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Bank filtration for climate resilience: potentiality of a new site along the Ismailia Canal in Egypt

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Abstract

Bank filtration (BF) is a nature-based solution that can provide safe drinking water at a low cost, in being a green technology that benefits from natural ecosystem services and saves energy as well. The objective of the present paper is to evaluate the potentiality of a new site for bank filtration along a surface water source that experiences periods of both high and low flow. This site is located along the Ismailia Canal in the eastern Nile Delta fringe of Egypt. The present evaluation is based on exploratory drilling, installation of monitoring infrastructure and monitoring of both water level and water quality parameters for one year. The site has favourable hydrogeological conditions; the mean hydraulic conductivity of aquifer materials (sand and gravel) is 18.98 m/day. Moreover, there is a hydraulic connection between canal and aquifer; under steady conditions, the canal feeds the aquifer. Using different tracers, such as Cl, EC, Sr and SO_4, the average bank filtration share is in excess of 95%. BF has reduced the particulates (turbidity) by 96%, total coliform by 99 % and total organic carbon (TOC) expressed as ultra-violet absorbance at 254 wavelengths (UVA254) by 44%. In addition, BF reduces concentrations of disinfection by-products due to its ability to remove organic matter. The potential degradation of TOC in the canal bed sediments may cause the release of iron (Fe) and manganese (Mn) to the bank filtrate water; this process is exaggerated during low-flow periods. Compared to conventional water treatment, BF is a cost-effective green technology, because no chemicals are used and no waste products are generated.

Key words: Green technology, low flow, drinking water, water quality, residence time

1. Introduction

The River Nile is the main drinking water supply in Egypt (89.5%), while groundwater and desalination represent 10% and 0.5, respectively (CAPMAS, 2019). Conventional water treatment through sand filtration techniques, followed by chlorine disinfection, is generally used in Egypt. Nevertheless, surface water sources do suffer from contamination, which is why bank filtration would offer a low-cost and clean alternative for drinking water supply or at least provide a pre-treatment step.

Bank filtration (BF) removes and/or degrades surface water contaminants as the infiltrating water moves from the surface water body to the pumping well (Hiscock & Grischek, 2002). It is pumping a higher water quality than that directly withdrawn from surface water. Under appropriate circumstances, reliable BF systems can remove pathogenic and non-pathogenic micro-organisms, and many (but not all) organic (including taste and odour-causing substances) and inorganic compounds, suspended solids and turbidity (Weiss et al., 2003). Potential treatment processes at BF are the following: filtration, biodegradation, adsorption and redox reactions (De Vet et al., 2010; Nagy-Kovács et al., 2019). The efficiency of riverbank filtration treatments in vertical well types is much higher than that of horizontal wells with radial drains located about 5 m below the bottom of the river (Górski et al., 2018). The BF system is cost-effective; it can provide the intake and act as a pre-treatment step in hybrid drinking water production systems. However, it can serve as a standalone treatment step before disinfection (Ray et al., 2002). BF compensates for peaks of contaminant concentrations and shock loads and also provides a time buffer between a surface-water contamination event and the contaminated water reaching a water treatment plant, usually at a lower concentration (Kühn & Müller, 2000).

The water level of the River Nile is projected to decline in the foreseeable future owing either to the construction of the Grand Ethiopian Renaissance Dam or to consequences related to climate change. The drop of the River Nile water level (by 0.5-1.5 m) has a substantial effect on BF parameters (e.g., travel time, share of bank filtrate) in the onset operation of wells (Abdelrady et al., 2020). One hundred and twenty-eight agricultural and industrial drains discharge water with a high load of chemical pollutants to the river. The current conventional water treatment plants cannot produce drinking water with adequate quality owing to pollution of surface water systems (Shamrukh & Abdel-Wahab, 2011). The Egyptian government has recently relied on bank filtration (BF) as a robust and economical technique to produce drinking water (Shamrukh & Abdel-Wahab, 2008; Ghodeif et al., 2016, 2018; Wahaab et al., 2019).

In Egypt, five BF sites along the River Nile in Upper Egypt have been producing drinking water that meets the permissible limit of Egyptian drinking water standards. Nevertheless, it has been observed that Fe and Mn contents are slightly below the drinking water limit in Egypt which are 0.3 and 0.4 mg/l, respectively (Ghodeif et al., 2017). Other investigations of BF sites in Egypt have noted the same result from redox processes (Ghodeif, 2011; Abdalla & Shamrukh, 2016; Ghodeif et al., 2018).

The objective of the present study is to evaluate the potentiality of a new site for bank filtration application as well as climate resilience. However, the site is constructed along the Ismailia Canal which experiences both high and low flow periods. The site is located in the eastern Nile delta under arid climatic conditions. The present evaluation is based on exploratory drilling, installation of monitoring infrastructure and monitoring of both water level and water quality parameters for one year. The bank-filtrated water quality is compared with the national drinking water standards (EHCW, 2007).

2. Regional setting

The banks of River Nile in Upper Egypt have favourable hydrogeological conditions for bank filtration. The quality improvement during bank filtration is estimated to be very advantageous in terms of particulate matter such as algae, micro-organisms, as well as turbidity. Data on hydrogeological conditions along the River Nile and on the relevance of organic pollutants and trace substances in Egypt constitute valuable information for planning projects of bank filtration sites with respect to well construction and residence times (Ghodeif & Grischek, 2015).

The Ismailia Canal extends from the River Nile at Cairo to Ismailia at the Navigation Suez Canal (Fig. 1). It is the principal source of drinking water supply for a great number of Egyptian citizens (about 12 million inhabitants); however, the Ismailia Canal is exposed to several sources of pollution (Stahl & Ramadan, 2008; Ghodeif et al., 2013). The currently implemented conventional treatment processes have failed to remove several pollutants such as pesticides, organ-chlorinated compounds and parasites (Abdel-Shafy & Aly, 2002). Pollution of source water has reduced the efficiency of sand filters due to accumulation of micro-organisms and frequent clogging. Moreover, chlorine that is usually used for disinfection in conventional water treatment can react with organic compounds to produce disinfection by-products such as trihalomethanes (THMs). The situation gets worse during low-flow periods that become more frequent due to climate changes and building huge dams in upstream countries (Ghodeif et al., 2017; Abdelrady et al., 2020). Moreover, winter closure is practiced annually by the Ministry of Water Resources and Irrigation (MWRI) in order to regulate the flow in the River Nile and its main branches during the season of minimum water requirements. MWRI also dredges the Ismailia Canal bed on a quarterly basis.

Our detailed investigations have been carried out at the site of El-Mahsama along the Ismailia Canal, in the Wadi El Tumilat depression that is a low-lying land area covered by River Nile sediments (Fig.1). The shallow aquifer of Wadi El Tumilat is composed of sand and has good hydraulic properties (El Shamy, 1992). The Ismailia Canal is

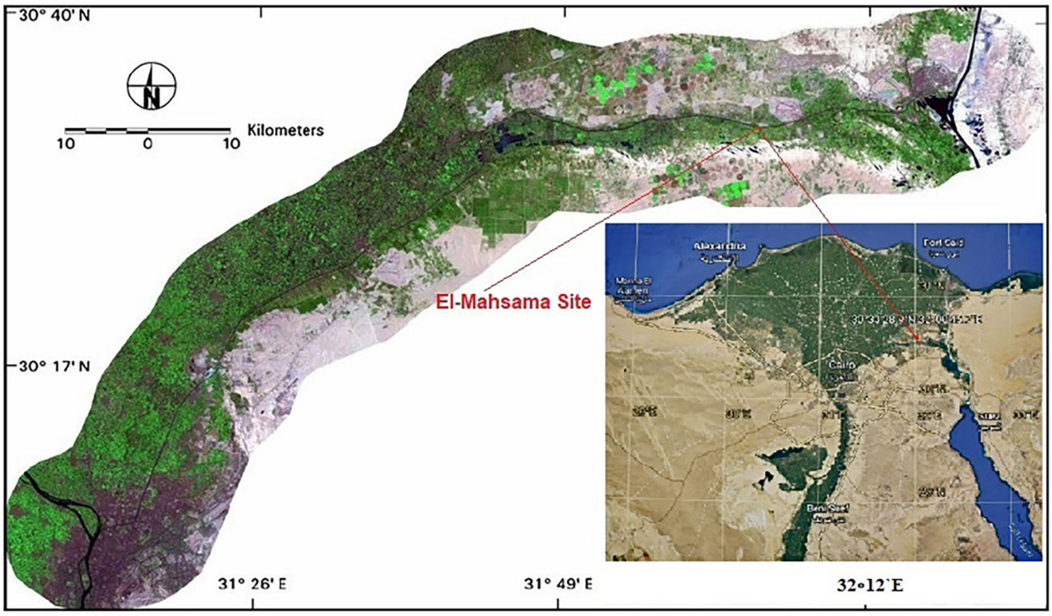

Fig. 1. Location map of the study area (El-Mahsama) along the Ismailia Canal (Eastern Nile Delta).

hydraulically connected to the aquifer and loses about 99.6 × 10^6 m^3 of its water budget to the aquifer (Geriesh et al., 2008).

3. Material and methods

3.1. Test site design

The main features and details around the selected site are shown in Figure 2. The site is located along the Ismailia Canal, some 30 km west of the city of Ismailia, and bounded by wetland and the El-Mahsama agricultural drain in the south. There are only few productive wells in the vicinity, used mainly for irrigation. The wells have a diameter of 100-200 mm and screens intervals are set at 12-18 m below ground level (m-BGL). Pumping wells are operated discontinuously depending on the time of day, crop rotation and irrigation technology with approximately 15 L/s.

During visual reconnaissance, favourable conditions for BF are indicated by the presence of alluvial

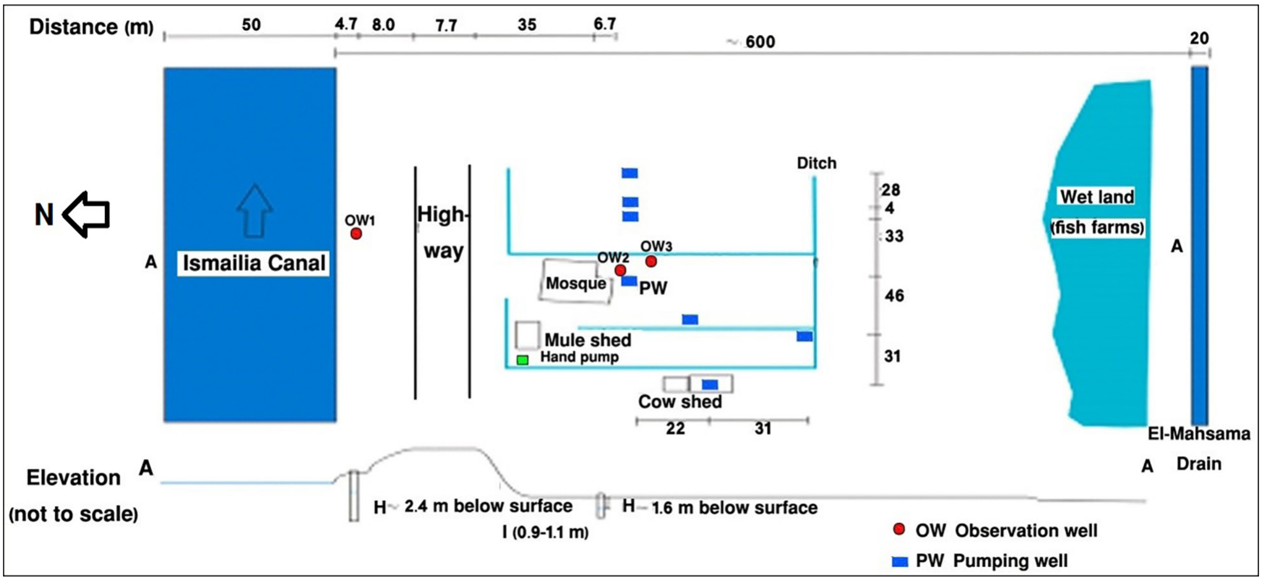

Fig. 2. Sketch showing locations of observation wells (OW) and pumping wells (PW) and other features around the site between the Ismailia Canal and El Mahsama Drain.

deposits and topographically relatively level land. Other factors to take into account are the presence of any existing wells near or on the riverbank which may already abstract some bank filtrate or can otherwise be used for monitoring water quality, landside wells to determine the quality of ambient groundwater, points of discharge of waste water into the rivers as a BF site should ideally be located upstream and site access (Ghodeif & Grischek, 2015).

3.2. Installation of monitoring wells at the selected site

Three monitoring wells have been installed at the El-Mahsama site, using the manual percussion drilling method. The drilled monitoring wells are distributed along the expected flow lines from the Ismailia Canal to landward groundwater. These monitoring wells are classified into the following categories: canal-side monitoring well (OW1), monitoring well near pumping well (OW2) and landside groundwater monitoring well (OW3). The distance between the monitoring well (of a total depth of 8 m and an inner diameter of 69 mm) (OW2) and the pumping well (PW) (Filter interval from 12 to 18 m-BGL, the inner diameter being 100 mm) is about 4 metres. The horizontal distance between the pumping well and the bank of the Ismailia Canal is about 50 metres.

3.3. Sampling and analyses of aquifer materials and water

Samples were collected from both the bed of the Ismailia Canal and aquifer material at the El-Mahsama site. Aquifer materials were collected from different depths during the drilling of the monitoring wells. Sieve analysis has been done for samples from the aquifer materials and cumulative curves were plotted. The hydraulic conductivity (K) for samples was calculated using both the Hazen approximation and Shepherd method for grain size analyses (Fetter, 2001). Water samples were monthly collected from March 2012 to May 2013. Sample collection, preservation, transportation and analysis were done according to standard procedures of the American Public Health Association (APHA, 2005) for water analyses. The water samples were collected from selected points of the Canal Bank filtration potential site (El Mahsama). They were divided into five samples that were collected from the following: the canal surface water, the canal-side monitoring well (OW1), landside groundwater monitoring well (OW3), the monitoring well near the pumping well (OW2) and the pumping well itself (PW). The field parameters that were measured include pH, dissolved oxygen (DO), electrical conductivity (EC) and temperature (T), by using the WTW-Multi-parameter instrument.

The major cations (Ca, Mg, K and Na) and anions (HCO_3, SO_4 and Cl) chemical analyses were carried out in the laboratory of the Geology Department, Suez Canal University, Egypt. Other analyses were done at HCWW Reference labs according to APHA standard methods for the examination of water and waste water (APHA, 2005). Event-based samples for specific parameters (Sr and DOC) were analysed at the Institute of Water Chemistry, TU Dresden, Germany.

3.4. Continuous monitoring for the canal BF system

Continuous monitoring for different well parameters was achieved through both data loggers and monthly field measurements. The three monitoring wells were equipped with data loggers (2-Baro-Diver); one worked as a barometer and the other as a diver for measuring pressure and temperature. The pressure was used as an indicator of water levels and pumping rates. One CTD diver was installed part-time in both canal-side monitoring well and landside groundwater monitoring well. The CTD diver measured electric conductivity (EC), pressure and temperature.

4. Results

Our results show the existence of a shallow, thin layer of clay at a maximum depth of 2.5 metres; the remainder of the section is composed of sand and gravel (Fig. 3). The total groundwater head refers to the existence of a hydraulic connection between surface water of the Ismailia Canal and groundwater at the El-Mahsama site. Transmissivity and storage coefficient were estimated using a pumping test and water levels in two groundwater monitoring wells (OW 2, OW 3); with T = 2.8 × 10-2 m^2/s and S = 0.0019. In recognition of a thickness of 100 m, a k-value of 2.8 × 10-4 m/s (24.2 m/day) was estimated.

Results of grain size analyses and estimation of hydraulic conductivity (K) for different samples at the El Mahsama site are presented in Table 1, indicating the correspondence of both Hazen and Shepherd methods of estimation of K at certain

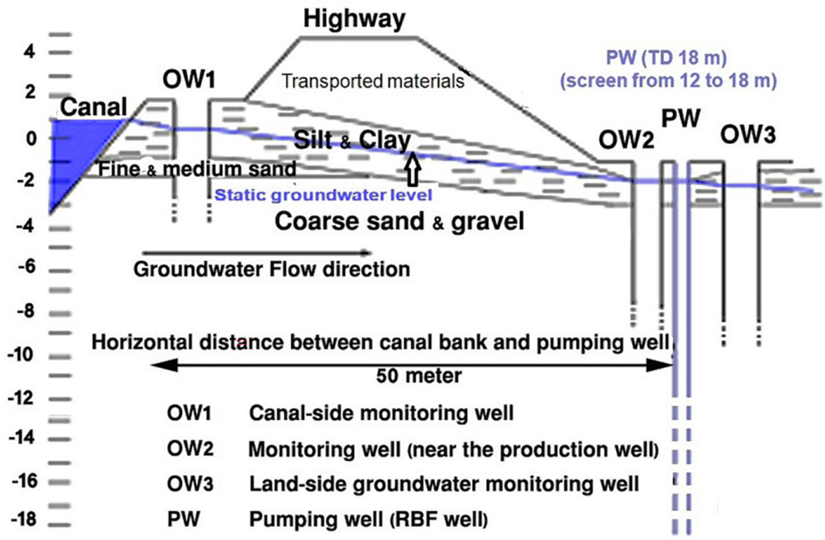

Fig. 3. Cross-section showing brief characterisation of hydrogeology and distribution of monitoring wells at the El-Mahsama site.

Table 1. Hydraulic conductivity (K m/d) for samples at the El Mahsama site.

Test site	Depth m	d_{10}	d_{50}	d_{60}	u d_{60}/d_{10}	Hazen m/d	Shepherd m/d
OW2	2.5	0.075	0.20	0.22	2.93	5.64	9.64
	4.0	0.100	0.25	0.26	2.60	10.02	13.94
	6.5	0.150	0.35	0.50	3.33	22.55	24.28
	8.0	0.100	0.20	0.30	3.00	10.02	9.64
OW3	4.0	0.090	0.35	0.48	5.33	8.12	24.28
	7–8	0.100	0.20	0.25	2.50	10.02	9.64
	9.0	0.124	0.38	0.40	3.23	15.41	27.81
OW1	3.0	0.050	0.09	0.10	2.00	2.50	2.58
	4.0	0.090	0.21	0.26	2.89	8.12	10.45
Aquifer drilling cuttings	4.0	0.090	0.35	0.70	7.78	8.12	24.27
	4.5	0.100	0.35	0.60	6.00	10.02	24.28
	7.0	0.150	0.22	0.29	1.93	22.55	11.29
	8.0	0.180	0.30	0.40	2.22	32.47	18.83
Mean K for the aquifer						12.70	18.29
	18.98 m/day						

depths but different at others. The Hazen method reveals hydraulic conductivity values for OW2 (near pumping well) sediments at a depth of 6.5 m to be 22.55 m/d, while the Shepherd method for the same depth gave a value of 24.28 m/d. The hydraulic conductivity for OW3 (landside groundwater) sediments at a depth of 9 m according to Hazen was 15.41 m/d, while Shepherd gave a value of 27.81 m/d. The hydraulic conductivity for OW1 (canal-side) at a depth of 4 m is 8.12 according to Hazen and 10.45 using the Shepherd estimation. The mean hydraulic conductivity of the aquifer materials is 18.98 m/day, which means that the aquifer is favourable for bank filtration from a hydrogeological point of view.

4.1. Water level monitoring

The water level was monitored at three monitoring wells (OW 1-3) either by data logger or taking manual measurements. The water level in the canal is measured by the MWRI (2013) at two surface water monitoring stations at Al-Salhia (25 km upstream) and at Ismailia, and data were extrapolated to the site location. Water level hydrographs are illustrated in Figure 4. The water level in the canal was above the water table. The groundwater flow direction is from the canal towards the extraction well. According to farmers in the area, the water table is consistently increasing and is particularly high after dredging the canal bed; this is done on a quarterly basis.

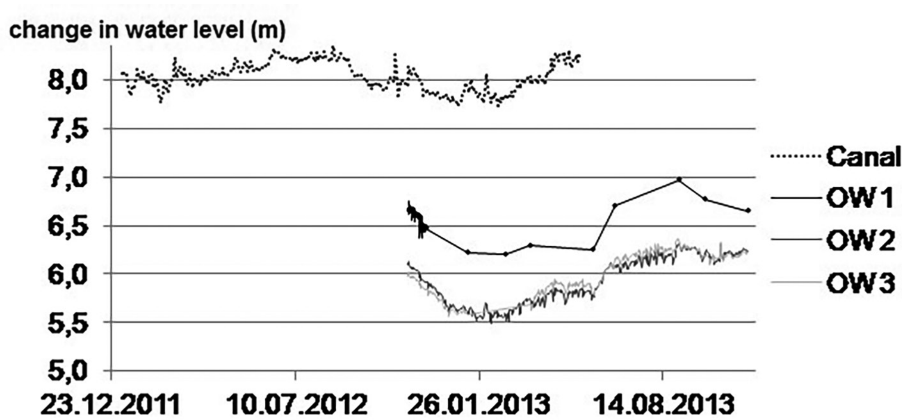

Fig. 4. Fluctuations of water levels in the Ismailia Canal (m) and observation wells at the site.

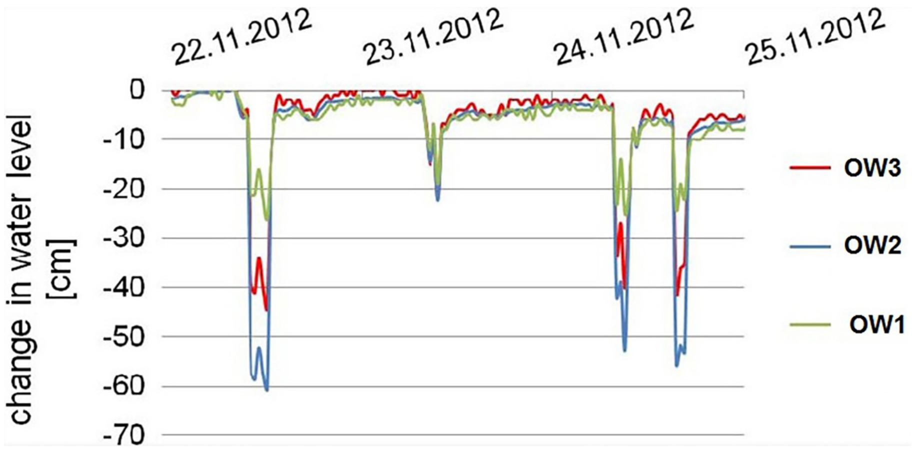

Fig. 5. The effect of well operation on the water level at three monitoring wells (OW1, OW2 and OW3).

The lowering of groundwater level by operation of the pumping well is shown at all measuring points at OW1-3 (Fig. 5). The decrease in OW2 (directly at the well) is greatest and extends to the diver canal (OW 1). Increasing the production rate causes greater a cone of depression in OW2; the water table is falling at OW1 even under low removal rates. This indicates a strong clogging of the streambed. Thus, the infiltration is limited and a higher withdrawal amounts would lead to unsaturated conditions below the bottom of the canal and possibly an undercutting of the canal.

4.2. Water quality and residence time

4.2.1. Water quality

Water from the Ismailia Canal comes from the River Nile, which means that water quality is similar and exceeds drinking water limit values for algae and bacteria indicators. Table 2 lists statistical results of water quality analyses for water from the Ismailia Canal, from observation wells (OW1, OW2 and OW3) and from pumping wells during the period between March 7, 2012 and November 14, 2013. The canal surface water and the pumped bank-filtrate water have similar salinities; the electric conductivity (EC) mean values are 376 and 399 μS/cm, respectively (Table 2). At the canal, the predominant major cations constituent order is Mg > Ca > Na and the most dominant anion order is HCO_3 > Cl > SO_4 during the summer season and Cl > SO_4 > HCO_3 during the winter season. These changes in ion patterns are due to low-flow periods and winter closure. Nitrate (NO_3) contents of the canal water ranged from 1.0 to 12 mg/L during the monitoring period. The major ion concentrations of the canal water and pumped bank-filtrate water are below the maximum contaminant level recommended by the Egyptian Higher Committee for drinking water (EHCW, 2007).

The pH values of water from the Ismailia Canal range from 7.8 to 8.6, while those for the canal BF well range from 7.3 to 7.9. This means that the surface water has an alkaline nature, the bank-filtrate water having a neutral trend. Water temperature is one of the most important characteristics of an

Table 2. Water quality as mean (MW), Min. and Max. at the El-Mahsama site during the period from March 7, 2012 to November 14, 2013. NTU – Nephelometer Turbidity Unit, DOC – Dissolved Organic Carbon, EC – Electrical Conductivity, n – number of samples.

Parameter		Canal				OW 1				OW 2				Pumping well				OW 3			
		n	MW	Min	Max	n	MW	Min	Max	n	MW	Min	Max	n	MW	Min	Max	n	MW	Min	Max
Turbidity	NTU	15	20.5	?	?									12	0.65	?	?				
T	°C	16	24.1	16.5	29.8	11	25.1	18.7	30.2	5	25.5	22.9	27.2	16	25.8	20.2	29.8	10	26.3	24.2	29.1
O_2	mg/l	15	8.6	3.9	11.6	11	1.4	0.1	8.6	5	0.6	0.3	0.9	16	1.6	0.1	5.1	10	0.7	0.1	2.1
pH	–	16	8.2	7.5	8.8	11	7.4	7.2	7.9	5	7.7	7.5	8.0	17	7.6	7.0	8.2	10	7.6	7.3	8.0
EC	µS/cm	15	376	271	465	10	471	375	620	1	409	344	473	16	399	325	493	10	393	345	444
Na	mg/l	2	30	25	36	1	44			1	32			2	27	19	35	2	25	22	29
K	mg/l	2	5	5	6	1	5			1	5			2	6	5	6	2	5	5	6
Ca	mg/l	2	35	35	36	1	53			1	44			2	46	38	54	2	36	33	40
Mg	mg/l	2	13	12	14	1	17			1	12			2	14	14	14	2	11	10	11
SO_4	mg/l	2	35	34	35	1	<10			1	36			2	36	29	42	2	27	24	30
NH_4	mg/l	6	<0.1	<0.01	0.1	2	0.1	<0.01	0.1	4	0.1	<0.01	0.2	4	0.05	<0.01	0.10	4	0.10	<0.01	0.1
Cl	mg/l	2	26	26	26	1	28			1	30			2	27	21	33	2	20	14	25
NO_3	mg/l	11	5	1	12	8	6	<2	12	4	6	<5	8	11	7	2	16	9	5	<2	19
HCO_3	mg/l	1	182											1	176			1	166		
Fe_{total}	mg/l	12	0.08	0.01	0.17	9	0.16	<0.02	0.30	4	0.18	0.10	0.25	12	0.18	0.09	0.37	9	0.09	<0.01	0.26
Mn	mg/l	1	0.1											1	0.21			1	<0.1		
Sr	mg/l	2	0.3	0.3	0.3									2	0.3	0.3	0.3				
DOC	mg/l	5	4.0	3.8	4.3	2	3.9	3.9	3.9	1	2.4			5	2.2	1.8	2.7	3	2.4	2.2	2.7
UVA_{254}	m^{-1}	5	6.1	5.7	6.6	2	6.8	6.6	7.0	1	4.0			5	3.4	2.6	4.4	3	4.4	3.9	5.4
Total coliform	Cfu/100 ml	4	820											3	1						
Algae total	Org/ml	3	4520											3	53						

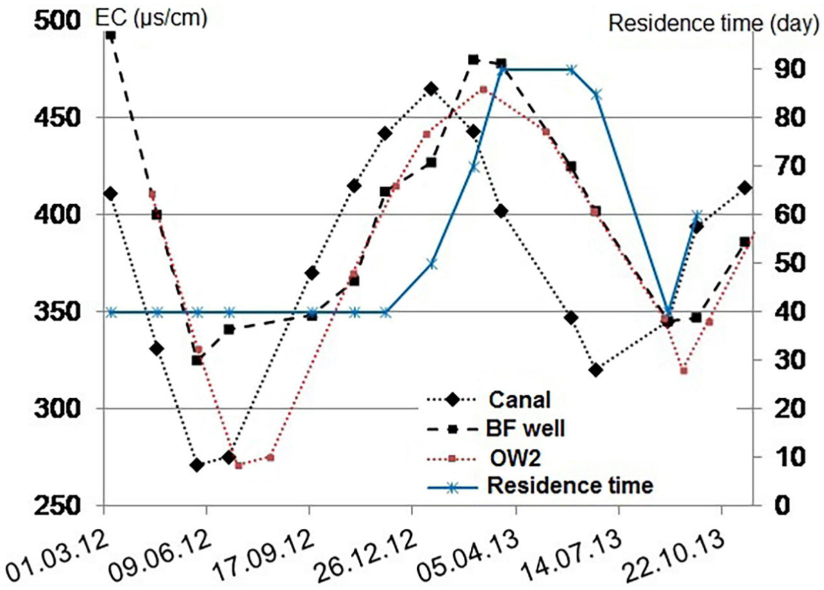

Fig. 6. Graphic determination of residence time.

aquatic system. It affects the dissolved oxygen levels where the solubility of oxygen in water decreases as water temperature increases. Moreover, it affects both chemical and biological processes, as well as solubility and reaction rates of chemicals. Temperature affects metabolism, growth and reproduction of micro-organisms (Sprenger et al., 2011). The temperature of surface water ranges from 16.5 to 29.8°C and for pumped water from 20.2 to 29.8°C. The mean value of dissolved oxygen in surface water is 8.6 mg/l and 1.6 mg/l for pumped water (Table 2). The main benefits of BF would be the removal of turbidity and reduction of total organic carbon. The mean turbidity value for both the Ismailia Canal and BF well is 20.5 and 0.65 NTU, respectively. The canal BF well shows the best results for removal of the turbidity, the efficiency exceeding 95%.

The specific absorbance (ultraviolet absorption) at 254 nm wavelength (UVA254) expresses the total organic carbon (TOC) contents (Reemtsma & Jekel, 2006). The variation of absorbance between surface water and the BF well reflects the higher content of total organic carbon in surface water than that in bank-filtrate water. It is a technically simple and fast method for determining natural organic matter, requiring neither expensive measurement equipment nor chemical reagents. In the Ismailia Canal, the absorbance values (UVA254) range from 5.7 to 6.6 m^{-1}, and dissolved organic carbon (DOC) from 3.8 to 4.3 (Table 2). In the BF well, the UVA254 values range from 2.6 to 4.4 m^{-1} and DOC values from 1.8 to 2.7 mg/l. The removal efficiency for dissolved organic carbon (DOC) in the BF well exceeds 40%. Organic compounds can impart an objectionable taste to water and cause the formation of trihalomethane species (THMs) by-products after disinfection with chlorine. The formation of THMs could be minimised by effective removal of organics from source water before disinfection (Reemtsma & Jekel, 2006). During the infiltration iron and manganese are reduced by the reduction of solid-TOC and go into solution. The heavy metal analyses for Mn and Fe showed that all water samples examined had concentrations below the maximum contaminant level for drinking water recommended by the Egyptian Higher Committee of Water (EHCW, 2007).

4.2.2. Residence time

Residence time was estimated from breakthrough curves of electric conductivity (Fig. 6). The electric conductivity along the Ismailia Canal has a seasonal cycle with the lowest values in the high-flow summer months from June to August. The measured electric conductivity in the canal has been shifted by the flow time (blue line) and is best adapted to the course of the measured electric conductivity in the BF well. From May 2012 to January 2013, the residence time was 40 to 50 days. In February, it rose to about 70 days and in March to about 90 days. With increasing canal water level, the residence time of June to August took between 40 and 90 days. The reason for the increase of residence time is still unclear. A possible explanation is that there is seasonal clogging of the streambed or a sunken groundwater gradient by flood irrigation. A decrease in residence time from June to August would be favoured by higher water levels in the canal or by dredging the canal bottom, which is done on a quarterly basis.

4.3. Bank-filtrate sharing

The efficiency of removal of suspended particles and pathogens in the simulated Canal BF system are significant and sufficient (Table 2). In order to evaluate the effectiveness and performance of the canal BF system, proportions of bank-filtrate water at the El Mahasama site have been calculated using electric conductivity (EC), chloride (Cl^-), sulphate (SO_4^{2-}) and strontium (Sr) tracers (Table 3). These tracers have been used because they are non-reactive and non-retarding; in addition, data on their distribution in aquatic environments are available.

Table 3. Bank filtrate share at the El-Mahsama site using various tracers.

Measuring point	EC (µS/cm)	SO_4^{2-} (mg/l)	Cl^- (mg/l)	Sr (mg/l)
Canal	376	34.5	25.8	0.3
BF Well	399	35.5	26.6	0.3
BF %	94	97	97	100

The bank filtration share (BF %) was calculated by using the mean value of conservative species (EC, SO_4^{-2}, Cl-, and Sr) and values for groundwater were not taken into account according to the following equation (Appelo & Postma, 1993):

$$BF\% = (X\_BF - X\_GW) / (X\_SW - X\_GW) \times 100$$

where: BF% – bank filtrate share in%, XBF- concentration in bank filtrate, XSW-concentration in surface water, XGW-concentration in groundwater.

The results show that the bank-filtrate share reaches 94%, using the EC (µS/cm), 97 % using Cl- and SO_4^{-2}(mg/l) and 100% using Sr (mg/l) as tracers. Due to the exfiltration flow conditions (the canal being a naturally recharging aquifer), a high proportion of bank filtrate is plausible.

5. Conclusions

The present paper assesses the potentiality of applying bank filtration (BF) along the Ismailia Canal as a new green technology to provide drinking water with climate resilience. The site was designed and three observation wells were distributed along the expected flow lines from the Ismailia Canal to the pumping well and landward groundwater. The observation wells were instrumented with data loggers (Baro and CTD divers) for continuous monitoring of water levels, water temperature and electric conductivity. Drilling results show the existence of a shallow, thin layer of clay at a maximum depth of 2.5 metres below ground surface and the remainder of the section is composed of sand and gravel facilitating the hydraulic connection between canal and aquifer. Moreover, the total groundwater head refers to the existence of a hydraulic connection at the investigated site (El-Mahsama). Water level measurements at the three observation wells indicate the presence of drawdown in all observation wells; the amplitude decreases with increasing distance from the pumping well. Drawdown underneath canal induces infiltration from the Ismailia Canal bank and bed. Canal BF proves the efficiency for the removal of suspended matters and pathogens even during periods of low flow. Moreover, BF has reduced concentrations of organic matter by 40%, which is considered a main cause for the formation of disinfection by-products after chlorination. This site has proved its ability to produce drinking water with more than 95% bank filtrate even at low-flow periods. Furthermore, canal bank filtration has the potentiality to reduce the total cost, compared to traditional water treatment plants. BF is a simple and low-cost green technology. There is no waste generated from BF, which gives it an environmental advantage and offers climate resilience.

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