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Using QUAL2K Model and river pollution index for water quality management in Mahmoudia Canal, Egypt

Ehab A. Elsayed

Drainage Research Institute, National Water Research Center, El-Qanater El-Khairiya, Egypt.

Corresponding author: ehab7878@hotmail.com ; ehab78new@yahoo.com

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Abstract

The Mahmoudia Canal is the main source of municipal and industrial water supply for Alexandria (the second largest city in Egypt) and many other towns and villages. In recent years, considerable water quality degradation has been observed in the Mahmoudia Canal. This problem has attracted increasing attention from both the public and the Egyptian government. As a result, this study aims at assessing the current seasonal variations in water quality in the Mahmoudia Canal and simulating various water quality management scenarios for the canal. The present research involves the application of the water quality model, QUAL2K, to predict water quality along the Mahmoudia Canal on a seasonal basis for the considered scenarios. Based on the QUAL2K simulations, the River Pollution Index (RPI) was used to appraise the conditions of water pollution at the intakes of the twelve water treatment plants (WTPs) located along Mahmoudia Canal.

The results showed that the QUAL2K model is successfully applied to simulate the water quantity and quality parameters of the Mahmoudia Canal in different seasons. For the current status of the canal, it was found that the highest pollution level occurred in autumn in which effluent water quality at all WTPs along the Mahmoudia Canal was classified as moderately polluted. In the other seasons, effluent water quality was categorized as moderately polluted at most WTPs in the Beheira governorate and negligibly polluted at all WTPs in the Alexandria governorate. Moreover, it was concluded that controlling the Rahawy drain discharge or treating its pollution loads before mixing with the Rosetta Branch may solve water quality problems of the Mahmoudia Canal and allow re-running of the Edko re-use pump station in summer, winter, and spring. However in autumn, additional measures will be required to mitigate pollution levels in the canal.

Introduction

Throughout the last fifty years the population of Egypt has grown more than threefold while, the availability of renewable water resources has remained the same. Consequently, the annual per capita share of renewable water resources (mainly provided by the Nile) has dramatically reduced from more than 2500 m^3 in 1950 to less than 900 m^3 in 2000, which is below 1000 m^3 cap^{-1} yr^{-1} "the international standard of water scarcity limit". It is further projected to fall to about 500 m^3 cap^{-1} yr^{-1} by the year 2050 (Ahmed Wagdy, 2008).

Therefore, the Egyptian government has endorsed several policies to confront prevailing water scarcity. Conservation of water, mainly by recycling agricultural drainage water in irrigation, has become the core of these policies. This drainage water is one of the most valuable water resources in Egypt created by intensive and large irrigation/drainage systems. Drainage water reuse is also requires relatively less infrastructure to be constructed and is a cheaper option. However, drainage water reuse practices have been threatened by deteriorating drainage water quality due to municipal and industrial wastewater pollution. Thus, environmental impacts are very important in the implementation of drainage reuse projects (Abdel-Azim and Allam, 2005).

The Rosetta Branch is one of two main branches of the Nile delta. Five agricultural drains (EL-Rahawy, Sabal, El Tahrir, Zaweit El-Bahr, and Tala drains) mix their water into the Rosetta Branch. Unfortunately, the branch receives more than 3 M m^3 day^{-1} of untreated or partially treated domestic and industrial waste. The Rahawy drain (which receives considerable wastewater from the Greater Cairo area) is the most important pollution source affecting Rosetta Branch. It was found that by controlling the Rahawy drain discharge, the water quality of the Rosetta Branch will be improved significantly and will comply with water quality standards (El Bouraie et al., 2011, El Gammal and El Shazely, 2008, and Donia, 2005).

The Mahmoudia Canal, the focus of the present study, takes fresh water from the Rosetta Branch at km 194.200. The Mahmoudia Canal has an important role in the economy, development and prosperity of the people in the western Nile Delta. In addition to providing irrigation water, the Mahmoudia Canal is a navigable canal and is the main source for the municipal and industrial water supply for Alexandria and many other towns and villages. In Alexandria (the second largest city in Egypt), the Mahmoudia Canal provides water supply companies with about 2.5 to 3 M $m^3 day^{-1}$, which varies in different seasons. In summer, due to large number of tourists, water demands increase and thus drinking water production increases also (Hamdard, 2010 and El-Gamal et al., 2009).

Examination of detailed data records held by the Drainage Research Institute (DRI) for the Mahmoudia Canal show that water quality parameters generally comply with the legal requirements, including salinity, and industrial and agrochemical contamination standards. Nevertheless, sewage pollution indicators were the only parameters in this canal that were consistently in excess. This may result in major negative impacts on water quality upstream of the intakes of drinking water plants causing serious effects on human health and the surrounding environment in general (NRMED, 2005).

Natural self-purification of the Mahmoudia Canal water is calculated and observed in two cases (Abukila, 2012). The first is a normal case, in which no drainage water is discharged directly into the Mahmoudia Canal downstream of its intake. The second is a simulated case, in which a simulated Edko irrigation pump station lifts drainage water from the Zarqun drain into the canal. It was evident that the Mahmoudia Canal receives pollutants from point and non-point sources (i.e. the Edko irrigation pump station and thrown garbage and wastewater input from local towns and villages located along the canal). However, the majority of the water quality problems of the Mahmoudia Canal are due to receiving low grade water from the Rosetta Branch. Furthermore, the canal needs 10.83 km to get rid of the influence of pollutants from the Edko irrigation pump station discharge. As a result, most of the water treatment plants (fed by the Mahmoudia Canal) in the Beheira Governorate will be affected by the Edko irrigation pump station discharge. However, not all the water treatment plants in Alexandria Governorate will be affected by the Edko irrigation pump station discharge.

In recent decades, many water quality models have been developed to assist in river water quality management. The QUAL2K model is one of the most famous tools for water quality simulations due to its flexibility, ease of use, and free availability. Numerous typical applications of the model have been developed and utilized on various river systems in many countries (Rashed and El-Sayed, 2014, Hanfeng et al., 2013; Ruibin Zhang et al. 2012; Vasudevan et al., 2011, and Kalburgi et al., 2010).

In order to facilitate the evaluation of water quality parameters, Horton (1965) proposed the first water quality index (WQI). House (1989) stated that the use of a Water Quality Index (WQI) allows 'good' and 'bad' water quality to be quantified by reducing a large quantity of data on a range of physical-chemical and biological variables to a single number in a simple, objective and reproducible manner.

The River Pollution Index (RPI) is an integrated indicator, which is employed by the Environmental Protection Administration of Taiwan (EPA) to explore and monitor trends for both planning and day-to-day management of surface water quality. The Taiwan EPA has used RPI to assess the conditions of surface water pollution over the past two decades (Wang et al., 2013; Chen et al., 2012, and Liou et al., 2003).

As stated above, many research studies have been conducted to assess the water quality of the Rosetta Branch and the Mahmoudia Canal (Abukila, 2012, El Bouraie et al., 2011, Hamdard, 2010, El-Gamal et al., 2009, El Gammal and El Shazely, 2008, and NRMED, 2005). Although most of the previous studies mention that the water uses and discharges of these canals vary significantly in different seasons of the year; almost no research has focused on evaluating or maintaining water quality on a seasonal basis.

Consequently, this research was initiated with the objectives of assessing the current seasonal water quality of the Mahmoudia Canal and simulating various water quality management scenarios for the canal. In this investigation, the QUAL2K model was applied to simulate the seasonal variations in water quality in the Mahmoudia Canal for the considered scenarios. Based on the QUAL2K simulations, the River Pollution Index (RPI) was used to appraise the conditions of water pollution at the intakes of the twelve water treatment plants located along the Mahmoudia Canal.

Study area description

The Mahmoudia Canal is located near the northern edge of the west Nile delta in the Behaira governorate ***Figure 1.*** It has been exploited to support agriculture, fisheries, industry, hydroelectric power, and recreation in the western delta region. Moreover, the major drinking water treatment plants (WTPs) in the Alexandria and Behaira governorates receive fresh water from the Mahmoudia Canal ***Table 1***. The canal runs for a distance of 77.170 km from the Rosetta branch of the Nile down to the Mediterranean Sea at Alexandria. It serves a total command area of about 130,200 hectares through 70 branch (distribution) canals.

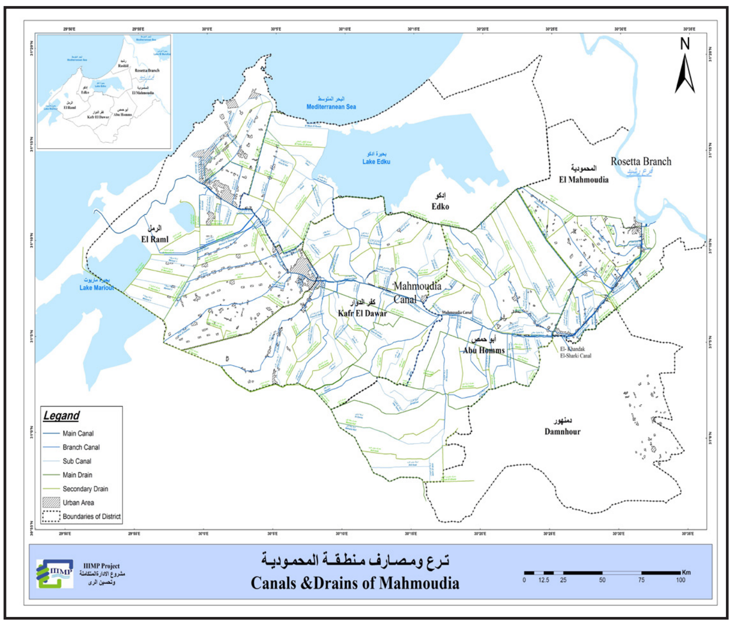

Figure 1: Mahmoudia Canal

The Mahmoudia Canal receives water from three different sources. The main source (that lifts about 80 percent of the total annual supply to the canal) is the El- Atf pumping station on the Rosetta branch. The canal is also fed from two subsidiary sources, namely the Edku pumping station, which lifts drainage water from Zarkon drain into the canal at km 8.850, and excess flow from the El-Khandak El-Sharki Canal at km 15.270. However, the mixing of the drainage water of the Etay El-Barud pump station into the El-Khandak El-Sharki Canal lowers its water quality. It should also be noted that the Edko Irrigation Pump Station was stopped from June 2009 due to the observed water quality problems in the Mahmoudia Canal, especially upstream of the intakes of drinking water plants (Abukila, 2012 and NRMED, 2005). ***Table 2*** displays the monthly amounts of water discharged into the Mahmoudia Canal from the El-Atf pump station and the El- Khandak El-Sharki Canal.

Table 1: Drinking water treatment plants fed from the Mahmoudia Canal

Governorate	Water treatment plant	Production (m^3 day^{-1})	Plant intake location	Chain (km)
Behaira	Al-Gadih	25000	Mahmoudia Canal	km 4.500
	Ficha	25000		km 5.500
	Monchat Nassar	25000		km 16.500
	Abou Hommos	100000		km 27.500
	Com Alkuenatur	250000	Kenawia Branch Canal – km 28.410 at Mahmoudia Canal	km 7.100
	Kafr El-Dawar	100000	Mahmoudia Canal	km 42.000
Alexandria	Al-Sayouif	970000	Mahmoudia Canal	km 61.300
	Al-Nozha	240000		km 66.000
	Al-Mamoura	630000	Pipeline from Al-Sayouif WTP - Mahmoudia Canal	km 61.300
	Al-Manshia	420000	Drinking Water Canal – km 54.650 at Mahmoudia Canal	km 15.250
	Bab Sharki	50000		km 15.500
	Forn El-Garia	200000		km 15.450

Table 2: The monthly amounts of water discharged into the Mahmoudia Canal from the El-Atf pump station and the El- Khandak El-Sharki Canal

Month	Discharge (Mll m^3 $month^{-1}$)	
	El-Atf pump station	El- Khandak El-Sharki Canal
Jul, 2010	371.786	46.5
Aug, 2010	346.819	46.5
Sep, 2010	288.056	45
Oct, 2010	240.332	46.5
Nov, 2010	197.236	45
Dec, 2010	147.97	46.5
Jan, 2011	79.902	46.5
Feb, 2011	131.224	42
Mar, 2011	139.648	46.5
Apr, 2011	228.372	45
May, 2011	313.024	46.5
Jun, 2011	328.546	45
Total	2812.915	547.5

Materials and methods

In order to achieve the study objectives, a methodology was designed to proceed with the investigation phases.

Water Sampling and Discharge Data

Under the umbrella of the Egyptian Ministry of Water Recourses and Irrigation (MWRI), the Drainage Research Institute (DRI) and Irrigation Sector (IS) measure the monthly discharges (Q) for all studied canals and drains.

Water samples were collected monthly during the year 2010/2011 (from July; 2010 to June, 2011) from six locations, four sites along the Mahmoudia Canal, one along the El- Khandak El-Sharki canal, and one along the Zarkon drain, ***Figure 2***. The collected water samples were analyzed at the Central Laboratories for Environmental Quality Monitoring (CLEQM) of the National Water Research Center (NWRC) for water quality parameters including: Electrical Conductivity (EC), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), and Ammonia Nitrogen (NH_4-N).

The water quality and quantity monitoring work was conducted once a month and the average values of the four seasons (summer and autumn of 2010, winter and spring of 2011) are presented in ***Table 3.***

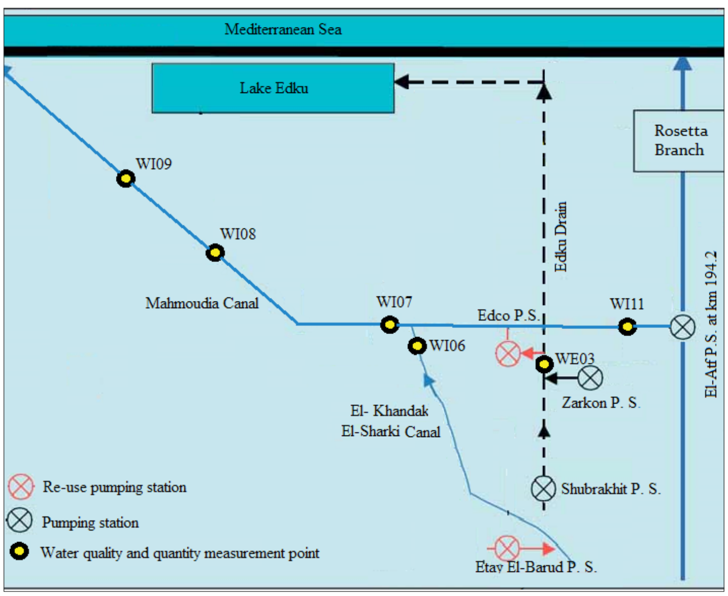

Figure 2: Schematic diagram of the measured water sample

Numerical Modeling and Simulations

The QUAL2K model can simulate up to 16 water quality parameters in dendritic streams that are well mixed laterally and vertically. A complete discussion of the model theory is described in the QUAL2K documentation and user's manual (Chapra and Pelletier, 2008).

In the current research, the Mahmoudia Canal is a dendritic canal and the transport is dominated by longitudinal changes. Thus, QUAL2K was used in this investigation as an appropriate model of water quality simulation. The total length of the Mahmoudia Canal was modeled and then subdivided into 13 different reaches in accordance with the geometry of the canal. The input data for the QUAL2K model were based on the monitoring data of the year 2010/2011. Additional data, such as geographic and hydraulic characteristics were collected from the Integrated Irrigation Improvement and Management Project (IIIMP), MWRI. Finally, the required seasonal meteorological data were obtained from the Alexandria International weather station, as it is the nearest weather station to the study area (http://www.wunderground.com/weather-forecast/EG/Alexandria_International.html?MR=1).

The accuracy of the model predictions was measured using statistics based on Mean Multiplicative Error (MME). The MME is employed as the error metric, owing to its significant advantages: scaling, proper sensitivity, lack of bias in determining critical deficit, and invariance with coefficient choice (Moog and Jirca, 1998). MME was calculated as follows:

$$MME \equiv \exp\left[\frac{\sum_{i=1}^{N} |\ln(K_P/K_M)_i|}{N}\right]$$

Where N is the number of measurements, K_P is the predicted value of the QUAL2K Model, and K_M is the measured value.

In this research, the QUAL2K model was applied to simulate four water quality management scenarios on the Mahmoudia Canal. For each scenario, QUAL2K investigated water quantity and quality status along the canal during the 4 seasons (Summer, Autumn, Winter, and Spring) for 6 parameters (Q, EC, DO, BOD_5, TSS, and NH_4-N). The considered scenarios are as follows:

(1) The first scenario: Simulating the current status of the canal in which the Edko irrigation pump station stops lifting drainage water from the Zarkon drain into the Mahmoudia Canal. The main purpose of this case is to validate the QUAL2K model and also to assess the current seasonal water quality along the canal.

(2) The second scenario: Re-running the Edko irrigation pump station, with its design capacity (5 m^3 s^{-1}), in order to cover irrigation needs along the canal and preserve/maximize the benefit of the great investment spent on the infrastructure of this vital pump station.

(3) The third scenario: Controlling the Rahawy drain discharge or treating its pollution loads in order to improve the water quality of the Rosetta Branch; hence the water quality at the head of the Mahmoudia Canal will comply with required standards (Donia, 2005 and El Gammal and El Shazely, 2008). In this scenario, the Edko Irrigation Pump Station is stopped.

(4) The fourth scenario: Controlling the Rahawy drain discharge and re-running the Edko irrigation pump station simultaneously.

River Pollution Index (RPI)

The River Pollution Index (RPI), which is employed by the Environmental Protection Administration of Taiwan (EPA), was chosen for the present study due to its reliability in evaluating surface water pollution and ease of application. The RPI is calculated using concentration levels of four parameters: DO, BOD_5, TSS, and NH_3-N,

Table 3: Average seasonal discharges and water quality parameters at the monitoring locations

Location	Site Code	Season	Water quantity and quality parameters					
			Q	EC	DO	BOD_5	TSS	NH_4-N
			$m^3 s^{-1}$	umhos	mg L^{-1}	mg L^{-1}	mg L^{-1}	ug L^{-1}
Mahmoudia Canal Headwater	WI11	Summer	134.66	463	2.87	11	8	700
		Autumn	93.32	678	2.67	19	21	700
		Winter	46.18	705	4.47	7	16	700
		Spring	87.58	702	2.57	14	19	700
Mahmoudia Canal Downstream of the junction with El-Khandak Canal	WI07	Summer	124	369	5.87	10	16	1144
		Autumn	90	412	5.9	17	19	900
		Winter	53	387	5.97	19	17	500
		Spring	87	380	5.67	18	12	500
Mahmoudia Canal Upstream of the Kafr Dawwar drinking water intake	WI08	Summer	67	451	8.3	5	6	1400
		Autumn	50	678	8.13	15	19	2400
		Winter	29	733	7.77	12	17	800
		Spring	45	675	8.13	11	17	900
Mahmoudia Canal Upstream of the Alexandria drinking water intake	WI09	Summer	38	409	8.13	4	6	1300
		Autumn	30	659	8.1	10	21	2400
		Winter	17	705	7.73	5	17	600
		Spring	26	638	8.13	6	19	600
Khandak Canal Upstream of the junction with Mahmoudia Canal	WI06	Summer	17.75	369	5.9	7	14	2373
		Autumn	17.55	409	5.87	12	20	1200
		Winter	17.36	388	4.13	14	19	200
		Spring	17.75	376	5.7	12	17	200
Outfall of Zarkon drain upstream of Edko Irrigation Pump Station	WE03	Summer	-	985	2.25	11	25	1100
		Autumn	-	1142	1.97	24	40	6000
		Winter	-	1143	2.47	24	43	1500
		Spring	-	1444	2.07	19	40	1200

each of which is ultimately converted into one of four index scores (1, 3, 6, and 10). Notably, RPI refers to the arithmetic average of these index scores and the RPI value ranges from 1 to 10 (Chen et al., 2012).

According to the river pollution index listed in ***Table 4***, the four pollution classifications are: unpolluted, negligibly polluted, moderately polluted, and severely polluted. In the present research, laboratory test results expressed Nitrogen content in water samples as NH_4-N. Accordingly and in order to calculate RPI, the values of NH_3-N were estimated using the molar mass approach as follows: $NH_3\text{-N} = (17.031/18.039)\times NH_4\text{-N} = 0.944\times NH_4\text{-N}$.

Based on the QUAL2K simulations, the River Pollution Index (RPI) was used to assess the conditions of water pollution at the intakes of the twelve water treatment plants located along the Mahmoudia Canal. For each of the four studied scenarios, RPI was calculated at each WTP intake in the four seasons (summer, autumn, winter, and spring).

Results and discussion

QUAL2K calibration and validation

QUAL2K was calibrated and compared with monitoring data taken along the Mahmoudia Canal in the four seasons (summer and autumn of 2010, winter and spring of 2011). It was then validated further. ***Figure 3*** displays EC, DO, BOD_5, NH_4, TSS and Q profiles along the Mahmoudia Canal for the first scenario (the current status of the canal).

Table 5 shows the values of Mean Multiplicative Error (MME) of the QUAL2K simulations for the water quality and quantity parameters in different seasons. MME results showed that on average the model predictions were in error by a factor ranged between 0.94 and 1.09. It was thus evident that the simulated values of the model were in close agreement with the measured values. This means that QUAL2K can be effectively applied to simulate the water quantity and quality parameters of the Mahmoudia Canal in different seasons.

From ***Figure 3*** it was observed that EC concentrations along the Mahmoudia Canal were less than 750 umhos in all seasons. This may allow planting all field crops, fruits, vegetables, and forage crops cultivated in the study area throughout the year without any lowering of productivity (NWRC, 2007). These results were in agreement with previous results obtained by NRMED (2005).

Along the canal, the concentrations of DO were greater than 6 mg L^{-1}, which complies with the standards of Egyptian law 48/1982. The DO level indicates that the Mahmoudia Canal is a healthy aquatic

Table 4: Definition of River Pollution Index (RPI), Chen et al., 2012

Parameters	Ranks			
	Un Polluted (UP)	Negligibly Polluted (NP)	Moderately Polluted (MP)	Severely Polluted (SP)
DO (mg L^{-1})	DO ≥ 6.5	6.5 >DO ≥ 4.6	4.5 ≥ DO ≥ 2.0	DO < 2.0
BOD_5 (mg L^{-1})	BOD_5 ≤ 3.0	3.0<BOD_5 ≤ 4.9	5.0 ≤ BOD_5 ≤ 15.0	BOD_5 > 15.0
TSS (mg L^{-1})	TSS ≤ 20.0	20.0<TSS ≤ 49.9	50.0 ≤ TSS ≤ 100	TSS >100
NH_3-N (ug L^{-1})	NH_3 ≤ 500	500<NH_3 ≤ 990	1000 ≤ NH_3 ≤ 3000	NH_3 >3000
Index Scores	1	3	6	10
RPI	RPI ≤ 2.0	2.0< RPI ≤ 3.0	3.1≤ RPI ≤ 6.0	RPI > 6.0

ecosystem. It is also clear that DO concentrations, in all seasons, were less than 6 mg L^{-1} at the head of the canal as a result of receiving low quality water from the Rosetta Branch. However, DO levels increased gradually in the downstream direction of the Mahmoudia Canal owing to natural self-purification of the canal water.

In all seasons except summer, BOD_5 and NH_4 values along the canal exceeded 6 mg L^{-1} and 500 ug L^{-1}, respectively, which violates Egyptian law 48/1982. However, in summer, BOD_5 levels were less than 6 mg L^{-1} in the last 38 km of the canal. The minimum values of BOD_5 and NH_4 occurred in summer and winter, respectively; while, the maximum values occurred in autumn. In addition, it was seen that TSS concentrations along the canal met the standards of Egyptian law 48/1982 in all seasons.

Table 5: Mean Multiplicative Error (MME) of QUAL2K simulations for the Mahmoudia Canal

Parameter		EC	DO	BOD_5	NH_4	TSS	Q
Mean Multiplicative Error (MME)	Summer	1.1	0.94	0.92	0.93	1.01	1
	Autumn	1.07	0.95	0.97	0.96	0.96	1
	Winter	1.04	0.99	0.82	1	0.95	0.98
	Spring	1.17	0.97	1.06	1.08	1.1	1.01
	Average	1.09	0.96	0.94	0.99	1	1

QUAL2K Simulation Results

Confident with the calibration and validation process results, QUAL2K was implemented to simulate the seasonal variation of the considered parameters along the Mahmoudia Canal for the proposed operating scenarios. ***Table 6*** shows the model output data at km 16.500 on the canal, the abstraction point of the Monchat Nassar WTP. This plant is the first WTP located downstream of the mixing points of the Edku pumping station and the outflow of the El- Khandak El-Sharki canal.

For the 4 studied scenarios, it was found that EC, DO, and TSS concentrations were within the acceptable limits of Egyptian law 48/1982 in the 4 seasons. This confirmed that for all considered scenarios, the Mahmoudia Canal was a healthy aquatic ecosystem and its water quality generally complied with the legal requirements of agricultural practices throughout the year. On the other hand, for scenario 1, BOD_5 and NH_4 values were higher than the allowable limits of Egyptian law 48/1982 in all seasons. This indicated the existence of organic loads in the Mahmoudia Canal.

Similar to the results of scenario 1, it was evident that for scenario 2, BOD_5 and NH_4 values in all seasons violated Law 48/1982. Furthermore, it was clear that values of all water quality parameters in scenario 2 were worst than those of scenario 1 in all 4 seasons, especially in winter. This means that for the current situation of the Mahmoudia Canal, re-running the Edko irrigation pump station (with its design capacity) will cause further deterioration in the canal's water quality.

It should be noted that for scenarios 3 and 4, BOD_5 and NH_4 concentrations were improved significantly; but the concentrations of scenario 4 were higher than those of scenario 3. For both scenarios, BOD_5 values were below the acceptable limit of law 48/1982 in summer; while, BOD_5 slightly exceeded the limit in the other seasons. Moreover, NH_4 levels met the standards of Egyptian law 48/1982 in winter and spring; but in autumn and summer, NH_4 violated the law.

River Pollution Index Calculations

For scenario 1, RPI was calculated at all WTPs along the Mahmoudia Canal in the 4 seasons, ***Figure 4***. According to the figure, the highest pollution level occurred in autumn in which all WTPs along the Mahmoudia Canal were classified as moderately polluted (MP). In summer, water quality was categorized as MP at all WTPs in the Beheira governorate and negligibly polluted (NP) at all WTPs in the Alexandria governorate. This may be due to the natural self-purification of the Mahmoudia Canal water.

In winter, water quality was classified as NP for all WTPs except for the Monchat Nassar WTP which was classified as MP. In spring, water quality was categorized as MP and NP for WTPs located upstream and downstream of the mixing point of the El- Khandak El-Sharki canal, respectively. This indicated that the concentration of contaminates in the water of the El- Khandak El-Sharki canal, resulting from the mixing of the drainage water of the Etay El-Barud pump station, was higher in winter, causing deteriorated water quality in the Mahmoudia Canal. On the other hand, the pollutants in the water of the El- Khandak El-Sharki canal were less than the Mahmoudia Canal, resulting in improved water quality in spring. ***Figure 5*** shows RPI values at WTPs along the Mahmoudia Canal for scenario 2. It is clear that pollution levels in scenario

2 were like those in scenario 1 in summer, autumn, and spring, whereas in winter, it is evident that re-running the Edko irrigation pump station led to an increase in pollution level at some WTPs from negligibly polluted to moderately polluted.

Based on ***Figure 6***, it can be seen that the pollution level along the Mahmoudia Canal was reduced significantly in scenario 3. The water quality at all WTPs along the canal was classified as unpolluted (UP) or negligibly polluted (NP) in summer, winter, and spring. But in autumn, pollution level at most WTPs located downstream of the mixing point of the El- Khandak El-Sharki canal was categorized as moderately polluted. This may be due to the existence of non-point pollution sources in addition to the high concentration of pollutants in the water of the El- Khandak El-Sharki canal in autumn.

As shown in ***Figure 7***, the RPI values for scenario 4 were estimated at all WTPs along the Mahmoudia Canal. It was found that RPI classification in scenario 4 was similar to that in scenario 3 in summer, winter, and spring. But in autumn, water quality at all WTPs located downstream of the Edko irrigation pump station was classified as moderately polluted.

Table 6: QUAL2K output data at the abstraction point of the Monchat Nassar Water Treatment Plant

Site Code	Season	Water quantity and quality parameters				
		EC (umhos)	(mg L^{-1})DO	BOD_5 (mg L^{-1})	TSS (mg L^{-1})	NH_4-N (ug L^{-1})
		≤ 750 *	≥ 6 *	≤ 6 *	≤ 500 *	≤ 500 *
Scenario 1	Summer	449	6.66	7. 1	8.5	1080
	Autumn	617	6.66	15.1	19.2	1348
	Winter	602	6.47	9.1	16.3	581
	Spring	637	6.65	12.3	17.4	656
Scenario 2	Summer	467	6.64	7.1	9	1084
	Autumn	641	6.6	15.4	19.9	1570
	Winter	645	6.18	10.2	18	660
	Spring	677	6.55	12.6	18.3	688
Scenario 3	Summer	449	6.86	4.4	8.5	886
	Autumn	475	7.09	6.4	19.2	1155
	Winter	464	6.6	8.4	16.3	424
	Spring	475	7.13	6.8	17.4	466
Scenario 4	Summer	467	6.83	4.5	9	897
	Autumn	506	7.02	7.1	19.9	1386
	Winter	517	6.31	9.5	18	498
	Spring	523	7.01	7.3	18.3	490

(*) Egyptian law 48/1982 (**) Shaded cells are the values that exceed allowable Egyptian law limits

Conclusion and recommendations

From the above research, the following can be concluded:

- The QUAL2K model is successfully applied to simulate the water quantity and quality parameters of the Mahmoudia Canal in different seasons.
- Similar to the results of previous research, it was found that the majority of water quality problems on the Mahmoudia Canal were due to receiving low grade water from the Rosetta Branch. However, it was concluded that the concentration of pollutants in the water of the El- Khandak El-Sharki canal was higher in winter and autumn, causing greater deterioration in the water quality of the Mahmoudia Canal.
- As a general result, all considered water quality parameters improved gradually in the downstream direction of the Mahmoudia Canal in most seasons. This confirmed the effective natural self-purification of the canal water.
- For all studied water quality management scenarios, DO, TSS and EC concentrations indicated that the Mahmoudia Canal was a healthy aquatic ecosystem and its water quality generally complied with the legal requirements of agricultural practices throughout the year. However, exceeding the thresholds for BOD_5 and NH_4 in some seasons limits the other uses of the canal water, especially domestic uses.
- From River Pollution Index (RPI) calculations for the current status of the Mahmoudia Canal, it was evident that the highest

pollution level in the canal occurred in autumn in which water quality at all WTPs along the canal were classified as moderately polluted. In the other seasons, water quality was categorized as moderately polluted at most WTPs in the Beheira governorate and negligibly polluted at all WTPs in the Alexandria governorate.

- For the current situation of the Mahmoudia Canal, re-running the Edko irrigation pump station with its design capacity (5 m^3 s^{-1}) may not be acceptable from an environmental viewpoint because it will cause further deterioration in the canal water quality, especially in winter.
- The results show that the pollution level along the Mahmoudia Canal was reduced significantly in scenarios 3 and 4. The water quality at all WTPs along the canal was classified as unpolluted (UP) or negligibly polluted (NP) in summer, winter, and spring. However, in autumn, pollution levels at most WTPs were categorized as moderately polluted.

As a result, controlling the Rahawy drain discharge or treating its pollution loads before mixing with the Rosetta Branch is highly recommended in order to achieve optimum water quality management for the Mahmoudia canal in summer, winter, and spring. However, in autumn, additional measures will be required to mitigate pollution levels in the canal (i.e. reducing non-point pollution sources and decreasing contaminant concentrations in the El- Khandak El-Sharki canal).

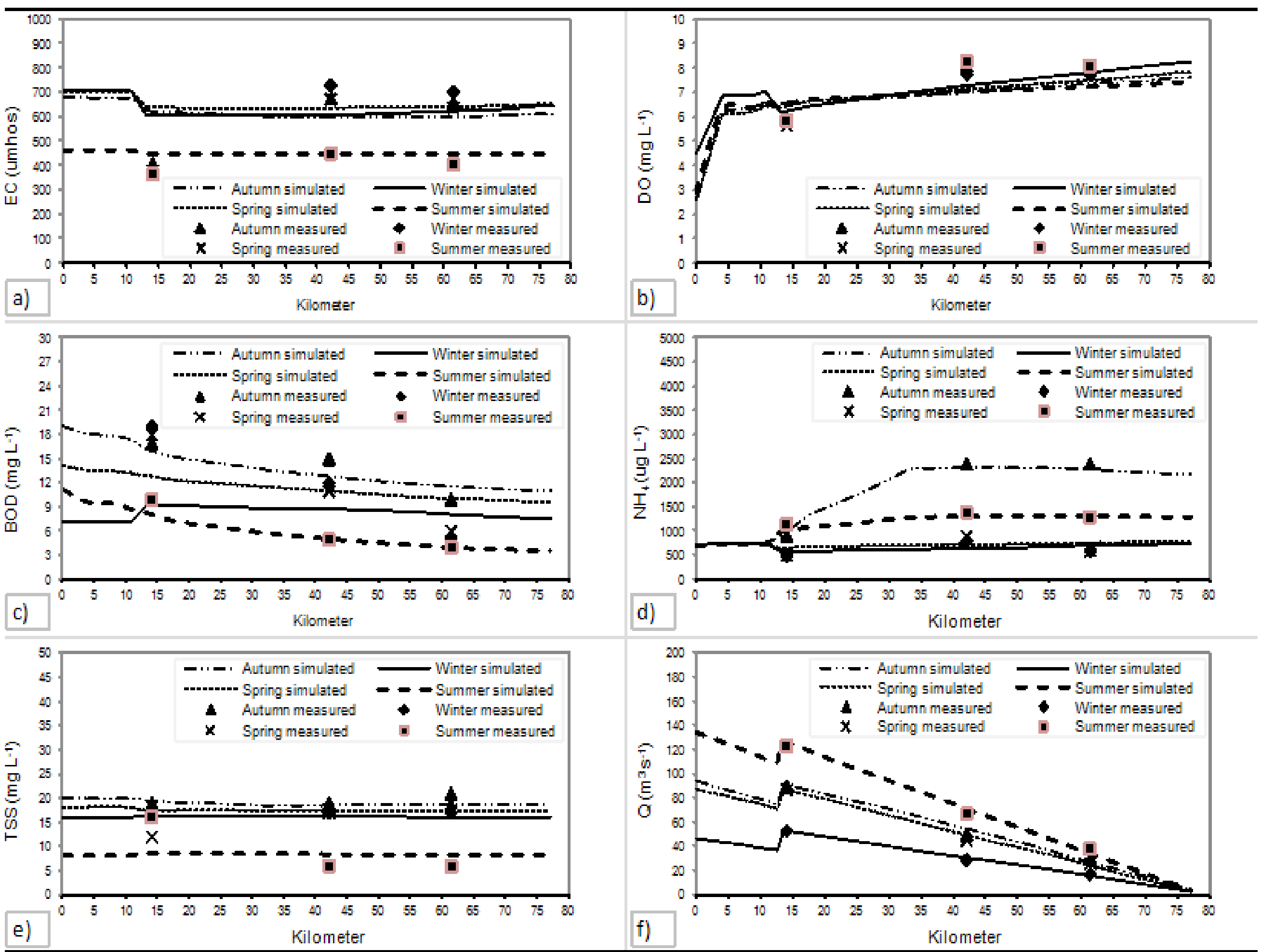

Figure 3: Verification of water quantity and quality parameters along the Mahmoudia Canal
a)EC b) DO c) BOD5 d) NH4 e) TSS f) Q

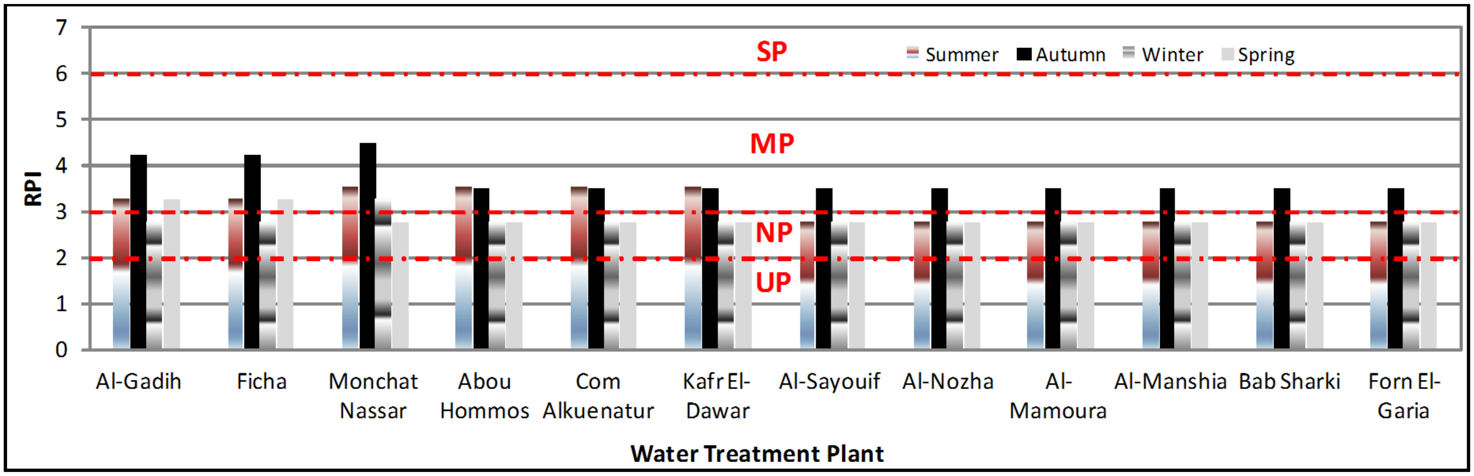

Figure 4: River Pollution Index at drinking water treatment plants along the Mahmoudia Canal for scenario 1

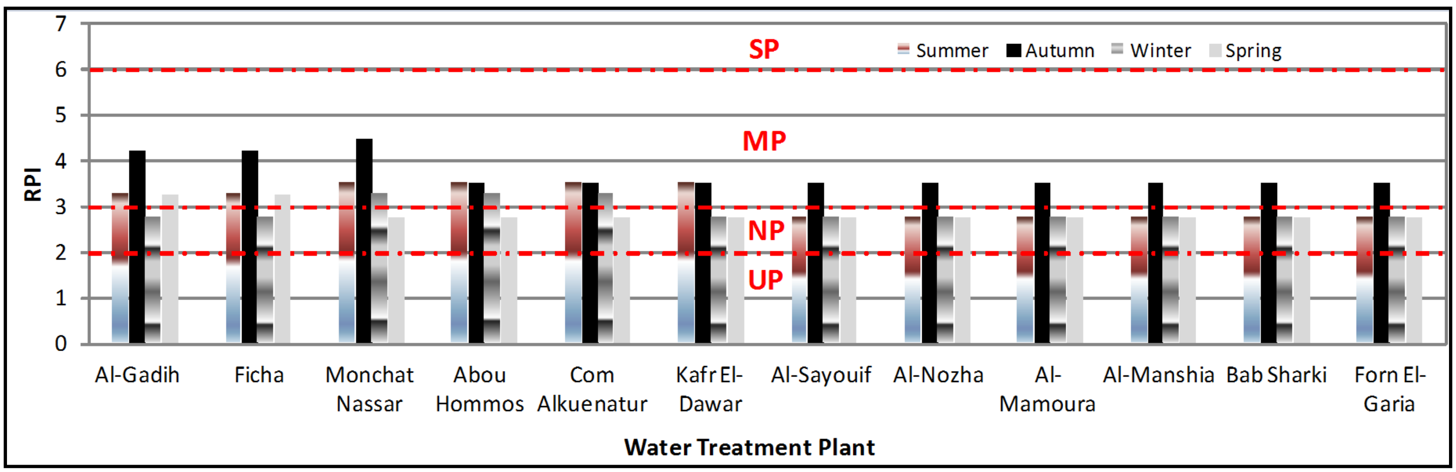

Figure 5: River Pollution Index at drinking water treatment plants along the Mahmoudia Canal for scenario 2

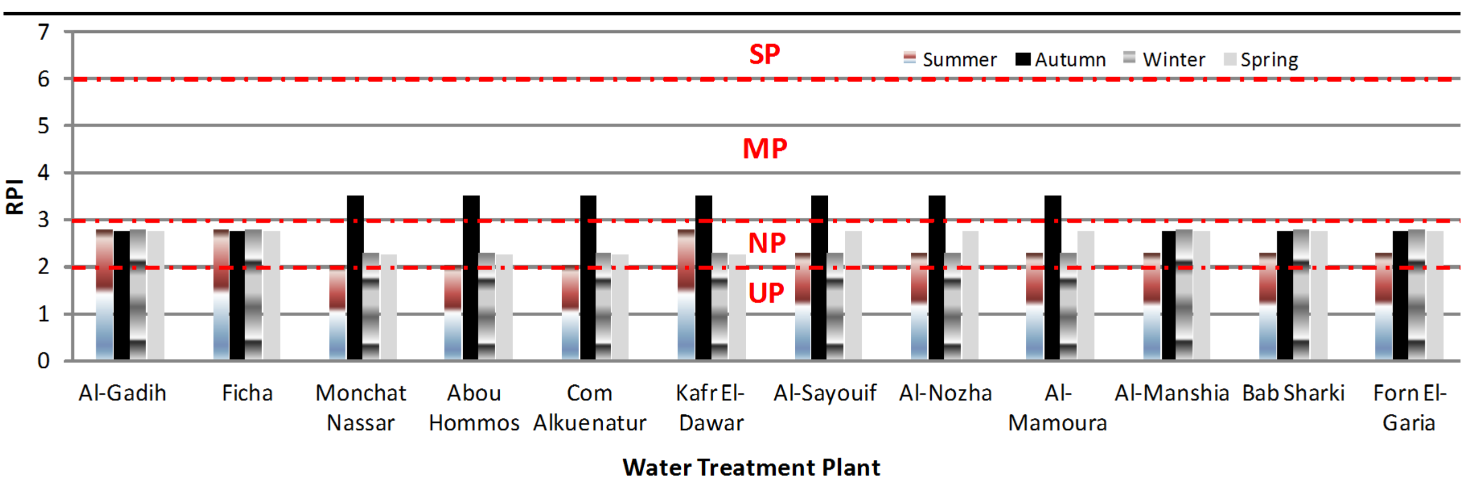

Figure 6: River Pollution Index at drinking water treatment plants along the Mahmoudia Canal for scenario 3

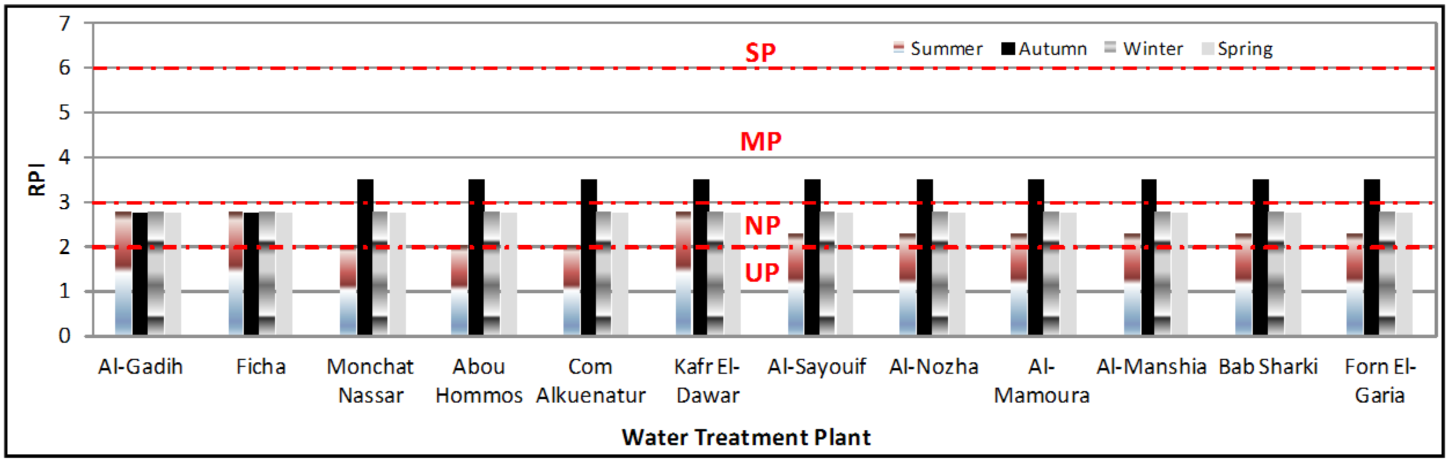

Figure 7: River Pollution Index at drinking water treatment plants along the Mahmoudia Canal for scenario 4

References

Abdel-Azim R. and Allam M.N., "Agricultural Drainage Water Reuse In Egypt: Strategic Issues And Mitigation Measures", In : Hamdy A. (ed.), El Gamal F. (ed.), Lamaddalen a N. (ed.), Bogliotti C. (ed.), Gu ellou bi R. (ed.). Non-Conventional Water Use:WASAMED Project, Bari:CIHEAM/EU DG Research, pp. 105-117, 2005.

Abukila A. F., "Assessment Of Natural Self Restoration Of The Water Of Mahmoudia Canal, Western Part Of Nile Delta, Egypt", Irrigation and Drainage Systems Engineering, Vol. 1, Issue 3, 2012.

Ahmad Wagdy, "Progress In Water Resources Management: Egypt", Proceedings of the 1st Technical Meeting of Muslim Water Researchers Cooperation (MUWAREC), Malaysia, December 2008.

Chapra, S.C.; Pelletier, and G.J.; Tao, H., "QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality", Version 2.11: Documentation and Users Manual; Department of Civil and Environmental Engineering, Tufts University: Medford, OR, USA, 2008.

El Bouraie M. M., Motawea E.A., Mohamed G.G., and Yehia M. M., "Water Quality Of Rosetta Branch In Nile Delta, Egypt", Suoseura 62(1), pp.31-37, Helsinki, 2011.

El-Gamal T., Meleha M.E., and Evelene S.Y., "The Effect Of Main Canal Characteristics On Irrigation Improvement Project", J. Agric. Sci. Mansoura Univ., Vol. 34, pp. 1078-1079, 2009.

Hamdard M., "Fresh Water Swaps: Potential For Wastewater Reuse A Case Study Of Alexandria, Egypt", UNESCO-IHE, 2010.

Hanfeng Y. E., Shuhai G.U.O., Fengmei L.I., and Gang L.I., "Water Quality Evaluation In Tidal River Reaches Of Liaohe River Estuary, China Using A Revised QUAL2K Model", Chinese Geographical Science, Vol. 23, No. 3, pp. 301–311, 2013.

Horton, R. K., "An Index Number System For Rating Water Quality", Journal of Water Pollution Control Federation, Vol. 37, No. 3, pp. 300–306, 1965.

House, M. A., "A Water Quality Index For River Management", Journal of the Institute of Water & Environmental Management, Vol.3, No. 4, pp. 336-344, 1989.

Hussein A. El Gammal and Hesham S. El Shazely, "Water Quality Management Scenarios In Rosetta River Nile Branch, Egypt", Twelfth International Water Technology Conference, IWTC12, Alexandria, Egypt, 2008.

Kalburgi P.B., Shivayogimath C.B., and Purandara B.K., "Application Of QUAL2K For Water Quality Modeling Of River Ghataprabha (India)", Journal of Environmental Science and Engineering, Vol. 4, No.12 (Serial No.37), Dec. 2010.

Moog D. B. and Jirka G. H., "Analysis of Reaeration Equations Using Mean Multiplicative Error", Journal of Environmental Engineering, Vol. 124, No. 2, February 1998, pp. 104-110, (doi: http://dx.doi.org/10.1061/(ASCE)0733-9372(1998)124:2(104)).

Noha Donia, "Rosetta Branch Waste Load Allocation Model", Ninth International Water Technology Conference, IWTC9, Sharm El-Sheikh, Egypt, 2005.

NRMED, Natural Resources Management and Environment Department, "Rapid Assessment Study: Towards Integrated Planning Of Irrigation And Drainage In Egypt", In Support Of The Integrated Irrigation Improvement And Management Project (IIIMP), FAO Corporate Document Repository, Final Report, Rome, 2005.

NWRC, National Water Research Center, "The operational drainage water reuse guidelines", (NAWQAM), 2007.

Rashed, A. and El-Sayed, E. A. (2014). "Simulating Agricultural Drainage Water Reuse Using QUAL2K Model: Case Study of the Ismailia Canal Catchment Area, Egypt", Journal of Irrigation and Drainage Engineering, 10.1061/(ASCE)IR.1943-4774.0000715 , 05014001.

Ruibin Zhang, Xin Qian, Xingcheng Yuan, Rui Ye, Bisheng Xia, and Yulei Wang, " Simulation Of Water Environmental Capacity And Pollution Load Reduction Using QUAL2K For Water Environmental Management", International Journal of Environmental Research and Public Health, Vol. 9, Issue 12, pp. 4504-4521, 2012.

Shiow-Mey Liou, Shang-Lien Lo, and Ching-Yao Hu, "Application Of Two-Stage Fuzzy Set Theory To River Quality Evaluation In Taiwan", Water Research, Vol. 37, pp.1406–1416, 2003.

Vasudevan M., Nambi, I. M., and Suresh Kumar, G., "Application Of Qual2k For Assessing Waste Loading Scenario In River Yamuna", International Journal of Advanced Engineering Technology, Vol. II, Issue II, pp. 336-344, April-June, 2011.

Yen-Chang Chen, Hui-Chung Yeh, and Chiang Wei, "Estimation Of River Pollution Index In A Tidal Stream Using Kriging Analysis", International Journal of Environmental Research and Public Health, Vol. 9, Issue 9, pp. 3085-3100, 2012.

Yeuh-Bin Wang, Chen-Wuing Liu, Pei-Yu Liao, and Jin-Jing Lee, "Spatial Pattern Assessment Of River Water Quality: Implications Of Reducing The Number Of Monitoring Stations And Chemical Parameters", Environ Monit Assess, Nov. 2013.

http://www.wunderground.com/weather-forecast/EG/Alexandria_International.html?