiological constituents cause a variety of diseases. An estimated 10,000 people die every day from water- and sanitation related diseases, and thousands more suffer from associated illnesses (Bosch *et al*., 2000**).** In this respect, enteric pathogens are typically responsible for waterborne sickness (Karaboze *et al*., 2003).

According to the most recent World Health Organization (WHO) estimates, 842 000 diarrheal deaths in low- and middle-income countries are caused by inadequate drinking-water, sanitation and hand washing practices (Hass *et al*., 2016). Despite large advances in water and wastewater treatment technologies, water-borne diseases still pose a major world-wide threat to public health. Water-borne pathogens infect around 250 million people every year resulting in 10-20 million deaths all over the world (Salah El-Din, 2005). Three of five people in developing countries have no access to safe drinking water, and only one of four people have some sort of water sanitation. According to WHO (2013), only 15-20% of the world's population has access to drinking water (treated, chlorinated or uncontaminated water). Potable water released into the distribution system becomes altered during its passage through pipes, open reservoirs, standpipes and storage tanks. Transient negative pressure and pipeline leak events provide a potential portal for the entry of groundwater into treated drinking water; and permit fecal indicators and microbial pathogens present in the soil and water exterior to enter the distribution system.

Water treatment involves two types of processes: physical removal of solids (mainly mineral and organic particulate matter) and chemical disinfection (killing/inactivating microorganisms). Treatment practices vary from system to system, but there are four generally accepted basic stages (Stewart *et al*., 2001). Coagulation, in which alum (an aluminum sulfate) or other metal salts are added to raw water (entries of plants) to aggregate particles into masses that settle more readily than individual particles. The initial chlorine is added through this stage to kill pathogens found in raw water. This is regularly followed by sedimentation, in which coagulated particles fall, by gravity, through water in a settling tank and accumulate at the bottom of the tank, clearing the water of much of the solid debris. Filtration, in which, water from the sedimentation tank is forced through sand, and gravel to remove solid particles not previously removed by sedimentation.

Disinfection, a chemical process whose objective is to control disease-causing microorganisms by killing or inactivating them, is unquestionably the most important step in drinking water treatment. Final chlorine is mandatory added to filtered water to destroy harmful microorganisms. An additional amount, known as "chlorine residual" is applied to protect treated water from re-contamination as it travels throughout the distribution system (Krasner *et al.,* 2006**)**. Water disinfection has been used to improve the hygienic quality of drinking water by removing waterborne bacterial pathogens since the early twentieth century. Chlorine is the most widely used disinfectant for this purpose by virtue of extremely high efficiency and relatively low cost. Life magazine in 1997 declared that filtration of drinking water plus the use of chlorine is probably the most significant public health advancement of the millennium (Anonymous, 1997).

The present study aimed at gaining insight into the efficiency of six major drinking water purification plants located at Great Cairo, in Egypt in relation to their intakes in River Nile. Different physico-chemical and bacteriological parameters were employed to generate an overall water quality index. Suggestions were also proposed for optimizing produced water quality.

Materials and Methods

Study area

The area of the present study covered three main governorates in Egypt namely, Giza, Cairo, and Qalubeya, and included six major drinking water purification plants located along the River Nile. These plants are: El-Hawamdeya, Embaba, El-Maadi, El-Amirya, Mostorod and El-Qanater. The study period extended from December 2014 through November 2015 comprising four different seasons in which, water samples were collected from raw source water (entries from River Nile) and treated water (exits from purification plants) with an overall of 144 water samples.

Water sampling procedure

Water sampling was carried out according to Standard Methods for Examination of Water and Wastewater (APHA, 2012). The water samples were collected in clean and sterile polyethylene plastic bottles without any dechlorinating agent for the physico-chemical analysis and sodium thiosulfate (0.1 ml of 3% Na_2S2O_3) for the microbiological analysis to neutralize residual chlorine present in treated water. Water samples of entries were collected from the subsurface layer of River Nile at depth 50 cm. Water samples of exits were collected from exits of purification plants taps after their sterilization. The samples were collected under consistent sampling procedures such that: presence of ample air space in the bottles (at least 2.5 cm) to facilitate mixing by shaking, keeping sampling bottles closed until it is to be filled, avoiding external contamination during sample collection, avoiding internal contamination of stopper or cap and bottle neck and filling container without rinsing. All samples collected for either chemical or bacteriological analysis were stored in an iced cooler box and delivered immediately to the laboratory for analyses at Central Health Laboratories of Ministry of Health & population and the Central Laboratory for Environmental Quality Monitoring (CLEQM) National Water Research Center (NWRC), Cairo, Egypt.

Water samples analysis

Water analysis was carried out according to Standard Methods for Examination of Water and Wastewater (APHA, 2012).

Physico-chemical analysis

All field parameters were measured in the field and rechecked in laboratory to ensure data accuracy; Temperature, pH, dissolved oxygen (DO), electric conductivity (EC) and total dissolved solids (TDS) were measured in water samples by using the multi-probe system, model Hydralab–Surveyor, Germany; Residual chlorine in treated water samples was measured by chlorine device HACH DR/980, using N, N-Diethyl-p-Phenylenediamine (DPD) colorimetric spectrophotometry. Once the samples were received in the lab, they were manually mixed by shaking and examined as follows: Ammonia (NH_3) was measured by using ammonia selective electrode, ORION model 95-12 attached to bench-top Ion analyzer, ORION model 940. Turbidity was measured by Nephelometric turbidity meter HACH, model 2100. Biochemical oxygen demand (BOD) was determined by ORION BOD fast respiratory system, model 890. Chemical Oxygen Demand (COD) was tested using potassium permanganate method. Total hardness, Calcium hardness (Ca. hardness), and Magnesium hardness (Mg. hardness) were measured by Titrimetric Method. Chloride (Cl^-) measured by Argentometric method. Nitrate (NO_3^-), Nitrite (NO_2^-), Phosphate (PO_4^{-3}), and Sulphate (SO_4^{-2}) were measured by Ion Chromatography. Total Alkalinity was measured by titration method. The concentrations of major cations, Calcium (Ca^{+2}), Sodium (Na^+), Magnesium (Mg^{+2}) and Potassium (K^+) as well as trace metals including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), zink (Zn), lead (Pb), nickel (Ni), aluminum (Al), manganese (Mn) and iron (Fe) were measured by using ICP-OES Model Varian lab Liberty Series II.

Bacteriological analysis

All collected samples were examined within 6 hours after collection according to Standard Methods for Examination of Water and Wastewater (APHA, 2012). Standard plate count (SPC) bacteria at 22°C and 37°C were determined by pour plate method No. 9215 B. For counting total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS), the membrane filter technique was applied according to standard method Nos. 9222B, 9222 D and 9230 C on M-Endo agar LES, M-FC agar and M-Enterococcus agar media, respectively using a filtration system completed with stainless steel autoclavable manifold and oil-free ''Millipore'' vacuum/pressure pump in which, water samples were filtered through sterile surface girded ''Sartorious'' membrane of a pour size 0.45 µm and diameter 47 mm. All media used were obtained in a dehydrated form, Difco-USA. Results were recorded as colony forming unit (cfu $100ml^{-1}$) using the following equation:

$$Total\ coliform\ colonies\ /100\ ml = \frac{coliform\ colonies\ counted\ \times 100}{ml\ sample\ filtered}$$

Water quality index (WQI)

Water quality index is a 100 point scale that was used to summarize results from a total of eight different measurements using computer program Microsoft Excel (Version, 2013) created by the National Sanitation Foundation, USA (Tyagil *et al*., 2013). The used measurements are: DO, FC, pH, BOD, Temp, PO_4^{3-} , NO_3^- and turbidity. The WQI makes reduction of large amounts of data into a single number, thus ranking water into one of five categories: very bad (0 – 25), bad (25 – 50), medium (50 – 70), good (70 – 90) and excellent (90 – 100).

Statistical analysis

Data mean values and percentages were calculated using Minitab 16 statistical software program (Minitab 2010).

Results and discussion

Results of physico-chemical and bacteriological analysis of water samples collected from entries and exits of water purification plants were presented in tables 1-6.

Physico-chemical characteristics of water samples

Physico-chemical parameters are considered principle tools in identifying the nature, quality and type of water for any aquatic ecosystem. Increased industry, agriculture urbanization, tourism and human activities are responsible for chemical pollution of water resources (Abdo, 2005).

Temperature

Temperature is very important parameter in water quality assessment as it indicates the nature and characteristics of sample source; metabolic rate of aquatic organisms and pollutants. The results showed temperature changes ranging between 20-22°C for entries samples and 20-21°C for exits samples (Tables 1&2). These changes depend on climate changes and time of sampling. All values were within the permissible limits indicating that the water temperature of all collected samples was affected only by the ambient air temperature with no thermal pollution (WHO, 1993).

Turbidity

Turbidity is the measure of no clarity (pollution) of water due to dredging operations, increased flow rates, floods, increased populations in bottom-feeding fish, increased erosion, organic matter and nutrients due to poor land usage. These actions cause increased levels of turbidity which may cause shallow areas to fill in faster, as well as impairment of aquatic habitat. From data given in Tables 1 and 2, turbidity values ranged from 2 to 3 NTU for entries samples and from 1 to 1.8 NTU for exits samples. Values violating permissible limits were mainly recorded in El-Qanater and Embaba plants. Such high values of turbidity in exits indicate that filtration stage in purification plants isn't properly working. Increased turbidity negatively affects aquatic life by reducing light penetration needed for photosynthesis. As far as concerning humans, increased turbidity makes the water aesthetically unpleasing, and requires greater processes to clean up water for human consumption (DRI, 2007).

Table 1: Mean values of physico-chemical parameters in water samples collected from entries in different seasons.

Parameters	**Units**	**Mostorod**	**El-Amirya**	**El-Qanater**	**Embaba**	**El-Maadi**	**El-Hawamdeya**	**LAW 48⁄1982**
Temperature	(^{0}C)	20	21	20	22	21	21	-
Turbidity	(NTU)	2	2	3	2	3	2	-
DO	(mg/l)	6.2	6.5	6.7	7.2	6.2	5.5*	not less than 6
pH	-	7.2	7.4	7.35	7.55	7.6	7.43	6.5 – 8.5
EC	(µmhos⁄cm)	389	385	385	335	349	380	-
Ammonia	(mg/l)	0.5	0.4	0.6*	0.5	0.4	0.7*	not to exceed 0.5
BOD	(mg/l)	6	6	7*	6.5*	5	4.5	not to exceed 6
COD	(mg/l)	17*	18*	17*	16*	15*	17*	not to exceed 10
TDS	(mg/l)	234	249	253	264	225	252	not to exceed 500
Total hardness	(mg/l)	162	167	167	161	179	170	-
Ca. hardness	(mg/l)	108	111	111	104	111	105	-
Mg. hardness	(mg/l)	53	56	56	58	68	65	-
NO_2^-	(mg/l)	0.3	0.1	0.3	0.3	0.2	0.2	-
NO_3^-	(mg/l)	0.9	0.7	0.7	0.8	0.6	0.4	not to exceed 2
PO_4^{-3}	(mg/l)	0.05	0.05	0.05	0.1	0.1	0.2	-
Cl^-	(mg/l)	28	26	27	19	25	23	-
SO_4^{-2}	(mg/l)	44	46	43	50	50	48	not to exceed 200
Total Alkalinity	(mg/l)	147	147	150	146	145	150	150
Ca^{+2}	(mg/l)	43	44	44	40	42	36	-
Mg^{+2}	(mg/l)	13	14	14	11	16	13	-
Na^+	(mg/l)	43	42	43	4	45	43	-
K^+	(mg/l)	5.7	6	6	5.5	6.5	5.2	-

**: values above standard limits; - : No available guideline; LAW 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution.*

Dissolved Oxygen (DO)

DO is considered as water quality indicator; where the high values indicate high metabolic rates of aerobic bacteria and vise versa. The depletion of DO indicates unfavorable environmental conditions in which anaerobic bacteria metabolism leads to production of ammonia and H_2S gases, in addition to decomposition of organic matters (Goher, 2002). Seasonal variation of mean values for DO showed ranges fluctuated between 5.5-7.2 mg⁄l for water samples collected from entries. All DO values were within permissible limits of the law 48⁄1982 (not less than 6) except in El-Hawamdeya entry (5.5 mg⁄l). On the other hand, DO values of exits ranged between 7-8.8 mg⁄l and were within the permissible limits (Tables 1&2).

pH

The pH is a measure of hydrogen ions and hydroxyl ions activity determining how acidic or basic the water source is. It also affects biological and chemical reactions in aquatic environment. The increase in pH in the rivers could be related to photosynthesis and growth of aquatic plants, where photosynthesis consumes CO_2 leading to rise in pH values (Yousry *et al.*, 2009). The study results showed that all pH values of water samples collected from either entries or exits were within the standard limits and fall within range 7.2 and 7.7 (Tables 1&2).

Electric conductivity (EC)

EC is used as an indicator of water ability to carry electric current (Mara and Horan, 2003). Seasonal variation of EC mean values (Tables 1&2) ranged between 335-389 and 321-365 µmhos⁄cm for water samples collected from entries and exits, respectively. The maximum values were recorded in entries (Entry of Mosotrod plant) where the raw water receives industrial wastes.

Table 2: Mean values of physico-chemical parameters in water samples collected from exits in different seasons.

Parameters	**Units**	**Mostorod**	**El-Amirya**	**El-Qanater**	**Embaba**	**El-Maadi**	**El-Hawamdeya**	**Decree 458⁄2007**
Temperature	(^{0}C)	21	21	20	21	20	20	-
Turbidity	(NTU)	1	1	1.8*	1.1*	1	1	not to exceed 1
DO	(mg/l)	7	7.8	8.1	7.8	8.8	8	-
pH	-	7.5	7.7	7.5	7.6	7.7	7.4	6.5 – 8.5
EC	(µmhos⁄cm)	325	365	322	321	325	358	-
Ammonia	(mg/l)	0.06	0.02	0.1	0.1	0.03	0.08	not to exceed 0.5
BOD	(mg/l)	2.2	0.5	1.5	1.3	0.5	1	-
COD	(mg/l)	0.8	0.8	1.6	0.9	0.9	2	-
TDS	(mg/l)	176	229	285	246	242	233	not to exceed 1000
Total hardness	(mg/l)	141	137	146	119	134	121	500
Ca. hardness	(mg/l)	74	82	73	75	83	73	350
Mg. hardness	(mg/l)	71	55	73	44	51	48	150
NO_2^-	(mg/l)	ND	ND	ND	ND	ND	ND	0.2
NO_3^-	(mg/l)	ND	ND	ND	ND	ND	ND	45
Cl^-	(mg/l)	36	38	37	41	40	39	250
SO_4^{-2}	(mg/l)	31	42	30	45	44	43	250
Total Alkalinity	(mg/l)	124	133	148	144	138	142	-
Na^+	(mg/l)	31	34	30	37	36	35	200

**: values above standard limits; - : No available guideline; ND: Not detected; Decree 458⁄2007: Decree of* Egyptian Ministry of Health for the quality standards (guidelines) of potable drinking and tap (house) water.

Ammonia (NH_3)

NH_3 is present in water as a result of the biological degradation of nitrogenous organic matter (Chapman, 1996). As indicated from Tables 1&2, the seasonal variation of mean values for NH_3 fluctuated between 0.4-0.7 mg⁄l and 0.02-0.1 mg⁄l for water samples collected from entries and exits, respectively. The maximum values were recorded in entries of El-Hawamdeya and El-Qanater plants where the raw water receives domestic, fecal wastes and sanitation discharges (values should not exceed 0.5mg⁄l). It is worth mentioning that, NH_3 in raw water may increase the chlorine demand, which may lead to "break-point" chlorination phenomenon. During chlorination, up to 68% of the initial chlorine may react with NH_3 forming chloramines and becomes unavailable for disinfection. Further more, the presence of NH_3 in raw water may result in drinking-water containing nitrite as a result of catalytic action or accidental colonization of filters by ammonium-oxidizing bacteria. Also, its presence may interfere with the operation of manganese-removal filters because too much oxygen is consumed by nitrification resulting in moldy and earthy-tasting water (El Gammal and El Shazely, 2008).

Biochemical oxygen demand (BOD)

BOD is used as an indicator of water pollution by organic matter. It is considered as a measure of the dissolved oxygen consumed by aerobic bacteria as they metabolize the complex unstable molecules of organic pollutants in the environment (Chapman, 1996). Seasonal variation of BOD mean values (Tables 1&2) fluctuated between 4.5-7 mg/l for entries and (0.5-2.2) mg/l for exits. Maximum values above limits (not to exceed 6 mg/l) were in samples collected from entries of El-Qanater and Embaba plants, while BOD values of exits were within limits.

Chemical oxygen demand (COD)

COD is the amount of oxygen required for chemical oxidation of organic matter in water and varies with water composition, concentration of the reagent, temperature, contact time and other factors (Nollet, 2007). COD mean values (Tables 1 & 2) fluctuated between 15-18 mg/l for entries and 0.8-2 mg/l for exits. All COD value in samples collected from entries were above limits (not to exceed 10 mg/l), while those from exits were within limits.

Total Dissolved Solids (TDS)

TDS high values lead to disturbance in aquatic environment due to rise in osmotic pressure and undesirable odor, taste and color. In the present study, seasonal variation of TDS mean values for water samples ranged between 225-264 mg/l for entries and 167-285 mg/l for exits. All TDS values in samples collected from entries and exits were within limits (not to exceed 500 mg/l for entries and 1000 mg/l for exits) (Tables 1&2).

Total hardness, major anions, cations and trace metals

All presented data collected from entries and exits of different water purification plants were within the permissible limits as given in Tables 1-4.

Table 3: Mean values of trace metals concentrations in water samples collected from entries in different seasons (values in mg/l).

Parameters	**Mostorod**	**El-Amirya**	**El-Qanater**	**Embaba**	**El-Maadi**	**El-Hawamdeya**	**LAW 48/1982**
As	0.01	0.01	<0.01	<0.01	<0.01	<0.01	not to exceed 0.01
Cd	0.001	0.001	0.001	<0.001	<0.001	0.001	not to exceed 0.001
Cr	0.01	0.01	0.01	0.01	<0.05	0.01	not to exceed 0.05
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	not to exceed 0.01
Zn	<0.01	0.01	0.01	<0.01	<0.01	<0.01	not to exceed 0.01
Pb	0.01	<0.01	0.01	0.01	<0.01	<0.01	not to exceed 0.01
Ni	0.02	<0.02	0.02	<0.02	<0.02	0.02	not to exceed 0.02
Al	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-
Mn	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	not to exceed 0.2
Fe	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	not to exceed 0.5

- : No available guideline; LAW 48/1982: Egyptian Law for protection of the River Nile and water ways from pollution.

Table 4: Mean values of trace metals concentration in treated water samples collected from exits in different seasons (values in mg/l).

Parameters	**Mostorod**	**El-Amirya**	**El-Qanater**	**Embaba**	**El-Maadi**	**El-Hawamdeya**	**Decree 458/2007**
As	< 0.1	ND	< 0.1	ND	< 0.1	ND	not to exceed 0.01
Cd	< 0.003	ND	< 0.003	ND	ND	< 0.003	not to exceed 0.003
Cr	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	not to exceed 0.05
Cu	< 2	< 2	< 2	< 2	< 2	< 2	not to exceed 2
Zn	< 3	< 3	< 3	< 3	< 3	< 3	not to exceed 3
Pb	< 0.01	< 0.01	< 0.01	0.001	0.001	0.001	not to exceed 0.01
Ni	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	not to exceed 0.02
Al	< 0.2	< 0.2	ND	< 0.2	< 0.2	< 0.2	not to exceed 0.2
Mn	ND	ND	ND	ND	ND	ND	not to exceed 0.4
Fe	0.03	0.02	0.01	ND	ND	ND	not to exceed 0.3

ND: Not detected; Decree 458/2007: Decree of Egyptian Ministry of Health for the quality standards (guidelines) of potable drinking and tap (house) water.

According to previously mentioned data from physico-chemical analysis it is obvious that, water intakes in River Nile is partially suffering from quality disorders. Some intakes (El-Qanater, Embaba, and El-Hawamdeya) recorded high concentrations of ammonia, biological oxygen demand, chemical oxygen demand, and depletion in dissolved oxygen. Domestic, agricultural and industrial discharges due to illegal human activities could be promoting factors for this problem. Our results were in agreement with those recorded by Donia and Farage (2005); El-Sherbini (2007) and Ezzat *et al.,* (2012). Meanwhile turbidity in water from purification plants exits was the principle defect.

Table 5: Mean values of bacteriological parameters in water samples collected from entries in different seasons.

	Sites	**SPC at 22°C**	**SPC at 37°C**	**TC**	**FC**	**FS**
		(CFU/ml)		**(CFU/100ml)**		
Winter	**Mostorod**	4x10^2	2 x10^2	3x10^2	2x10^2	22
	El-Amirya	225	113	120	50	16
	El-Qanater	80 x10^2	18x10^2	245x10^2*	185x10^2*	8x10^2
	Embaba	5x10^2	4x10^2	186x10^2*	25x10^2*	2x10^2
	El-Maadi	4x10^2	2x10^2	5x10^2	3x10^2	40
	El-Hawamdeya	4x10^2	3x10^2	67x10^2*	18x10^2	70
Summer	**Mostorod**	8x10^2	4x10^2	5x10^2	3x10^2	50
	El-Amirya	5x10^2	2x10^2	3x10^2	1x10^2	40
	El-Qanater	160x10^2	52x10^2	100x10^3*	40x10^3*	6x10^3*
	Embaba	12x10^2	9x10^2	58x10^3*	6x10^3*	8x10^2
	El-Maadi	10x10^2	8x10^2	9x10^2	7x10^2	80
	El-Hawamdeya	11x10^2	9x10^2	52x10^3*	5x10^3*	4x10^2
Spring	**Mostorod**	7x10^2	6 x10^2	4x10^2	2x10^2	36
	El-Amirya	360	210	186	68	27
	El-Qanater	140 x10^2	32x10^2	48x10^3*	18x10^3*	4x10^3*
	Embaba	7x10^2	4x10^2	36x10^3*	3x10^3*	4x10^2
	El-Maadi	4x10^2	3x10^2	9x10^2	7x10^2	55
	El-Hawamdeya	8x10^2	6x10^2	28x10^3*	3x10^3*	2x10^2
Autumn	**Mostorod**	7x10^2	5x10^2	3x10^2	2x10^2	42
	El-Amirya	480	180	2x10^2	80	36
	El-Qanater	152x10^2	48x10^2	69x10^3*	27x10^3*	4x10^3*
	Embaba	9x10^2	6x10^2	42x10^3*	5x10^3*	6x10^2
	El-Maadi	6x10^2	4x10^2	8x10^2	5x10^2	65
	El-Hawamdeya	7x10^2	4x10^2	27x10^3*	3x10^3*	3x10^2

SPC: Standard plate count bacteria; TC: Total coliforms; FC: Fecal coliforms; FS: Fecal streptococci;
**: Values above standard limits.*

Table 6: Mean values of bacteriological parameters in treated water samples collected from exits in different seasons.

	Sites	SPC at 22°C	SPC at 37°C	TC	FC	FS
		(CFU/ml)		(CFU/100ml)		
Winter	Mostorod	13	9	ND	ND	ND
	El-Amirya	26	18	ND	ND	ND
	El-Qanater	12	8	ND	ND	ND
	Embaba	19	12	ND	ND	ND
	El-Maadi	13	7	ND	ND	ND
	El-Hawamdeya	10	5	ND	ND	ND
Summer	Mostorod	11	7	ND	ND	ND
	El-Amirya	6	2	ND	ND	ND
	El-Qanater	35	25	ND	ND	ND
	Embaba	33	27	ND	ND	ND
	El-Maadi	19	16	ND	ND	ND
	El-Hawamdeya	26	18	ND	ND	ND
Spring	Mostorod	7	5	ND	ND	ND
	El-Amirya	23	17	ND	ND	ND
	El-Qanater	11	9	ND	ND	ND
	Embaba	17	11	ND	ND	ND
	El-Maadi	14	8	ND	ND	ND
	El-Hawamdeya	8	5	ND	ND	ND
Autumn	Mostorod	14	10	ND	ND	ND
	El-Amirya	16	8	ND	ND	ND
	El-Qanater	14	8	ND	ND	ND
	Embaba	8	4	ND	ND	ND
	El-Maadi	8	5	ND	ND	ND
	El-Hawamdeya	10	5	ND	ND	ND
	Decree 458/2007	Not to exceed 50	Not to exceed 50	Not to exceed 2	Free	Free

SPC: standard plate count bacteria; TC: Total coliforms; FC: Fecal coliforms; FS: Fecal streptococci;
ND: Not detected; Decree 458/2007: Decree of Egyptian Ministry of Health for the quality standards (guidelines) of potable drinking and tap (house) water.

Bacteriological characteristics of water samples

Bacteriological characteristics are still the primary issue in any water quality assessment program, especially those used for drinking purposes. As a result, a set of indicator microorganisms has been identified and is now commonly applied to determine the hygienic suitability of water for various uses. The relative abundance of these indicators in a sample can serve as a warning of the likely presence of other or more dangerous pathogens in water (WHO, 2004).

Bacteriological analysis of water samples collected from entries and exits of six main drinking water purification plants were presented in Tables 5 & 6, and illustrated by Figs. 1, 2 & 3 as follows:

Standard plate count (SPC) bacteria

Data presented in Tables 5 and 6 indicated that mean values of SPC bacteria at 22°C and 37°C were within normal limits. Seasonal variation of SPC mean values fluctuated between 225 - 160×10^2 CFU/ml at 22°C and 113 - 52×10^2 CFU/ml at 37°C for samples collected from entries, while between 6 -35 CFU/ml at 22°C and 2 - 27 CFU/ml at 37°C for water samples collected from exits. SPC bacteria represent the aerobic and facultative anaerobic bacteria that derive their carbon and energy from organic compounds. The number of recovered bacteria depends on medium composition, period and temperature of incubation. SPC count is useful for evaluating the efficiency of treatment processes as well as monitoring the bacterial re-growth potential and biofilm development within the distribution systems (Reasoner, 1990).

Total coliforms (TC)

Coliforms group is defined as those aerobic and facultative anaerobic, Gram-negative, non-spore forming, rod shaped bacteria that can ferment lactose within 24 h at 35°C and produce CO_2 gas within 48h. It includes multiple bacterial genera such as *Escherichia*, *Klebsiella*, *Enterobacter* and *Citrobacter* (APHA 2005).

TC bacteria (Fig.1) in water samples were recorded as given in Tables 5&6. Seasonal variation of TC values fluctuated between 120 - 100x10^3 CFU⁄100 ml for water samples collected from entries, while in water samples collected from exits TC bacteria were undetectable. The maximum value of TC bacteria was in entry of El-Qanater plant (100x10^3CFU⁄100ml) in summer season. About 50% of water samples collected from raw water in River Nile exceeded the international standard limits recommended by Tebbutt (1998) (TC should not exceed 5000 CFU/100 ml). Much more restricted limits have been reported by Cabelli (1978) who recommended a maximum total coliforms count of 1000 CFU/100ml, particularly in surface water that are going to be used as drinking water supply.

Fecal coliforms (FC)

Fecal coliforms are natural inhabitants of the gastrointestinal tracts of humans and other warm-blooded animals. These bacteria in general cause no harm. However, because they are eliminated with feces, they are sometimes associated with pathogens that can transmit human diseases such as cholera (*Vibrio cholerae*), typhoid fever (*Salmonella typhi*), Shigellosis (*Shigella*), Salmonellosis (*Salmonella),* and gastroenteritis (*Campylobacter jejuni, E. coli* and *Giardia lamblia)*. The threat of such diseases transmission becomes more serious as the population density increases and more sewage pollutes public water supplies. This group comprises bacteria such as: *E. coli* and *Klebsiella pneumoniae*. Fecal coliforms, and particularly *E. coli***,** remain the best overall indicators of fecal pollution in water (Edberg *et al.*, 2000). Fecal coliforms are facultatively anaerobic, rod-shaped, gram-negative, non-spore forming bacteria. They are capable of growth in the presence of bile salts or similar surface agents, oxidase negative, and produce acid and gas from lactose within 48 h at 44±0.5ºC (Doyle and Erickson, 2006).

FC bacteria (Fig.2) were counted and demonstrated in Tables 5&6. Seasonal variation of FC values ranged between 50 – 40x10^3CFU/100ml for entries while in exits FC bacteria were undetectable. The maximum value of FC was in water samples collected from entry of El-Qanater plant (40x10^3 CFU⁄100ml) in summer season. About 45.8% of water samples collected from raw water in River Nile exceeded the international standard limits recommended by Tebbutt (1998) (FC should not exceed 2000 CFU/100 ml). Much more restricted limits have been reported by Cabelli (1978) who recommended a maximum total coliforms count of 200 CFU/100ml, particularly in surface water that are going to be used as drinking water supply.

Fecal streptococci (FS)

The fecal streptococcus group consists of a number of species of the genus *Streptococcus*, such as S.*faecalis, S.faceium, S.bovis, S.equines, S.avium,* and *S.gallinarum* that are normally found in feces and gut of warm-blooded animals. Unlike the coliform bacteria, they are Gram positive and also tend to live longer in water than fecal coliforms (Godfree *et al.*, 1997).

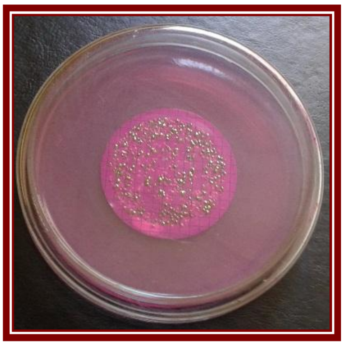

Fig.1: Total coliform colonies

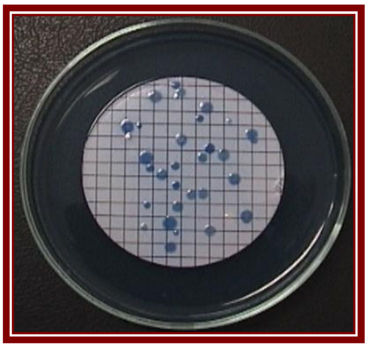

Fig.2: Fecal coliform colonies

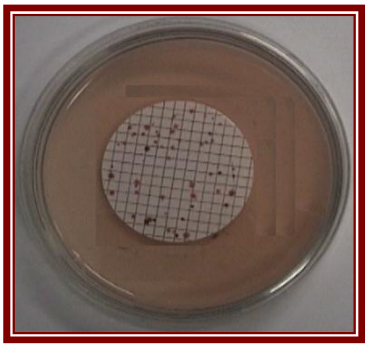

Fig.3: Fecal streptococci colonies

FS bacteria (Fig.3) in water samples were listed in Tables 5&6. Seasonal variation of FS mean values fluctuated between 16 - 6x10^3 CFU/100ml for entries while in exits they were undetectable. The maximum value of FS was in entry of El-Qanater plant (6x10^3 CFU/100ml) in summer season. About 27.3% of Nile water samples exceeded the international standard limits recommended by Tebbutt (1998). FS should not exceed 1000 CFU/100 ml for surface water that is going to be used as drinking water supply.

According to TC, FC and FS values obtained in this study, the investigated plants entries (Intakes in River Nile) could be ranked from higher to lower pollution levels as follows; El-Qanater, Embaba, El-Hawamdeya, El-Maadi, Mostorod and El-Amirya, respectively. Our results were in harmony with those obtained by Shash *et al.,* (2010) who reported that the total and fecal coliforms could be detected in Nile water at Great Cairo reaching 10^3-10^4 CFU⁄ 100ml. Saleh (2009) found that the log count of total coliform in Nile water reached 4 - 6 MPN-index/100 ml. These relatively high counts might be due to pollution generated from 34 industrial facilities discharging to the Nile water between Aswan and Cairo.

Seasonal variation of microbiological indicators revealed maximum pollution levels in summer season, followed by autumn, spring and was least in winter. This could be attributed to one or more of the following reasons; high temperature grades which promote bacterial activity in aquatic system that needs oxygen consumption leading to depletion in dissolved oxygen values, increased human activities, animal and agricultural activities, direct and indirect sewage, industrial and agricultural discharges (Sabae, 2004). Unlike water quality at River Nile branches (Rosetta and Damietta), maximum pollution load was always recorded in winter season, most probably due to accumulation of wastes in drains which is usually accompanied by winter closure, low water level in River Nile branches, and pollutants discharge (Sabae and Rabeh, 2007 and El-Bahnasawy, 2013). On the other hand, increasing discharge at high flood (summer season) usually releases excess water which in most cases improves the quality in River Nile branches (Yousry *et al*., 2009).

Residual chlorine determination

Chlorine is added to water for killing disease-causing bacterial pathogens to prevent the spread of waterborne diseases. For achieving this purpose, chlorine is added during water treatment stages; to raw water (initial chlorine) and to treated finished water (final chlorine). Chlorine in treated water (exits of plants) is measured to make sure they are sufficiently high to remove pathogenic bacteria and maintain adequate safety for drinking water in distribution systems which travel for long distances to reach consumers' taps (Essa, 2002 and Krasner *et al.,* 2006).

According to standard limits issued by Egyptian Ministry of Health (Decree 458⁄2007), residual chlorine in treated water intended for drinking use should not be less than 2 mg⁄l and not to exceed 5 mg⁄l. As indicated in Table 7 and Fig. 4, measurements of residual chlorine in treated water during study period recorded obvious chlorine deviation (<2mg⁄l) in exits of investigated plants; El-Qanater (83%), Embaba (75%), El-Hawamdya (58%), El-Maadi (50%), Mostorod and El-Amirya plants (25%). Such operational disorder could implicate serious drawback in distribution networks, regardless apparent efficiency of water purification plants in drinking water industry as indicated from previous bacteriological results (Table 6) where no bacterial indicators (TC, FC & FS) were detected in finished water product. The presence of bacteria in tap water could be related to several factors including decrease in chlorine dose, survive the disinfection process, open reservoirs or storage units, when repair work is done or new mains are added to the system, bacterial re-growth and biofilm development within the distribution systems (Geldreich, 1996 and El-Sadek, 2013).

Table 7: Residual chlorine in treated water samples collected from exits (Values in mg/l).

Months	Mostorod	El-Amirya	El-Qanater	Embaba	El-Maadi	El-Hawamdeya
January	1.5*	2.1	1.7*	2	2.3	1.8*
February	2	2.2	2.2	1.6*	1.7*	1.5*
March	1.4*	2	2	1.5*	1.5*	2.2
April	2	0.2*	1.4*	2	2	1*
May	2.2	2.2	1.4*	1.8*	2.5	2
June	2	2.1	1.2*	1.7*	1.8*	1.7*
July	2.2	2.1	1.3*	1.8*	1.9*	1.5*
August	2.2	2.1	1.3*	2.1	1.3*	1.2*
September	1.5*	2.2	1.3*	1.7*	2	2
October	2	2.1	1.2*	1.3*	2.4	2.2
November	2	1.8*	1.5*	1.9*	1.3*	2.5
December	2.2	1.9*	1.22*	1.5*	2	1.9*
Deviation %	25%	25%	83%	75%	50%	58%

*: *Values below recommended standard limits.*

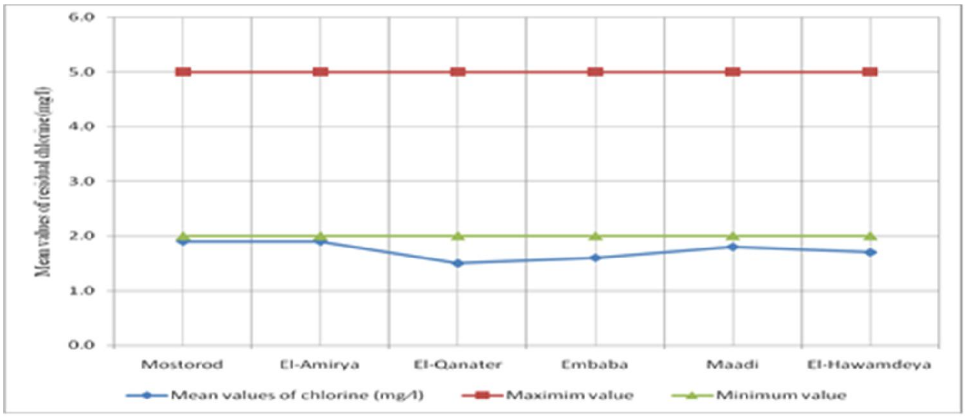

Fig. 4: Mean values of residual chlorine (mg/l) in drinking water treatment plants exits.

Table 8: Mean values of water quality index (WQI) for water samples collected from entries in different seasons.

Sites	WQI	Quality
Mostorod	71.3	Good
El-Amirya	72.2	Good
El-Qanater	68.9	Medium
Embaba	69.2	Medium
El-Maadi	70.0	Good
El-Hawamdeya	69.5	Medium

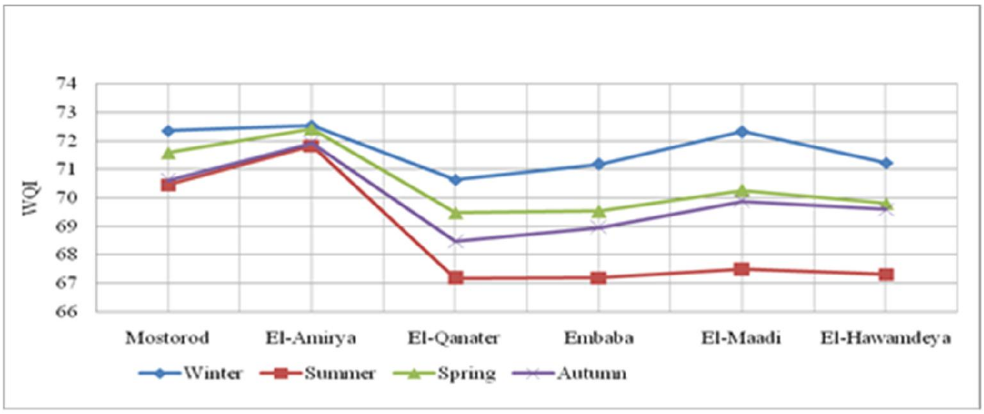

Fig. 5: Seasonal variation of water quality index (WQI) for water samples collected from entries.

Water quality index (WQI)

WQI was calculated in order to describe the overall quality status of investigated water purification intakes in River Nile and their corresponding exits from plants. Results
showed that the quality of raw water of entries was good in all seasons for El-Amirya, Mostorod and El-Maadi, and medium in all seasons for El-Qanater, Embaba and El-Hawamdeya, respectively (Table 8 and Fig. 5). Meanwhile, drinking water quality of exits was good (but not excellent) in all seasons for the six plants (Table 9 and Fig. 6). Being not excellent most probably due to elevated turbidity values which exceeded limits and depletion of residual chlorine as previously reported. The calculated water quality index thus supported the analytical data recorded in our study.

Table 9: Mean values of water quality index (WQI) of water samples collected from exits in different seasons.

Sites	WQI	Quality
Mostorod	74.4	Good
El-Amirya	75.3	Good
El-Qanater	72.1	Good
Embaba	72.6	Good
El-Maadi	74.2	Good
El-Hawamdeya	73.7	Good

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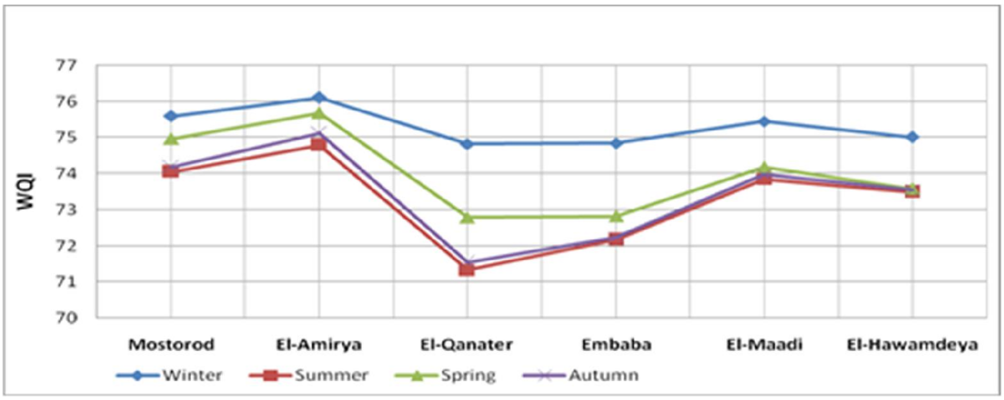

Fig. 6: Seasonal variation of water quality index (WQI) for water samples collected from exits.

Conclusion and recommendations

The present study concluded that, some water intakes in River Nile (El-Qanater, Embaba, and El-Hawamdeya) were partially suffering from quality disorders concerning physico-chemical and bacteriological characteristics. They were categorized being of medium quality. Industrial, agricultural, and sewage wastes are key factors in this environmental problem. Drinking water purification plants (exits) suffered mainly from elevated turbidity and depletion in residual chlorine. They were categorized being of good but not excellent quality. Operational deficiency in filtration and disinfection stages could be responsible.

The study recommends the protection of raw water resources from pollution (River Nile and its branches) by enforcement of actual applying of LAW 48⁄1982. Such step should be coupled with rising the efficiency of water purification plants especially filtration and disinfection stages to ensure safe drinking water free of disease-causing agents, and prevent bacterial re-growth in distribution systems which travel for long distances to reach consumers' taps. Further research should be acknowledged to track the fate of microbial quality and its health significance in drinking water distribution networks.

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