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Problems of drinking water treatment along Ismailia Canal Province, Egypt*

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Abstract: The present drinking water purification system in Egypt uses surface water as a raw water supply without a preliminary filtration process. On the other hand, chlorine gas is added as a disinfectant agent in two steps, pre- and post-chlorination. Due to these reasons most of water treatment plants suffer low filtering effectiveness and produce the trihalomethane (THM) species as a chlorination by-product. The Ismailia Canal represents the most distal downstream of the main Nile River. Thus its water contains all the proceeded pollutants discharged into the Nile. In addition, the downstream reaches of the canal act as an agricultural drain during the closing period of the High Dam gates in January and February every year. Moreover, the wide industrial zone along the upstream course of the canal enriches the canal water with high concentrations of heavy metals. The obtained results indicate that the canal gains up to 24.06×10^6 m^3 of water from the surrounding shallow aquifer during the closing period of the High Dam gates, while during the rest of the year, the canal acts as an influent stream losing about 99.6×10^6 m^3 of its water budget. The reduction of total organic carbon (TOC) and suspended particulate matters (SPMs) should be one of the central goals of any treatment plan to avoid the disinfectants by-products. The combination of sedimentation basins, gravel pre-filtration and slow sand filtration, and underground passage with microbiological oxidation-reduction and adsorption criteria showed good removal of parasites and bacteria and complete elimination of TOC, SPM and heavy metals. Moreover, it reduces the use of disinfectants chemicals and lowers the treatment costs. However, this purification system under the arid climate prevailing in Egypt should be tested and modified prior to application.

Key words: Drinking water treatment, Hazardous by-products, Natural attenuation, Ismailia Canal, Egypt
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INTRODUCTION

Location

The Ismailia Canal is constructed in the years of 1858~1863 to supply drinking water to the villages on the Suez Canal zones and to the workers during digging the Suez Canal Navigation Route. The Ismailia Canal extending eastward for about 125 km from the River Nile at Shupra, north of Cairo, to Ismailia city on the Suez Canal (Fig.1). It flows through considerable varieties of geological environments including Nile silts and muds, Miocene limestone, marls and sandstone, Oligocene gravels and basaltic sheets along its upstream western side, while its downstream eastern side is mainly occupied by Wadi El-Tumilat sands and muds.

The Ismailia Canal is the principle source of drinking water supply for a great number of the Egyptian citizens (about 12 million inhabitants), including those living in northern part of Cairo, Shupra El-Kheima, Mattaria, Musturod, Abu-Zaabal, Inchas, Belbeis, Abbasa, Abu-Hammad, Zagazeeg and El-Tell El-Kabier, before entering the Suez Canal Province.

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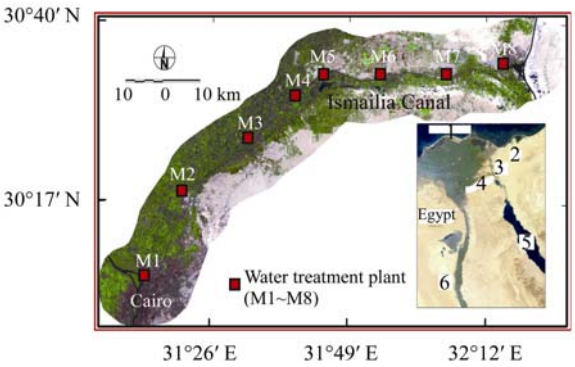

Fig.1 Location map of Ismailia Canal and water treatment plants
1: Mediterranean Sea; 2: Sinai; 3: Suez Canal; 4: Ismailia Canal; 5: Gulf of Suez; 6: Nile River

Problem definition

The Ismailia Canal is endangered from unwise, direct and indirect activities in the surrounding environments (Figs.2~4). Microbial contaminants, such as viruses and bacteria, and inorganic and organic contaminants were found in its running water (Geriesh *et al*., 1999). They have added constraints on the traditional drinking water treatment techniques and have led to the formation of trihalomethanes (chloroform and other chlorine by-products). These compounds have carcinogenic effect (IARC, 1991).

Fig.2 Collapses of the canal bank due to the seepage effluent

Fig.3 Close distribution of farmer's houses to the canal banks

Fig.4 Industrial zone located directly on the canal bank

The upstream portion of the Ismailia Canal (from Cairo to Abu-Zabal, western side) includes the largest industrial zones in the region (Shupra El-Kheima, Musturod and Abu-Zaabal industrial zones). The canal acts as an effluent stream along these sites. Chemical leakages and fallen dusts from these industries pollute the canal water.

The downstream reaches of this canal face high pollution risks, as it acts as effluent stream during the winter season. Following this season, algae are highly flourished and cause serious problems in water treatment plants, especially during the pre-chlorination process (Geriesh *et al*., 2004).

Objectives

The main objective of this study is to assess the drinking water quality produced from the Ismailia Canal surface water to ensure a safe source of drinking water supply. Also, it aims to find a suitable natural attenuation process to purify these water supplies from specific pollutants. Therefore, our ultimate goal aims to eliminate the pre-chlorination process in water treatment plants.

Water treatment system

A representative number of eight water treatment plants (WTPs) were examined in the present study. These plants are Mattaria (M1), Abu-Zaabal (M2), Belbeis (M3), Abbasa (M4), El-Tell El-Kabier (M5), El-Qassasein (M6), Abu-Sower (M7) and Ismailia (M8), which distribute along the canal from upstream to downstream, respectively (Fig.1). Four of these plants, M2, M3, M6 and M7, are of compact unit type plant. They produce about 1.5×10^6 m^3/d of drinking and domestic water. The treatment techniques in all of these plants are similar and comprise the coagulation and sedimentation basins that are composed of sand and gravel filters of one or two

layers, each about 40~60 cm thick (compact units use filter tanks of 1.5 m diameter), and one to two reservoirs for the post chlorination process. The alum dosing of about 30~35 mg/L is added in the coagulation basins. Chlorine gas is added in two steps, the pre-chlorination (before filtration) process and the post chlorination (post filtration) process. The retention time in most of these units varies between 20 and 60 min. The chlorine gas dose amounts are 3~5 mg/L for the pre-chlorination and 2~3 mg/L for the disinfection of the filtered water.

Hydrogeological boundary conditions

The Quaternary aquifers around the Ismailia Canal consist of two hydrogeologic units. The shallow aquifer, especially along the eastern downstream reaches, consists of fine sand and silts mixed with clays and evaporates with thickness varied between 10 and 30 m. The deeper aquifer is of especial importance for the water supply in the region, which consists of fluviatile deposits forming sequence of loose gravely sands alternating with clay and mud lenses. The thickness of this sequence amounts up to 200 m along the canal course. The salinity of the groundwater in the shallow aquifer varies between 340 mg/L and 7650 mg/L of Na-mix (no dominant anion) to Na-Cl type, respectively. The low salinity water is detected in areas close to the canal course revealing the effect of aquifer recharge by the canal water. The salinity of the deeper aquifer rarely exceeds 1500 mg/L and is mainly of Na-mix type. The Quaternary main unit unconformably overlies the Miocene and Oligocene rocks that are rich in evaporate contents. Along the western side, Oligocene gravely sands and basaltic sheets are cropping out on the surface along the canal course enabling external recharge source for the canal water, especially during the winter low stage season. The groundwater flow is directed toward the east and northeast and finally discharged into the Suez Canal and its lakes to the east or into the Lake Manzala to the northeastern side.

MATERIALS AND METHODS

Thirty-eight water samples were collected from the discharged water of different treatment plants. Both raw water and treated water were sampled in winter and summer seasons. Samples were collected in 250 ml-glass bottles and used for bacteriological, organic and physiochemical analyses in the laboratories of the Faculty of Science, Suez Canal University.

Additionally, 26 water samples were treated, conserved and transported to Tuebingen and Hohenheim Universities in Germany for heavy metals analyses and the halogenated by-products using high resolution inductively coupled plasma-mass spectrometer (HR-ICP-MS) and gas chromatograph, GLC (HP6800), respectively, after liquid-liquid phase extraction of hydrocarbons using hexane solvent.

The physicochemical parameters including pH, EC, and temperature were measured directly at the sampling sites.

The major chemical and bacteriological analyses were carried out following the APHA standard methods (APHA *et al*., 1995). Bacteriological analysis includes total coliform bacteria, whereas chemical and organic analyses include total dissolved solids (TDS), total organic carbon (TOC), suspended particulate matter (SPM), HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, PO_4^{3-}, Na^+, Ca^{2+}, Mg^{2+}, As, Cd^{2+}, Pb, Cu, Co, Ni, Zn^{2+}, Hg, Cr, Fe, Mn and THMs species.

To give highlight on the relationship between the surface water and the groundwater in the study area, flow measurements were carried out along the main canal course using spiral current meter.

RESULTS AND DISCUSSION

Surface water flux changes

The seepage rate along the canal course was measured at four cross sections during the winter seasons (period of closing the High Dam gates) and summer seasons. These sections are: S1 at 20 km from Mattaria to Abu-Zaabal; S2 at 28 km from Abu-Zaabal to Belbeis; S3 at 37 km from Belbeis to Qassasein and S4 at 35 km from Qassasein to Ismailia. Depths of the canal water vary between 4.6 and 2.5 m from upstream to downstream, respectively. During the closing period of the High Dam gates (January to February), the depth of water in the canal remarkably decreases to be varied between 0.5 and 1.3 m from upstream to downstream, respectively. The obtained data are listed in Table 1, from which the following remarks could be obtained:

Table 1 Results of flow measurements along Ismailia Canal Course

Section No.	Date of measurements	Discharge rate (m^3/d)		Net side flow (m^3/d)	Seepage quantity (m^3/d)	Seepage rate (m/d)	Stream condition
		Upstream	Downstream				
S1	Winter, Feb. 7	6048000	3888000	2087200	72800 (1.20%*)	0.060	Influent
	Summer, July 7	9072000	5238400	3724000	109600 (1.21%)	0.080	Influent
S2	Winter, Feb. 7	3888000	3728800	465000	−305800 (7.80%)	−0.430	Effluent
	Summer, July 7	5238400	4588000	642000	8400 (0.16%)	0.009	Influent
S3	Winter, Feb. 7	3728800	2243200	1532000	−46400 (1.20%)	−0.030	Effluent
	Summer, July 7	4588000	2754000	1799200	34800 (0.76%)	0.020	Influent
S4	Winter, Feb. 7	2243200	345600	2019200	−121600 (5.40%)	−0.120	Effluent
	Summer, July 7	2754000	352450	2222400	179150 (6.50%)	0.160	Influent
Average	Winter, Feb. 7	6048000	345600	6103400	−401000 (6.63%)	−0.090	Effluent
	Summer, July 7	9072000	352450	8387600	331950 (3.66%)	0.065	Influent

Negative values point to quantities of water losses from the canal to the adjacent aquifer (influent stream); Positive values point to quantities of water added to the canal from the adjacent aquifer (effluent stream). *Seepage quantity percent=Seepage quantity/upstream discharge rate

1. All the measured sections are acted as effluent stream during the winter season except the upstream section, located between Mattaria to Abu-Zaabal, which acted as influent stream (Fig.5). The canal gained water from the surrounding groundwater with an average value of 401000 m^3/d (about 6.6% of the canal water flux), mainly along the canal course from Abu-Zaabal to Ismailia at the downstream part.

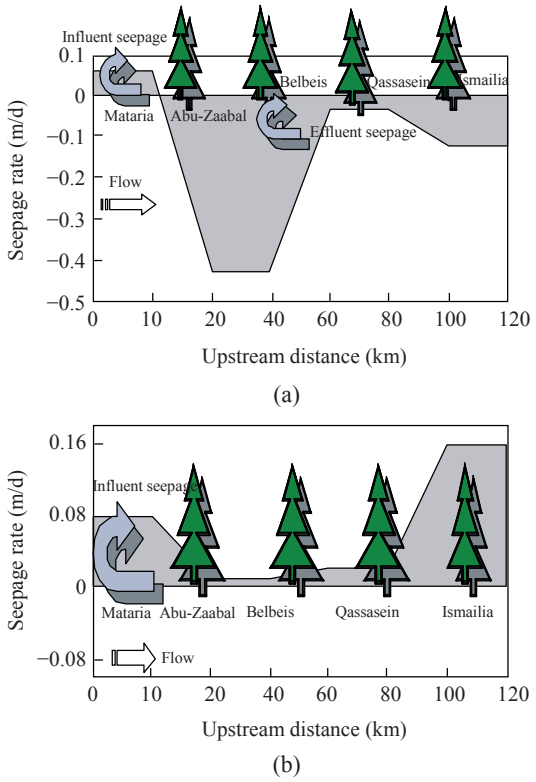

Fig.5 Seepage conditions along Ismailia Canal course. (a) Winter, 2007; (b) Summer, 2007

2. During summer season, the canal acted as influent stream along its whole course (Fig.5). The canal losses about 331950 m^3/d of its water flux during this season (3.7% of the canal flux). The maximum seepage rate (0.16 m/d) was recorded for the section between Qassasein and Ismailia, which is characterized by its sandy composition and low relief topography. The most influenced section by the effluent seepage was that from Abu-Zaabal to Belbeis at the upstream reaches (Fig.5), which is characterized by its sandy composition and high relief topography. A maximum seepage quantity of an order of 7.8% of the canal flux at this section is recorded.

3. Considering that the closing period continued only during January and February of the year, the canal will gain an amount of 24060000 m^3 from the surrounding shallow groundwater aquifers, while during the rest of the year, the canal losses about 99585000 m^3 of its water budget.

It is worth to mentioning that the seepage from or to the canal course greatly affects the quality of canal water where, during winter season (effluent seepage), water salinity increases and pollution rate is rapidly growing up, which negatively affects the drinking water treatment processes. Beside the aforementioned problem, it is expected that the areas around the downstream reaches of the canal will greatly suffer from water logging and salinization problems.

Quality of raw water

The analyses of raw water (canal water) indicated that most of the major ion concentrations are

below the maximum contaminant level (MCL) recommended by the Egyptian Higher Committee of Water (EHCW, 1995) and by the American Environmental Protection Agency (EPA, 2003). The most dominant major ion constituent order is Ca>Na>Mg and HCO_3>Cl>SO_4, along the upstream sector of the canal, and Na>Ca>Mg and HCO_3>SO_4>Cl, along the downstream sector. The general TDS trend shows a remarkable increase in concentration from upstream to downstream, with values ranging between 227~288 mg/L in summer and 284~415 mg/L in winter, respectively (Fig.6). This change in the canal water composition may reflect the interaction between the canal water and the shallow groundwater in the study areas, especially, during the winter season.

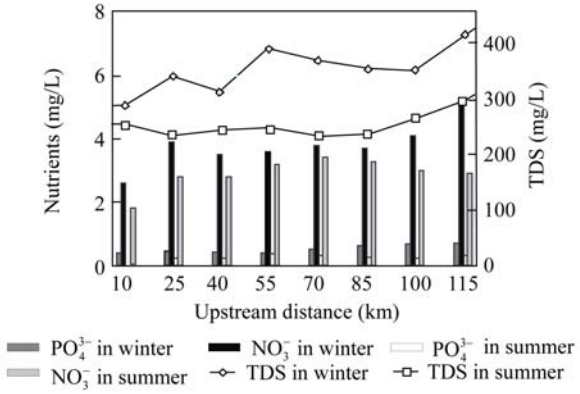

Fig.6 Changes of TDS and nutrients as pollutants indicators in Ismailia Canal water during the low stage winter and the high stage summer seasons

The microbiological analyses, carried out for the water intakes of the examined water treatment plants during the two seasons (Table 2) showed high total coliform bacterial counts in the sampled water, with values as high as 390 MPN (most probable number)/ml. There is a remarkable difference between the examined locations of the water treatment units. Samples collected from the intake of unit M1 along the upstream reaches (influent seepage) have the lowest bacterial count (105 MPN/ml). Generally, microbiological content increases along the effluent sections of the canal course.

Nitrates and phosphates are significantly increased during winter season, with mean concentrations of 3.4 mg/L. TOC showed abrupt increases during February 2007, due to the low stage level of the canal during this season (effluent conditions). TOC varied between 2.4 and 5.3 mg/L with an average value of 3.23 mg/L (Table 2). The higher values are recorded in the downstream reaches of the canal. TOC can impart an objectionable taste to water following slight chlorination due to the formations of THMs by-products.

The heavy metals analyses (Pb, Cd, As, Hg, Mn, Co, Ni, Cr, Zn and Fe) (Table 2) showed that all of the examined raw water samples have concentrations below MCL recommended by the EPA (2003) and by EHCW (1995), but their concentrations are obviously increased in tap water and some of them violate the MCL as will be discussed hereafter.

Quality of treated water

1. Nutrients

The measured nitrate concentration ranged from 1.8~5.1 mg/L. High nitrate contents were detected in both raw and treated waters at the downstream reaches in winter season. Phosphate also exists with high levels along this section. It ranges between 0.12 and 0.73 mg/L. This distribution of nutrient is highly conformable with the results obtained by flow measurements. The most effluent seepage parts of the canal have the higher nutrients contents. Another related problem arises from the presence of these contaminants, where it helps the microorganisms to be flourishing in the distribution system and appeared as a biofilm in all parts of the distribution system (pipes, reservoir walls and back of the tab filters).

2. Microbiology

Almost all the treated waters are free from coliform bacteria. However, along the distribution system, the analyses indicated that most of the examined drinking water samples are rich in total bacterial count (Table 2). Bacterial content increases in the distributary's network system, most probably due to the reverse leakages from the contaminated shallow groundwater during the cutoff periods of water pumping. Also, the existence of biofilms rich in nutrients is the best environments for growth of bacteria. Biofilms are a collection of microorganisms surrounded by the slim which formed by the growth of these microorganisms and attached to either an inert or living surface. Biofilms can also cause corroding water pipes, clogging water filters, causing rejection of medical implants, and harboring bacteria that contaminate drinking water (EPA, 2003).

A maximum bacterial count of 23 MPN/ml was recorded for the most distal parts of the distribution system at treatment plants M6 along the downstream reaches. It is evident from the field observations that the water discharge rates in this net are not regularly stable. There are many intermittent cut-off periods due to electricity blackouts. These cutoffs lead to hydraulic changes and facilitate the growth of bacteria. Also, there are some leakage problems in the network distribution system. Meanwhile regular clean up of these nets is not performed.

3. Heavy metals

Although the heavy metals in raw water supplies in most of the examined WTPs are of low concentration levels, most of these metals (^{111}Cd, ^{207}Pb, ^{66}Zn, ^{60}Ni, ^{52}Cr, ^{59}Co, ^{56}Fe and ^{55}Mn) are enriched during the treatment process (Table 2 and Fig.7). This could be attributed to the adsorption of these metals by the organic matter retained in these filters during low discharge rates. The increase uptake of the dissolved oxygen by bacteria, oxygen depletion causes basic changes in the redox environment in the filters materials that are rich in organic maters. Under such conditions, some of the former precipitated Fe-oxihydroxides may be dissolved and release their adsorbed heavy metal load into the water (Geriesh *et al*., 2004).

Table 2 Results of chemical and microbiological analyses related to the EPA and EHCW standards

Parameters		EPA standard	EHCW standard	Raw water			Finished water			Distribution system		
				No.	Range (Min~max)	Mean value	No.	Range (Min~max)	Mean value	No.	Range (Min-max)	Mean value
Physical and major constituents												
PH		6.5~8.5	6.5~9.2	16	7.7~8.2	7.9	−			16	7.2~7.9	7.6
TDS (mg/L)		500	1200	16	227~409	322	−			16	232~412	325
Sulfate (mg/L)		200	400	16	22~68	38.12	−			16	24~67	37.8
Chloride (mg/L)		200	500	16	14~80	29.87	−			16	16~84	30.32
N-nitrate (mg/L)		10	10	16	1.8~5.1	3.34	−			16	1.5~4.8	3.12
Phosphate (mg/L)		1	No index	16	0.12~0.67	0.39	−			16	0.11~0.56	0.37
Calcium (mg/L)		75	200	16	19~36	27.18	−			16	17~35	26.89
Magnesium (mg/L)		30	150	16	8~28	13.75	−			16	9~31	14.07
Sodium (mg/L)		No index	200	16	20~62	32.93	−			16	23~68	34.14
Trace and toxic constituents												
As (μg/L)	Winter	0	10	16	0.98~1.65	1.2	16	0.98~1.72	1.18			
	Summer				0~<1	<1		0~<1	<1			
Pb (μg/L)	Winter	0	10	16	0.65~3.76	1.4	16	1.06~6.23	1.98			
	Summer				1.37~5.88	3.1		1.44~13.8	4.0			
Fe (μg/L)	Winter	300	300	16	8.14~112	34.50	16	6.04~145	45.62			
	Summer				32~263	123		29~410	163			
Cd (μg/L)	Winter	5	10	16	0.09~0.56	0.31	16	0.18~2.52	0.74			
	Summer				0.065~0.13	0.12		0.057~0.27	0.13			
Mg (μg/L)	Winter	50	100	16	0.56~2.08	1.19	16	0.86~2.38	1.34			
	Summer				5.76~26.5	11.8		1.6~35.8	12.9			
Zn (μg/L)	Winter	50	50	16	9.8~97.4	33.96	16	12.8~112.6	51.78			
	Summer				1.95~12	12		1.68~32.2	11.8			
Cl (μg/L)	Winter	10	No index	16	0.19~0.34	0.25	16	0.31~0.48	0.48			
	Summer				0.43~2.03	1.05		0.5~1.46	1.16			
C (μg/L)	Winter	10	No index	16	0.03~0.12	0.061	16	0.05~0.17	0.09			
	Summer				>0.025			>0.025				
Al (μg/L)	Winter	50	No index	16	36~135	76.9	16	85.4~176	110.8			
	Summer				4.9~58.2	15.1		3.9~51.9	13.1			
Microbiological and organic constituents												
SPM (mg/L)		−	−	16	8~23	16.4	16	5.2~12.8	7.9	−		
Coliform (MPN/ml)		0.0	10	16	105~345	243	16	0	0	16	0~23	8
TOC (mg/L)		No index	No index	16	2.4~5.3	4.07	16	1.3~4.6	2.89	−		
Total THM (μg/L)		80	100	−			*16	52~112	84.81	16	35~101	73.68

*Pre-chlorination process

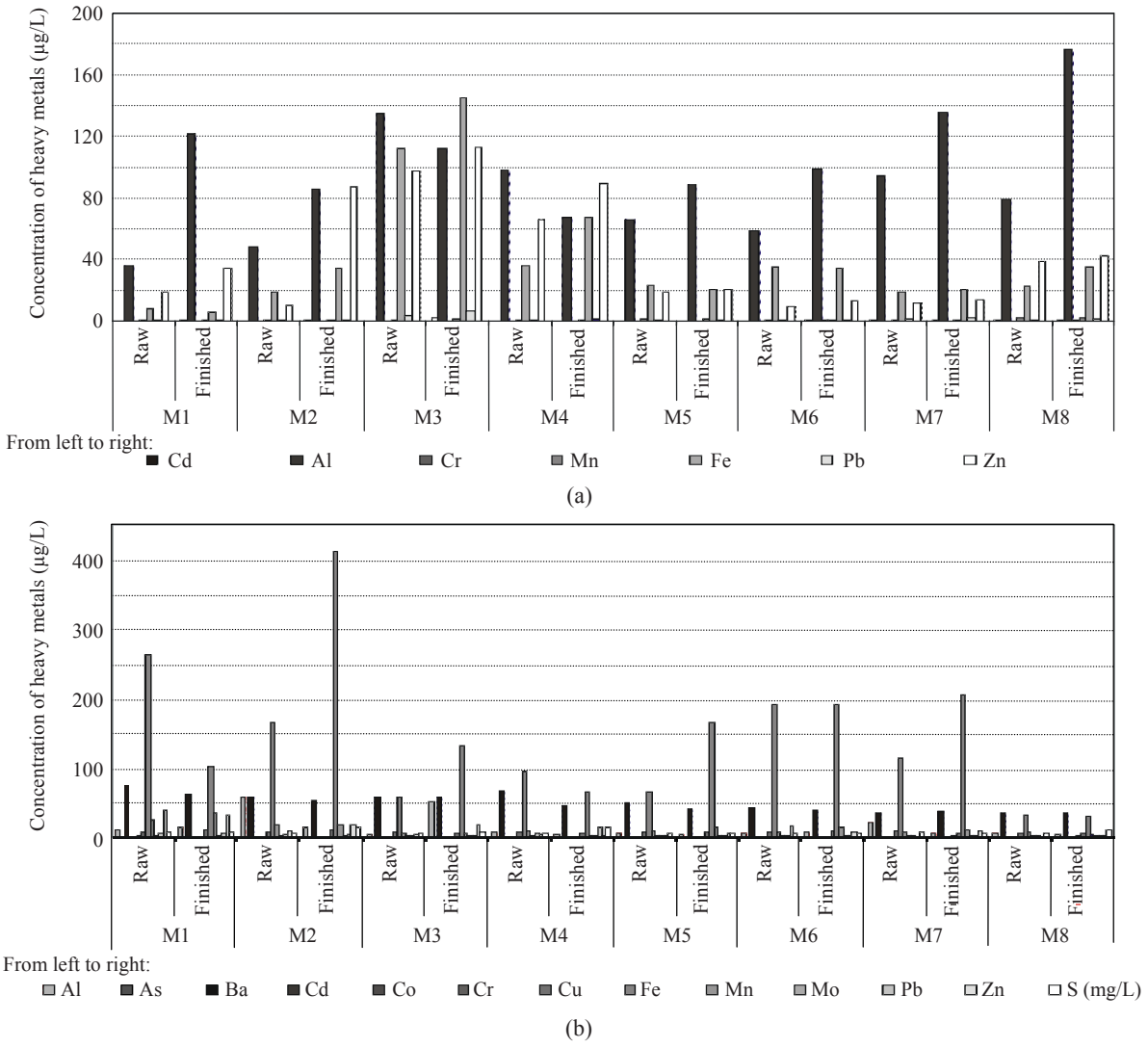

Fig.7 Enrichment of heavy metals during treatment works in the examined WTPs in winter (a) and summer (b) seasons

On the other hand, the chelating property of the organic humus in absorbing the dissolving ions is probably the most important role of humus and suspended particulate matters (SPM) with respect to living systems. By chelating the ions, they facilitate the uptake of these ions by several mechanisms, one of which is preventing their precipitation; another seems to be the direct and positive influence on their bioavailability (Habtamu, 2007).

However, some samples showed no significant changes during filtration processes. Among these is the plant M5, which is newly constructed with a large filtering area. It uses also good ventilation technique that has high capability to oxidize the organic matters and precipitate the heavy metal contents. However, none of the examined treatments plant has 100% filtering capacity to remove all the existing heavy metals.

It also could be noticed that heavy metals concentrations are higher in winter than in summer due to the effluent conditions of the canal during this season. Iron, manganese and lead show higher concentration in summer than in winter, which may be attributed to the digging activities to enlarge the canal course along the upstream area during sampling period, where the upstream area is characterized by iron rich soil and basaltic sheets.

Disinfectants by-products

1. Trihalomethanes (THMs)

Fortunately, chlorine disinfectants have com-

pletely eliminated from our life the risks of waterborne diseases such as typhoid fever, cholera, malaria and dysentery. However, the health benefit of chlorination has introduced some possible risks from the by-products of the disinfection process. If there is too much chlorine present, it can react with the organic matters to produce THM or damage the watering system by causing corrosion of distribution piping. On the other hand, if there is no enough chlorine available, bacteria in water will not be destroyed.

The most commonly found chlorine disinfection by-products species of THM are chloroform ($CHCl_2$), bromo-dichloromethane ($CHBrCl_2$), dibromo-chloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$), of which chloroform is the major component (Rook, 1974).

The concentration of the THMs in the examined water samples for both the pre-chlorination process (coagulation basins) and the finished water (treated water) in the distribution system of the eight examined water treatment plants are summarized in Table 3. From this table, it is noticed that the concentrations of THMs are remarkably increased during winter season in all of the examined treatment units, which may be attributed to the flourishing of microbiological life during this low stage of the canal water and increasing of the effluent income to its course. The THMs exceed the optimal EPA level (*MCL*=80 μg/ml) in the treated water during this season in five treatment plants (M2, M3, M4, M6 and M7). A detected maximum value of 112 μg/ml is recorded in the pre-chlorination process of unit M2 during winter season (Fig.8).

The obtained results also indicated that the concentration of THMs during the treatment process is higher than those recorded in the distribution system

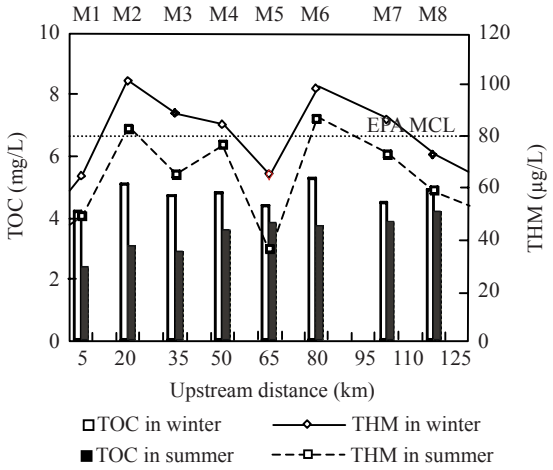

Fig.8 Changes of THM in the treated water in accordance with the changes of TOC of the raw water supply during the low stage winter and the high stage summer seasons

Table 3 Total Trihalomethanes (TTHMs) contents in the examined samples combined with TOC and Cl_2 dose

Water treatment plant ID	Date (Season)	WTP (pre-chlorination)			Finished water (filtered)			
		TOC (mg/L)	Cl_2 dose (mg/L)	TTHMs (μg/ml)	TOC (mg/L)	Filter efficiency (TOC reduction percent)	Cl_2 dose (mg/L)	TTHMs (μg/ml)
M1	Winter, Feb. 7	4.2	3.5	**85**	2.4	43	2.5	64
	Summer, July 7	2.4	3.5	52	1.3	46	2.5	48
M2	Winter, Feb. 7	5.1	3.0	**112**	4.1	20	3.0	**101**
	Summer, July 7	3.1	3.0	**91**	2.8	10	3.0	**82**
M3	Winter, Feb. 7	4.7	3.5	**97**	4.5	5	3.0	**88**
	Summer, July 7	2.9	3.5	78	2.4	18	2.7	64
M4	Winter, Feb. 7	4.8	3.5	**92**	3.0	38	2.6	**84**
	Summer, July 7	3.6	3.5	**84**	2.0	45	3.0	76
M5	Winter, Feb. 7	4.1	2.5	78	2.1	50	2.5	65
	Summer, July 7	3.8	2.5	58	1.7	56	2.4	35
M6	Winter, Feb. 7	5.3	4.0	**102**	4.6	14	3.0	**98**
	Summer, July 7	3.7	3.5	**97**	2.7	27	2.5	**86**
M7	Winter, Feb. 7	4.5	5.0	**92**	4.2	7	3.2	**86**
	Summer, July 7	3.9	3.5	**85**	3.2	18	2.5	72
M8	Winter, Feb. 7	4.9	3.5	**88**	3.0	39	2.7	72
	Summer, July 7	4.2	3.0	66	2.3	46	2.3	58

Figures marked in bold exceed EPA (2003) MCLs

(varied between 4% and 25%). This could be attributed to the high organic matter contents in the pre-chlorinated water. The relationship between THMs and TOC is significantly positive as shown in Fig.8.

It is inferred that the problem of THM formation is mainly related to the pre-chlorination processes in the treatment units and the excess TOC concentrations in the raw water supply system. Therefore, eliminating this process from the examined units is of significant importance to prevent THM formation.

2. Health risks impact

Presence of THMs in drinking water, especially chloroform, is of carcinogenic effect (IARC, 1991). Several studies (Brown, 1974; Wolf *et al*., 1977; EPA, 2003) suggested that chlorination by-products may be linked to heart, lung, kidney, liver, reproductive problems including miscarriage rate, and central nervous system damage.

When taken in total, the cancer evidence is probably the strongest among the possible reasons total trihalomethanes (TTHM) health risks. For these reasons TTHM in public water supplies are limited by EPA (2003) to 0.08 mg/L.

Lead can lead to infants and children delays in physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults can suffer kidney problems and high blood pressure; therefore, EPA reduces MCL of Pb into zero level.

Cadmium exceeding MCL can lead to kidney damage. Arsenic can lead to skin damage or problems with circulatory systems, and may have increased risk of getting cancer. Safe drinking water should be free of arsenic.

Problem solving facilities

1. Short term action

(1) Filtering

Filtration using fine sorts of tap filters could greatly reduce the SPM from the tap water that normally contains the highest load of adsorbed organic and heavy metals. Although this step is very important, it could not eliminate the dissolved toxic substances and disinfectants by-products such as THMs. It should also be noted that the filters will be clogged in a short time span and could be a good environment for growing new generations of bacteria and micro-organisms unless regular cleaning and washing is applied.

(2) Boiling and aerating

Boiling the water could eliminate the microbes and THMs, especially the most volatile chloroform species. Water should be boiled for few minutes and then leaved to be cooled and aerated in a room temperature. This method alone could not eliminate the SPM and consequently the high loads of the non-dissolved organic matters and the adsorbed heavy metals, but it may concentrate these metals and complicate the treatment process.

In a convenient way, it is recommended as a better than none, to apply filtering and boiling with aeration as a complete method to reduce the violations of SPM and the halogenated by-products.

2. Long term action

The reduction of TOC and SPM should be one of the central goals of any treatment plan to avoid the disinfectant by-products and eliminate the toxic heavy metals from the treated water as well. The only way to achieve this goal is to use a pre-filtering step in the purification process without adding any type of chemicals (natural attenuation). A proposed multi-barrier filtration system (Figs.9 and 10) is presented by this study to produce a safe drinking water supply. The system consists of four purification steps. The first step consists of three rectangular shaped pre-filtering gravelly sand basins, each of 50 m×100 m in dimension and 1.2 m in depth, completely isolated from ground bottom and connected to each other through tile drains of 0.5 m diameter. The drained water goes to the second filtering step (slow sand filtration basins). These basins contain fine to medium grained sands with bottomless base and 1.2 m filter thick. The slow filtering system consists of four parallel rectangular basins, 25 m×60 m each, as shown in Fig.10. Each of the considered basins has a water inlet weir to aerate the entered water. The water from the slow sand filtering basins can be collected through tiles drains (1 m thick) to a main collector and finally to the pump stations at which disinfectants can be added with a small dose to the public use directly. The recommended disinfectant agent should be chloride dioxide or chloramines to reduce the production of by-products. By this design, organic substances and SPM will be reduced and degraded in the top active microbial layer of the infiltration medium and

the subsequent underground passage. The combination of sedimentation, gravel pre-filtration, slow sand filtration and underground passage showed good elimination of parasite and complete elimination of coliform bacterial comparable to other highly expensive treatment processes (e.g., membrane filtration), under real operating conditions.

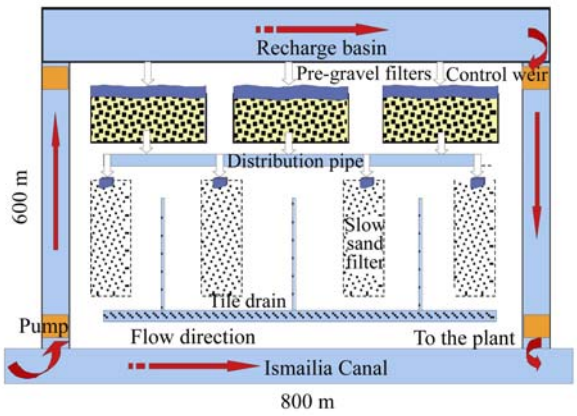

Fig.9 Proposed artificial recharge design

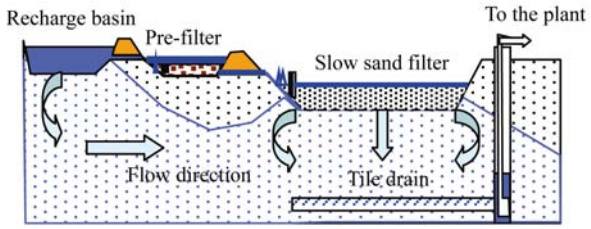

Fig.10 Cross section of the proposed artificial recharge design

The production rate will depend mainly on the selected gravel and sand sizes and the dimensions of the filtration basins. Taking into consideration the retention time, that should be quite enough to make the high efficiencies of the system (at least 30 d). This could be simulated and modeled in a laboratory scale before application (Skark *et al*., 2006).

The proposed design has been tested and applied in Germany for a hundred year. A good example is the treatment plant of Shwerte, Dortmund, northwest of Germany. Many studies (Hütter and Remmler, 2006; Hütter *et al*., 2006; Preuß and Nehrkom, 1996; Preuß and Schulte-Ebbert, 2000) proved the capability of this purification system to reduce most of the pathogenic microorganisms, completely removal of coliform bacteria, elimination of heavy metals and complete reduction of DOC and SPM. Moreover, it reduces the use of disinfectants chemicals and lowers the treatment costs.

However, the application of this purification system under a different climatic condition, such as that is prevailing in Egypt, should be tested and revised before application. So we strongly recommend starting putting the foundation of a field test site to ensure the applicability of the proposed design under the arid climatic conditions and then going to the production steps.

CONCLUSIONS AND RECOMMENDATIONS

The present treatment system for drinking water supply along Ismailia Canal Province does not meet the stringent safe drinking water regulations and could threat the consumers' health. It has low filtering efficiency (<60%), high pollutants violations, e.g., THMs, heavy metals enriched and microbes in the accompanied distribution system.

The instability of the canal flux during the year greatly contributes to the treatment regulations of the tested plants as it adds additional contaminants load from the surrounding agricultural environments during the low stage winter closing period of the High Dam gates. Therefore, steady flow on the canal water is recommended or protected zones along the effluent sections of the canal should be established.

Waste disposals from the seepage from the villages and septic tanks, distributed very close to the canal course and the agricultural effluent, are the major sources of contamination. In addition, the wide industrial zone along the upstream course of the canal enriches the canal water with high concentrations of heavy metals (especially Fe, Pb, Zn, As and Cd), where it exists on the worst effluent section of the canal course.

The reduction of TOC and SPM should be one of the central goals of any treatment plan to avoid the disinfectants by-products and eliminate the heavy metals from the treated water as well. The only way to achieve this goal is to use a pre-filtering step in the purification process without adding any type of chemicals (natural attenuation). A proposed multi-barrier filtration system is presented by this study to produce a safe drinking water supply. Howerver, it

should be tested and verified for application through a detailed field test site.

The drinking water consumers should be announced from their water public sector by adequate information or seasonal reports about their drinking water quality and the contaminants violation that exists, to decide whether they continue drinking it or not and what they can do to reduce the contaminants violation.

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