Prediction and evaluation of natural self-restoration of the water of Mahmoudiya canal, western part of Nile Delta, Egypt

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Abstract: The objectives of this paper are to study the effect of discharge of Zarqun drain into Mahmoudiya canal on the natural self-purification along the canal stream and to suggest and simulate different scenarios to improve the water quality of the Mahmoudia canal system to safely discharge water of Zarqun drain into it. Natural self-purification model based on oxygen sag curve introduced by Streeter and Phelps has been applied in two cases; the first is the current situation case, where no drainage water is discharging into the canal because of Edko Irrigation Pumping Station stops lifting drainage water from Zarqundrain into the canal. The second case provides additional safe reuse water through lifting drainage water from Zarqundrain into the canal using Edko Irrigation Pumping Station. The result of this case will determine the required canal length to achieve self-purification. Different scenarios will be designed to simulate different conditions of the water quality system improvement. The best scenario has been stated and detailed and recommendations have been done.

Keywords: Mahmoudia canal; oxygen sag curve; dissolved oxygen deficit; natural self-purification; Egypt.

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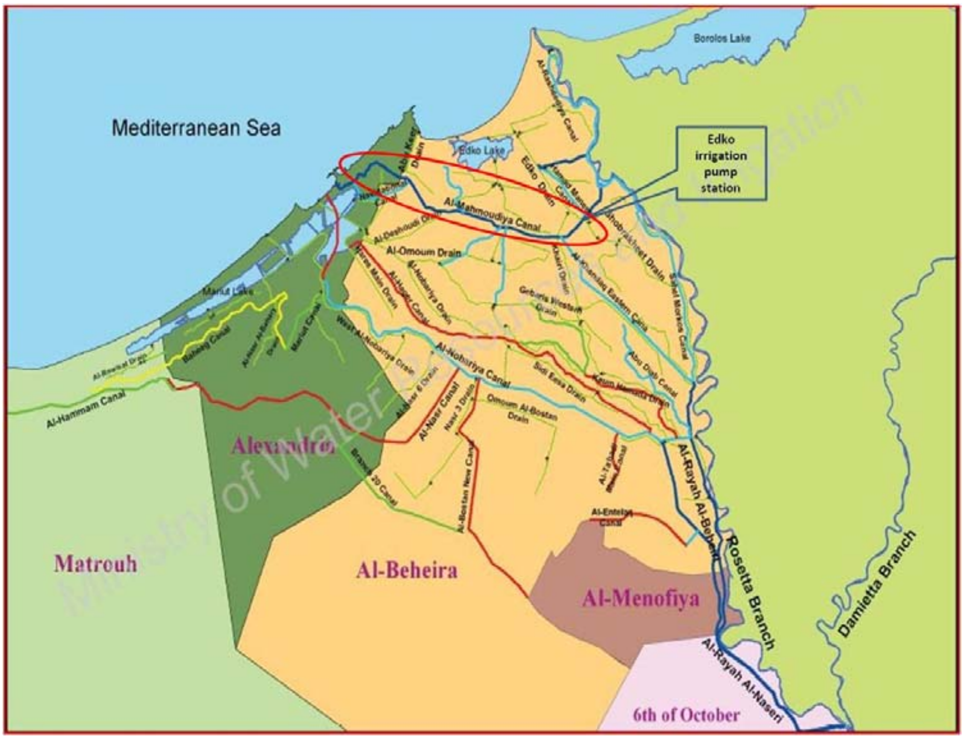
1 Introduction

Mahmoudia canal, on the Northern edge of Baheira Governorate, west part of Nile Delta, has an important role in the economic development and prosperity of the people in

Baheira and Alexandria Governorates. Mahmoudia canal is located at the northern edge of Baheira Governorate. The canal off-take from Rosetta branch is at 194,200 km. The actual served area of the canal is 130,200 hectares. The total length of the canal is 77,170 km and there are seventy small canals that branch off this canal. Mahmoudia canal has three sources of water; two fresh water sources which are from the Rosetta branch via El-Atf Pumping Station at the head of the canal, and Khandak ElSharky canal at 13,200 km on Mahmoudiya Canal. The third is drainage water from Zarqun drain at 8,500 km on the canal via Edko Irrigation Pumping Station which is lifting part of Zarqun drain water into the canal.

The canal receives pollutants from point and non-point sources (El-Gamal et al., 2009; Masoomullah, 2010). These pollutants led to significant deterioration of the water quality in the canal. The point source of pollutants is Edko drain in Baheira Governorate which supplies Mahmoudiya canal with drainage water in order to cover irrigation needs along the canal and drinking water for Alexandria city. The intake of the water treatment plant of Alexandria and many water treatment plants of Baheira Governorates are the downstream of these mixed three sources (Figure 1). The water treatment plants which are feeding by Mahmoudia canal are listed in the Table 1. In Alexandria, water supply companies are producing various amounts of water in different seasons. In summer, due to huge number of tourists, the water demands increase and thus the production too.

Figure 1 Mahmoudia canal (see online version for colours)



Source: Ministry of Water Resources and Irrigation (2005)

Table 1 Water supply companies which feeding by Mahmoudia canal

Governorate	*Water treatment plant*	*Production (m^3/day)*
Baheira	Algadih*	25,000
	Ficha*	25,000
	Monchat Nassar	25,000
	Abou Hommos	100,000
	Com Alkuenatur	250,000
	Kafr El-Dawar	100,000
Alexandria	Al-Sayouif	970,000
	Al-Mamoura	240,000
	Bab Sharki	630,000
	Al-Manshia	420,000
	Forn el garia	50,000
	Al-Nozha	200,000

Note: *Before Edko irrigation pump station discharge

Source: Baheira Water & Drainage Company (2011) and Alexandria Water Company (2011)

Several studies showed that Mahmoudiya canal are suffering from the negative effects of non-point pollution sources (El-Gamal et al., 2009; Masoomullah, 2010).

The dissolved oxygen (DO) concentration is a primary measure of a stream's health. Many water streams in Egypt have suffered from DO deficit, which is very critical to aquatic life (Elsokkary and AbuKila, 2012).

Water quality modelling in a river has developed from the pioneering work of Streeter and Phelps (1925) who developed a balance between the DO supply rate from reaeration and the DO consumption rate from stabilisation of an organic waste in which the biochemical oxygen demand (BOD) deoxygenation rate was expressed as an empirical first order reaction, producing the classic DO sag model. This developed balanced was really a great achievement when Streeter and Phelps, in 1925, were able to propose a mathematical equation that demonstrates how DO in the Ohio River decreased with downstream distance due to degradation of soluble organic BOD by considering a first order of degradation reaction at a constant river velocity (Yudianto and Yuebo, 2008).

This study was initiated with the objective of studying the effect of the discharge from Zarqun drain into Mahmoudia canal on the natural self-purification along the canal and to suggest and simulate different scenarios to improve the water quality of the Mahmoudia system.

2 Materials and methods

2.1 Determining natural self-purification of Mahmoudia canal

The used natural self-purification model consisted of five measures. These five measures are described as follows:

1 *DO saturation, DO_{sat}* represented values of various water temperatures which have been computed using the American Society of Civil Engineering Committee on Sanitary Engineering Research (1960) formula, as follows:

$$DO_{Sat} = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \quad (1)$$

where

DO_{sat} DO saturation concentration, mg/l

T water temperature, °C.

The DO_{sat} concentrations generated by this formula must be corrected for differences in air pressure caused by air temperature changes and for elevation above the mean sea level (MSL).

The correction factor has been calculated according to equation (2).

$$f = \frac{2{,}116.8 - (0.08 - 0.000115A) \times E}{2{,}116.8} \quad (2)$$

$$\textit{The corrected } DO_{sat} = \textit{output equation}_1 \times \textit{output equation}_2 \quad (3)$$

where

f correction factor for above MSL

A air temperature, °C

E elevation of the site, feet above MSL.

Because elevation of Mahmoudia canal is between 0 to less than 2 metres above the MSL, *the equations (2) and (3) are neglected*.

2 *Ultimate BOD_5, L_a:* The BOD test measures:

- the molecular oxygen consumed during a specific incubation period for the biochemical degradation of organic matter (carbonaceous BOD_5)
- oxygen used to oxidise inorganic material such as sulphide and ferrous iron
- reduced forms of nitrogen (nitrogenous BOD_5) with an inhibitor (trichloromethyl pyridine).

If an inhibiting chemical is not used, the oxygen demand measured is the sum of carbonaceous and nitrogenous demands, so-called total BOD_5 or ultimate BOD_5. Ultimate BOD_5 can be computed according to Lee and Lin (2000) which were calculated by using equation (4).

$$L_a = BOD_5 \times 1.46 \quad (4)$$

where

L_a ultimate BOD_5, mg/l.

3 *Streeter-Phelps oxygen sag formula:* The method most widely used for assessing the oxygen resources in streams and rivers subjected to effluent discharges is the Streeter-Phelps oxygen sag formula that was developed for use on the Ohio River in 1914. The well-known formula is defined as follows (Streeter and Phelps, 1925).

$$D_t = \frac{k_d \times L_{aU}}{k_2 - K_d}\left(10^{-k_d t} - 10^{-k_2 t}\right) + D_a 10^{-K_2 t} \tag{5}$$

where

D_t DO saturation deficit downstream, mg/l ($DO_{sat} - DO_a$) at time t

t time of travel from two points, days

D_a initial DO saturation deficit of upstream water, kg/day

L_{au} ultimate upstream BOD (BOD_5), kg/day

k_d de-oxygenation coefficient to the base 10, per day

k_2 re-oxygenation coefficient to the base 10, per day.

4 *De-oxygenation rate, (k_d):* The Streeter-Phelps oxygen sag equation is based on two assumptions:

- at any instant the de-oxygenation rate is directly proportional to the amount of oxidisable organic material present
- the re-oxygenation rate is directly proportional to the DO deficit.

According to Lee and Lin (2000), mathematical expressions for k_d was calculated according to equation (6).

$$k_d = \frac{1}{\Delta t}\log\frac{L_{au}}{L_{ad}} \tag{6}$$

where

k_d de-oxygenation rate, day

Δt time of travel from upstream to downstream, days

L_{ad} ultimate downstream BOD (BOD_5), mg/l.

The k_d values are needed to correct for stream temperature according to equation (7)

$$k_{d@T} = k_{d@20} \times (1.047)^{T-20} \tag{7}$$

k_d value at any temperature T °C and $k_{d@20} = k_d$ value at 20.

Because BOD_5 has determined laboratory at 20°C so equation (7) does not used.

5 *Re-oxygenation rate, k_2:* According to Lee and Lin (2000), mathematical expressions for k_d can be calculated according to equation (8).

$$k_2 = k_d\,\frac{\overline{I}}{\overline{D}} - \frac{\Delta D}{2.303\Delta t\overline{D}} \tag{8}$$

where

k_2 re-oxygenation rate, day

$\overline{L}$ average ultimate BOD_5 load upstream and downstream (kg/day)

$\overline{D}$ average DO deficit load upstream and downstream (kg/day)

ΔD difference DO deficit upstream and downstream (kg/day).

The k_2 values are needed to correct for stream temperature according to equation (9)

$$k_{2@T} = k_{d@20} \times (1.02)^{T-20} \quad (9)$$

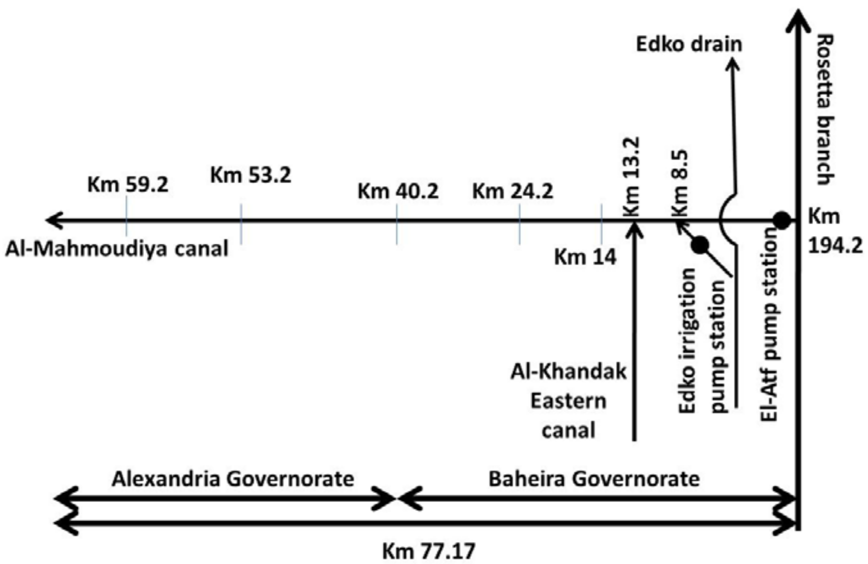
k_2 value at any temperature T °C and $k_{2@20} = k_2$ value at 20°C.

Because BOD_5 has determined laboratory at 20°C so equation (9) not use.

2.2 Applying natural self-purification model of Mahmoudia canal

Natural self-purification was calculated for the reach from Km 14 to 59 subsequent to Edko Irrigation Pumping Station and Khandak ElSharky canal discharge at 8.5 km and 13.20 km, respectively (Figure 2).

Figure 2 Schematic diagrams of the measured water samples



Natural self-purification was applied in two cases:

1 the first was current situation case, where Edko Irrigation Pumping Station is stopped; hence it has been stopped since June, 2009

2 the second case provides additional safe reuse water through lifting drainage water from the Zarqun drain into the canal using Edko Irrigation Pumping Station.

3 Results and discussion

Based on accomplishing the designed methodology, results were obtained, analysed and are presented here, as follows:

3.1 Assessment of water quantity which feeds

According to Egyptian Ministry of Water Resources and Irrigation, the quantity of 3.360 billion m^3/year has been discharged into Mahmoudia canal (Table 2) from both Rosetta branch (194.0 km) via El-Atf Pumping Station at the head of the canal and via Khandak ElSharky canal at km 13.200 on Mahmoudia canal and the third water source is the drainage water from Zarqun drain at 8,500 km on Mahmoudia canal via Edko Irrigation Pumping Station which lifts part of Zarqun drain into the canal.

Table 2 Water Resources lifted by El-Atf Pumping Station and Al-Khandaq Eastern canal

Month	*Discharge (billion m^3/month)*	
	El-Atf Pumping Station	*Khandak ElSharky canal*
May, 2010	0.313	0.047
Jun, 2010	0.329	0.045
Jul, 2010	0.372	0.047
Aug, 2010	0.347	0.047
Sep, 2010	0.288	0.045
Oct, 2010	0.240	0.047
Nov, 2010	0.197	0.045
Dec, 2010	0.148	0.047
Jan, 2011	0.078	0.047
Feb, 2011	0.131	0.042
Mar, 2011	0.140	0.047
Apr, 2011	0.228	0.045
Total	2.813	0.548
	3.360	

It is worthy to note that Edko Irrigation Pumping Station has been stopped since June, 2009 due to water quality problems. This is because many drinking water intakes located on the downstream of the mixing point.

3.2 Assessment of water quantity which feeds Mahmoudia canal

3.2.1 Mahmoudia canal (km 0.0)

Process the following characteristics:

1 The pH values of the waters are within the permitted standard range (pH 7–8.5) (FAO, 1985).

2 The concentrations of TDS in the waters verity between 281 and 546 mg/l.
No health-based guideline value for TDS has been proposed by World Health Organization (WHO, 2008). However, the palatability of water with a TDS level less than 600 mg/l is generally considered to be good for drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than 1,000 mg/l (WHO, 2008). The quality of irrigation water is defined by the type and the concentrations of dissolved salts and substances. The most significant ions are the

cations of calcium, magnesium, sodium and the anions of carbonate, sulphate, and chloride. They are apart from the absolute concentrations of ions, Loukas (2010). The quality criteria of irrigation water have deducted from Food and Agricultural Organization (FAO, 1985) regulations for three hazard categories:

a no problems

b gradual increasing problems from the continuous use of water

c immediate development of severe problems.

The water quality for irrigation use according to these criteria indicates that there is no problem when Mahmoudia canal water is used for irrigation.

3 The concentrations of TSS in the waters varied from 1.10 to 5.80 mg/l.

4 The median value of DO concentrations is 5.62 mg O_2/l and this indicates that pollution loading is depleting oxygen levels.

5 The median values of BOD_5 and COD concentrations are 18 mg/l BOD_5 and 29 mg/l COD. Which are reflecting the high organic load in water of Mahmoudia canal is a part from Rosetta branch.

6 The nitrate (NO_3) and ammonia (NH_4) concentrations were within the permissible limits (<10 and <5, respectively) according to FAO (1985).

7 Fecal coliform counts exceeded the WHO (1989) Guidelines (1,000 CFU/100) ml in almost all waters hence, the median was 3,050 CFU/100 ml. This is an indication of the discharge of human wastes in Mahmoudia canal through Rosetta branch.

According to United States Agency for International Development (2003), Rosetta Branch, starting downstream of Delta Barrage, receives relatively high concentrations of organic compounds, nutrients and oil and grease. The major sources of pollution are Rahawy Drain which receives part of Greater Cairo wastewater, Sabal Drain, El-Tahrrer Drain, Zawiet El-Bahr Drain and Tala drain. At Kafr El-Zayat, Rosetta branch receives wastewater from Maleya and Salt and Soda Companies.

This indicates that the majority of water quality problems is occurring in the intake of Mahmoudia canal due to receive low-grade water quality from Rosetta Branch.

3.2.2 Outfall of Khandak ElSharky canal

The Khandak ElSharky canal has discharged at 13,200 km in Mahmoudia canal. The water quality of this canal can be summarised as follows:

1 The pH values of the waters are within the permitted standard (FAO, 1985).

2 The concentrations of TDS are less than those in Mahmoudia canal and the maximum concentration is 317 mg TDS/l.

3 The concentrations of TSS in the waters varied from 2.95 to 9.5 mg/l.

4 DO concentrations ranged from 5.17 to 7.31 mg/l.

5 The median values of BOD_5 and COD concentrations are 11 mg/l BOD_5 and 19 mg/l COD which are reflecting the organic load received in Khandak ElSharky canal.

6 The NO_3 and NH_4 concentrations were within the permissible limits (<10 mg/l and <5 mg/l, respectively) according to FAO (1985).

7 Fecal coliform counts exceeded WHO (1989) Guidelines of 1,000 CFU/100 ml in almost all water and the median is 2,550 CFU/100 ml. This is an indication of the discharge of human wastes into Khandak ElSharky canal.

The mixing of the drainage water at Etay El-Barud Pumping Station on Khandak ElSharky canal lowered water quality of Khandak ElSharky canal downstream of the point of re-supply. More water with high pollution load results in worse water quality. This reproduces high concentrations of BOD_5, COD, total coliform and fecal coliform. However, the concentration of contaminates in water of Khandak ElSharky canal were less than those of Mahmoudia canal.

3.2.3 Zarqun drain

Zarqun drain discharges its water at km 8.500 of Mahmoudia canal via Edko Irrigation Pumping Station which is lifting part of Zarqun drainage water into Mahmoudia canal. As previously mentioned, Edko Irrigation Pumping Station has been stopped since June, 2009 up till now. The water quality of this drain can be summarised as follows:

1 The pH values of waters are within the permitted standard (FAO, 1985).

2 The concentrations of TDS in water varied from 537 to 1,074 mg/l. It is less than the maximum limit (2,000 mg/l) according to FAO (1985).

3 The concentrations of TSS in the waters varied from 7 to 5.5 mg/l.

4 DO concentrations ranged from 0.37 to 3.80 mg/l which indicates high pollution loads in the drain.

5 The median values of BOD5 and COD were 29 mg BOD_5/l and 48 mg COD/l.

6 NO_3 concentrations were within the permissible limits (<10) except in July, 2010 which was 11 mg NO_3-N/l.

7 NH4 concentrations were within the permissible limits (<5) according to FAO (1985).

8 The median count of fecal coliform was 7,750 CFU/100 ml. This is an indication of the discharge of human wastes into Zarqun drain.

According to United States Agency for International Development (2003), Delta drains are mainly used for discharge of predominantly untreated or poorly treated wastewater (domestic and industrial), and for drainage of agricultural areas. As a result, they contain high concentrations of various pollutants such as organic compounds (BOD5, COD), nutrients, fecal bacteria, heavy metals and pesticides. This explains the increased concentrations of BOD_5, COD and fecal coliform.

3.3 Evaluation natural self-purification in Mahmoudia canal

Natural self-purification is calculated for the reach from 14 km to 59 km subsequent to Edko Irrigation Pumping Station and Khandak ElSharky canal discharge at 8.5 km and 13.20 km, respectively (Figure 2). Tables 3 to 6 represent an example of calculation of natural self-purification using the dataset for the reach from 14 km to 59 km.

Table 3 Measured hydraulic data of the stream

Case	Q_{14} (m^3/month)	Q_{59} (m^3/month)	Q_{14} (m^3/sec)	Q_{59} (m^3/sec)	Q_a (m^3/sec)	*V* (m/sec)	*V* (Km/h)
1	273,232,200	135,910,683	105.41	52.43	78.92	0.99	3.56
2	286,232,200	148,910,683	110.43	57.45	83.94	1.04	3.74

Notes: Q_{14} = Q at 14 km; Q_{59} = Q at 59 km; $Q_a = 0.5\ (Q_b + Q_e)$; V = velocity.

Table 4 Measured field and laboratory chemical characteristic data of the stream

	Temp °C	BOD_5 (mg/l)	BOD_5 (kg/day)	L_a (kg/day)	DO_{sat} (mg/l)	*DO* (mg/l)	*DO deficit* (mg/l)	*DO deficit* (kg/day)
Case 1								
$\text{Upstream}_{\text{Km14}}$	24.44	16.67	151,826	221,666	8.2640	5.59	2.67	24,354
$\text{Downstream}_{\text{Km59}}$	24.47	14.52	65,781	96,040	8.2592	5.52	2.74	12,410
Case 2								
$\text{Upstream}_{\text{Km14}}$	24.44	17.22	164,297	239,874	8.2640	4.91	3.35	32,001
$\text{Downstream}_{\text{Km59}}$	24.47	15.24	75,647	110,444	8.2592	4.61	3.65	18,114

Notes: $BOD_5\ (\text{kg/day})_{\text{Upstream}} = BOD_5\ (\text{mg/l}) \times Q_{14}\ (m^3/\text{sec}) \times 60 \times 60 \times 24 / 1{,}000$
$= \text{Col}_{3\ \text{of Table 4}} \times Q_{14}\ (m^3/\text{sec}) \times 86.4$
$BOD_5\ (\text{kg/day})_{\text{Upstream}} = BOD_5\ (\text{mg/l}) \times Q_{59}\ (m^3/\text{sec}) \times 60 \times 60 \times 24 / 1{,}000$
$= \text{Col}_{3\ \text{of Table 4}} \times Q_{59}\ (m^3/\text{sec}) \times 86.4$
$L_a\ (\text{kg/day}) = BOD_5\ (\text{Kg/day}) \times 1.46 = \text{Col}_{4\ \text{of Table 4}} \times 1.46$
DO_{sat} compute from equation (1)
$\text{DO deficit (mg/l)} = DO_{sat} - DO_{field} = \text{Col}_{6\ \text{of Table 4}} - \text{Col}_{7\ \text{of Table 4}}$
$\text{DO deficit (kg/day)}_{\text{Upstream}} = \text{DO deficit (mg/l)} \times Q_{14}\ (m^3/\text{sec})$
$\times 60 \times 60 \times 24 / 1{,}000 = \text{Col}_{8\ \text{of Table 4}} \times Q_{14}\ (m^3/\text{sec}) \times 86.4$
$\text{DO deficit (kg/day)}_{\text{Downstream}} = \text{DO deficit (mg/l)} \times Q_{59}\ (m^3/\text{sec})$
$\times 60 \times 60 \times 24 / 1{,}000 = \text{Col}_{8\ \text{of Table 4}} \times Q_{59}\ (m^3/\text{sec}) \times 86.4$.

Table 5 Calculation procedures to estimate decay rates

Case	Δt	K_d (day)	$\bar{L}$ (kg/day)	$\bar{D}$ (kg/day)	ΔD (kg/day)	K_2 (day)
1	0.53	0.69	158,853	18,382	–11,944	6.50
2	0.50	0.67	175,159	25,057	–13,887	5.18

Notes: Δt = [distance between upstream and downstream/V(Km/h)] / 24 then
Δt = (distance between upstream and downstream/$\text{Col}_{8\ \text{of Table 3}}$) / 24
K_d compute from equation (6)
$\bar{L}$ = average ultimate BOD_5 load upstream and downstream from (Table 4)
$\bar{D}$ = average DO deficit load upstream and downstream from Table 4
ΔD = difference DO deficit load upstream and downstream from Table 4
K_2 compute from equation (8).

Table 6 Estimated DO deficit and DO with respect to time (days) and space (km)

t (day)	Case 1				Case 2			
	Distance (km)	DO deficit (kg/day)	DO deficit (mg/l)	DO (mg/l)	Distance (km)	DO deficit (kg/day)	DO deficit (mg/l)	DO (mg/l)
0.000	14.000	24,354	2.67	5.59	14.000	32,001	3.35	4.91
0.015	15.283	24,131	2.65	5.61	15.348	31,798	3.33	4.93
0.030	16.566	23,843	2.62	5.65	16.696	31,513	3.30	4.96
0.045	17.849	23,505	2.58	5.68	18.044	31,161	3.27	5.00
0.060	19.132	23,130	2.54	5.72	19.391	30,756	3.22	5.04
0.075	20.415	22,728	2.50	5.77	20.739	30,310	3.18	5.09
0.090	21.698	22,307	2.45	5.81	22.087	29,832	3.13	5.14
0.105	22.981	21,872	2.40	5.86	23.435	29,328	3.07	5.19
0.120	24.264	21,429	2.35	5.91	24.783	28,807	3.02	5.24
Etc… until the end of the canal at 77.170 km								

Notes: Natural self-purification is calculated at 14 km
t = proposed time step to perform calculations (day) = 0.015
Distance = (t × V (km/h) × 24) + 14 = ($Col_{1\ of\ Table\ 6}$ × $Col_{8\ of\ Table\ 3}$ × 24) + 14
DO deficit (kg/day) compute from equation (5)
DO deficit (mg/l) = ((DO deficit (kg/day) / Q_{14} (m^3/sec)) × 1,000 / (60 × 60 × 24)
DO (mg/l) = $DO_{sat} - DO_{field}$.

3.3.1 Natural self-purification in Mahmoudia canal

Case 1 (current situation) represents no drainage water is discharging into Mahmoudia canal. This is because Edko Irrigation Pumping Station has stopped lifting drainage water from the Zarqun drain into the canal. Figure 3 illustrates the oxygen sag curve based on DO deficit of the case 1. The data showed that DO deficit decreased with distance due to the re-oxygenation rate was higher than de-oxygenation rate. According to Chapman (1996), the release of untreated domestic or industrial wastes high in organic matter into stream led to a marked decline in oxygen concentration and under certain conditions resulting in anoxia and also a release of ammonium and nitrite downstream the effluent input. The effects of the canal are directly linked to the ratio of effluent load to canal water discharge. The most obvious effect of organic matter along the length of the canal is the 'oxygen-sag curve' which can be observed from a few kilometres to 100 downstream of the input.

Model calibration can be achieved by comparing the simulation output with the measured data within certain calibration criteria. The average deviations between the measured and simulated values expressed as a percentage were 11%.

Figure 4 represents the simulated case of Edko Irrigation Pumping Station for lifting drainage water of Zarqun drain into the canal. The data showed that DO deficit had decreased with distance. According to Figure 4, at 35.57 km on the canal, the concentration of DO in case 2 is almost equal the initial concentration of DO in the case 1. This points out that the reach is needed 21.57 km to get rid of the influence of pollutants from Edko Irrigation Pumping Station discharge. As a result, all drinking water treatment plants in Baheira Governorate will be affected by Edko Irrigation Pumping Station discharge in a suit running, while all drinking water treatment plants in Alexandria Governorate will not be affected by Edko Irrigation Pumping Station discharge in a suit running.

Figure 3 Calculated and observed value of DO deficit and related distance (Case 1)

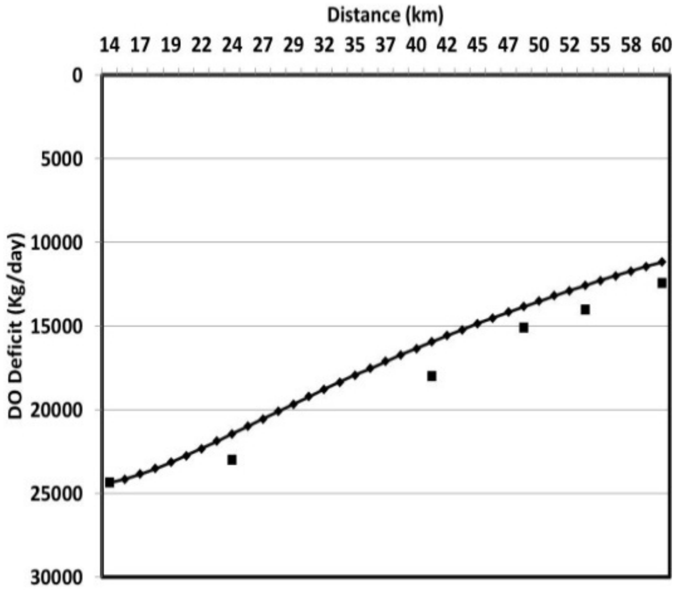
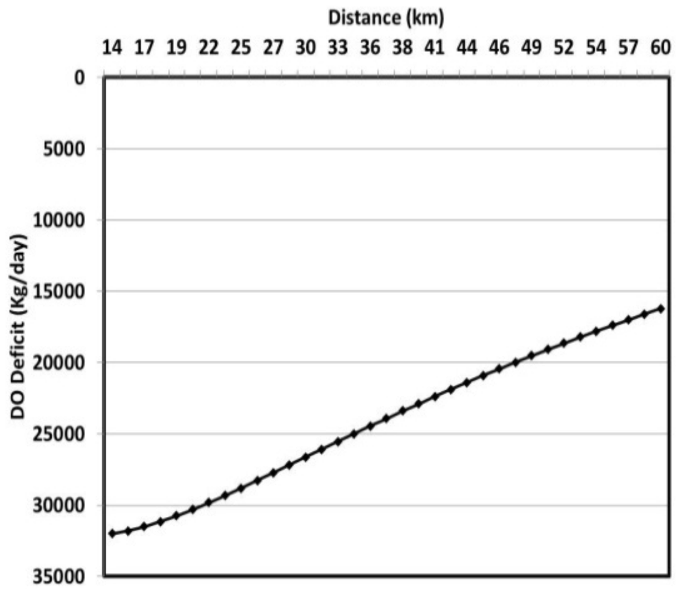


Figure 4 Calculated value of DO deficit and related distance (case 2)



According to Figures 3 and 4, the results of the interplay of the biological oxidation and re-aeration rates are represented by first-order kinetics. In the early stages, oxidation greatly exceeds re-aeration because of high CBOD concentrations and stream DO concentrations close to saturation (i.e., small deficit). As oxygen is used faster than it is resupplied, stream DO concentrations have been decreased. As the waste moves downstream, the consumption of oxygen has been decreased with the stabilisation of waste and also the supply of oxygen from the atmosphere is increased because of the greater deficits. The driving force to replenish oxygen by atmospheric re-aeration is directly proportional to the oxygen deficit (i.e., low oxygen concentration). At some points downstream the waste discharge, the decreasing utilisation and the increasing supply are equal. This is the critical location, where the lowest concentration of DO has been occurred. Further downstream, the rate of supply exceeds the utilisation rate, resulting in a full recovery of the DO concentration. This explanation is also supported by USEPA (1997).

3.3.2 *Oxygen deficit of water sources of Mahmoudia canal*

Table 7 illustrates the oxygen deficit (mg/l) in the different water sources feeding Mahmoudia canal. The results showed that Zarqun drain more polluted water sources. Hence it has more oxygen deficit than other sources. The oxygen deficit ranged from 4.70 to 8.71 mg /l of Zarqun drain, while was from 1.33 to 3.51 in the waters of the Rosetta branch lifted by El-Atf Pumping Station. The lowest oxygen deficit was in Khandak ElSharky canal was ranged from 0.93 to 2.98 mg/l.

Table 7 Oxygen deficit as mg/l and Kg/day of water sources of Mahmoudia canal

Month	*Elatf Pumping Station*		*Khandak ElSharky canal*		*Zarqun drain*	
	Oxygen deficit (mg/l)	*Oxygen deficit (kg/day)*	*Oxygen deficit (mg/l)*	*Oxygen deficit (kg/day)*	*Oxygen deficit (mg/l)*	*Oxygen deficit (kg/day)*
May, 2010	3.51	36,610	2.98	4,618	7.60	9,686
Jun, 2010	3.37	36,872	2.83	4,248	5.67	7,235
Jul, 2010	3.11	38,531	2.86	4,432	8.71	11,102
Aug, 2010	3.09	35,672	2.15	3,326	5.29	6,743
Sep, 2010	2.53	24,299	2.16	3,241	7.31	9,317
Oct, 2010	2.13	17,092	2.55	3,958	6.44	8,214
Nov, 2010	1.98	13,000	1.24	1,856	6.33	8,077
Dec, 2010	1.33	6,547	0.93	1,437	5.42	6,916
Jan, 2011	2.44	6,492	1.32	2,042	7.35	9,378
Feb, 2011	3.08	13,453	1.98	2,766	4.70	5,991
Mar, 2011	1.87	8,710	1.53	2,373	7.21	9,194
Apr, 2011	2.81	21,360	2.32	3,474	7.48	9,543

Notes: DO deficit (mg/l) = $DO_{sat} - DO_{field}$
DO deficit (kg/day) = DO deficit (mg/l) × Q (m^3/sec) × 60 × 60 × 24 / 1,000
Q of Elatf Pumping Station and Khandak ElSharky canal from Table 2
Q of Zarqun drain is 14.76 m^3/sec which maximum amount can be lifted by Edko Irrigation Pumping Station.

A lower amount of water in the Zarqun drain (maximum discharged is 14.76 m^3/sec) compared with the amount of water lifted by El-Atf Pumping Station and Khandak ElSharky canal (Table 2). Therefore, the oxygen deficit (kg/day) of Zarqun drain was less than the oxygen deficit (kg/day) in the rest of water sources feeding the Mahmoudia canal. While further oxygen deficit (kg/day) was present in waters of Mahmoudia canal.

4 Conclusions

Natural self-purification of water of Al-Mahmoudia canal according to oxygen sag curve showed that the reach need 21.57 km to get rid of the influence of pollutants from Edko irrigation pump station discharge. As a result, most of water treatment plant in Beheira Governorate will be affected by Edko irrigation pump station discharge in a suit running, while all water treatment plant in Alexandria Governorate will not be affected by Edko irrigation pump station discharge in a suit running.

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