A MODELLING APPROACH TO MANAGE WATER QUALITY AT GHARBIA MAIN DRAIN, EGYPT

M. Mohamed[1], A. Elansary[2], M. Moussa[3]

[1]Assistant Professor, Environmental Engineering Program, Zewail City of Science and Technology, Giza, Egypt, Email: mkhaled@zewailcity.edu.eg
[2] Professor of Hydraulics, Irrigation and Hydraulics Dept., Faculty of Eng, Cairo University, Giza, Egypt
[3]Associate Professor, Environmental Engineering Program, Zewail City of Science and Technology, Giza, Egypt

ABSTRACT

The fundamental problem addressed during this study lies in the poor quality of surface water in Gharbia Main drain (Kitchener drain). This drain receives agricultural,domestic, industrial, as well as solid wastes from villages and cities located around its path. The main objective of this research is to manage water quality at the drain. The service area of the drain was divided into 6 main basins in order to facilitate the identification of the critical basins along the drain. Water samples were collected from the drain at each basin, and analyzed for different parameters by three different certified laboratories. The parameters included chemical oxygen demand (COD), total suspended solids (TSS),total nitrogen (TN), and total phosphorus (TP).The concentrations of the selected parameters were also obtained from the literature data. Data analysis was conducted using the box plot tool in order to identify the most reliable data to be used as a benchmark for comparison with the modeling data. A tailored water quality modeling was created using MATLAB to simulate pollutant transport in Gharbia Main drains. Exponential and mass balance equations were used to estimate the targeted water quality parameters along the drain path. Model validation was performed between model estimation and actual data. From an economic point of view, it is recommended to apply the depollution projects in the most critical basins. Thus, a comparison was conducted between the current situation and three proposed scenarios of improving water quality at most critical basins through reducing the load of the domestic wastewater.The model results showed that basins No.1, 2, and 6 have priority over the other basins to enhance the level of sanitation services, where they receive huge domestic wastewater loads which significantly affect the water quality at Gharbia Main drain. The results of the model also showed that improving water quality at basins No. 1, 2, 3, and 6 or basins No. 1, 2, 4, and 6is expected to significantly improve water quality at the drain.

Keywords: Gharbia Main Drain, Water quality modeling, Surface water management, MATLAB software, Mass balance
Received 25May 2017.Accepted 11 July 2017
Presented in IWTC 20

1 INTRODUCTION

The Gharbia Main drain (Kitchener drain) considers as one of the largest drainage systems in Egypt, which is located north of Cairo in the central part of the Nile Delta region.It extends about 69 km starting at Gharbia Governoratenorth of Tanta city and flowing through Dakahliya and Kafr El Sheikh Governorates and at the end empties into the Mediterranean Seaat Balteem city (EL Gammal et al., 2009). The drain discharges about 17.3 m^3/sec to the Mediterranean Sea.Al-Khashaa weir is located 10 km downstream the discharge point to the Mediterranean Sea for the purpose of reducing the flow rate to the sea. The drain width ranges from 22 to 60 m. The catchment area of the drain is about 1,855 km^2 (458,440 acres) (EL Gammal et al., 2009). Eleven districts are located in these three governorates and served by Kitchener drain; 5 in Gharbia Governorate, 3 in Kafr El-Sheikh Governorate, and 3 in Dakahliya Governorate.

Seven lifting pumping stations (PS) are located along the path of the drain for the purpose of increasing the downstream head of water. Six out of these seven PS are located upstream Al-Khashaa weir. Al Sijaiyyah PS is located at the beginning of the drain which lifts water to Kitchener drain from Tahwilat Samatay drain. Samatay PS is located 11 km downstream Al Sijaiyyah PS and lifts the water to Kitchener drain from Samatay Al-Asfal drain. Pumping stations numbers 5, 6, 3, and 4 are located 6, 21, 29, and 29 km downstream Samatay PS, respectively,and they lift water to Kitchener drain from drains numbers 5, 6, 3, and 4, respectively. The last PS is called Hafir Shehab El-Din and is located directly downstream Al-Khashaa weir. It lifts water to Kitchener drain from Samatay Al-Asfal drain. There are also six mixing pumping stations located along the path of the drain and they are responsible for mixing drain water with fresh water from the canals. The pump capacity in 5 out of the 6 mixing stations does not exceed 1 m^3/s, while Al Hamoul mixing station that is located 35.5 km downstream Al Sijaiyyah PS and contains 3 pumps with an average design capacity of 10 m^3/s. All the mixing and lifting pumping stations are operated by the Ministry of Water Resources and Irrigation. There are six feeders are located along the path of the drain and they withdraw about 5,000,000 m^3/day from the drain.

Kitchener drain receives agricultural,domestic, industrial, as well as solid wastes from villages and cities located around its path. The discharges from domestic, industrial, and agricultural activates represent 23, 2, and 75%, respectively (EL Gammal et al., 2009).The drain receives high organic loads from non-point sources indicating low coverage with sanitation service in the drain catchment area (Ministry of Water Resources and Irrigation, 2002). About 21.4% of the BOD load received by the drain is from domestic point sources, 61.1%from domestic on-point sources, while the remaining 17.5% is probably from industrial sources (Ministry of Water Resources and Irrigation, 2003).The main domestic point sources that contribute significantly to water pollution at Kitchener draincincludeMahalla and Tanta wastewater treatment plants (WWTPs). The flow from Mahalla WWTP (160,000 m^3/day) is directly discharged without prior treatment to the drain because the plant is currently out of service. Tanta WWTP discharges about 150,000 m^3/day of partially treated wastewater to Kitchener drain because the secondary treatment units at the plant are not working optimally. The main industrial facilities that contribute significantly to water pollution at Kitchener drain include El-Nasr Spinning, Weaving and Dyeing Company, Misr Spinning and Weaving Company, and Tanta Oil and Soap Company.

Using untreated wastewater in the irrigation purposes may lead to the presence of heavy metals in vegetables and food crops (Balk hair and Mohammad, 2016).The drainage water at Kitchener drain does not comply with the Egyptian standards for irrigation (EL Gammal et al., 2009). There are high to moderate restriction on the use of the water for irrigation purposes because ithas high salinity levelsaccording to Food & Agriculture Organization of the United Nation (FAO) guidelines (FAO, 1992). According to FAO guidelines, the biological oxygen demand (BOD)concentration in the drain meets the quality criteria for only class A crops, while the TSS concentration do not meet the quality criteria for all crop classes (FAO, 1992).Goyal (2016) has collected soil and water samples from canals located in El-Hamoul district, Kafr El-Sheikh governorate and a high concentration of heavy metals were reported in the soil samples, as well as in all the survived canals, especially after harvesting wheat and clovercrops. The author has concluded that the use of water from Kitchener drain for irrigation purposes represent a real threat to food security due to the accumulation of these heavy metals inhuman body.

The main purpose of this research is to evaluateand managewater qualityat Kitchener drain. A tailored water quality modeling software was employed to compare between different scenarios for the purpose of reducing the domestic loads from most critical basins before reaching the drain. This study also aims to specify the most critical basins along the drain.

2 MATERIALS AND METHODS

2.1 Study Area

The service area of Kitchenerdrain was divided into 6 main basins in order to facilitate the identification of the critical basins along the drain, as shown in Figure 1. Further, the flow rate was estimated or measured in 13 selected sections (Figure 1) along the drain to facilitate the identification of water withdrawal and discharge to the drain. Table 1 lists the technical details for each section regarding its location, the name of the subsidiary drains and pump stations located in each section, as well as the corresponding agricultural area for each section which is estimated at 382,440 acres in total. The study area at the drain extends about 56.5 km starting fromSegaaia pumping station to Khashaa weir because no drain water goes above Khashaa weir.

2.2 Water Sampling and Analysis

Water samples were collected on May 2016 from 5 points along the drain, and analyzed for different parameters by three different certified laboratories; National Research Center (NRC), Soil and Water Laboratory, and Environmental Monitoring Center - Ministry of Health and Population. The parameters included chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP). Historical data regarding the flow rate and water analysis at the same sampling points were also obtained from the Egyptian Environmental Affairs Agency for the same month. The research protocol included creating box plots to identify the most reliable data to be used as a benchmark for comparison with the modeling data. A box plot provides a graphic representation of the largest and smallest data points, the second quartile (median), the first quartile (25% of the data below the median), and the third quartile (25% of the data above the median), and any out liers exist in a sample (Navidi, 2010).

The load from each pollution source was calculated in each basin to help identify the most critical basins. The quantity of domestic wastewater in each basin was calculated based on the population in the service area. The load for each parameter was calculated based on the average per capita per day for each parameter (45 kg/cap/year for COD, 22.5 kg/cap/year for TSS, 4 kg/cap/year for TN, and 0.25 kg/cap/year for TP). These loads were calculated depends on the assumption that most of WWTPs operate at 50% efficiency. The quantity of industrial wastewater has been calculated based on the available record for each factory. The loads for COD, TSS, and TN were calculated using the publicly available measurements for these parameters in each direct and indirect pollution source. Direct pollution generates around 79,930 m^3/day, while indirect flow corresponds to a discharge flow of around 53,637 m^3/day.The drainage water quantity ranges from 35% to 40% of the irrigation water. The irrigation water has been calculated based on the irrigation demand for each crop during the four seasons. The total amount of phosphorus and nitrogen produced for each crop is estimated based on the data provided by Soil, Water & Environment Research Institute.

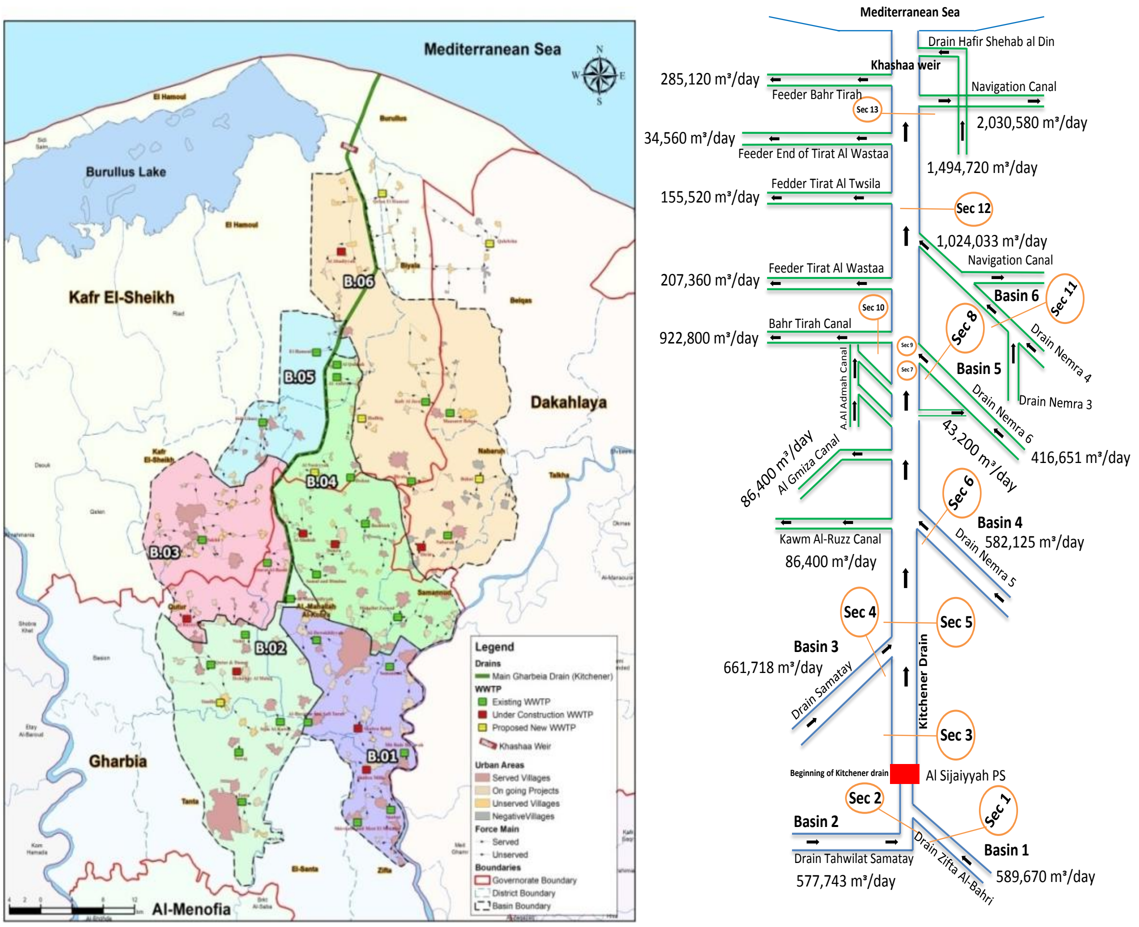

Figure 1.Six main basins of Kitchener drain and the selected sections along the drain

Table1. Locations of the sections along Gharbia Main drain

Section	Station (km)	Basin	Agricultural Area (acre)	Sub-drain & P.S.
Sec 1		Basin 1	54,750	Zifta Al-Omomy
Sec 2		Basin 2	74,755	Tahwilat Samatay
Sec 3*	0	Basin 1 & 2	129,505	Segaaia P.S
Sec 4	11.5	Basin 3	28,775	Samatay Al-Asfal & Samatay P.S.
Sec 5	12.8	-	-	Main drain
Sec 6	22.2	Basin 4	72,200	Nemra 5 & Nemra 5 P.S.
Sec 7	35	-	-	Main Drain
Sec 8	35.75	Basin 5	39,290	Nemra 6 & Nemra 6 P.S.
Sec 9	36.2	-	-	Main Drain
Sec 10	36.2	-	-	El- Hamoul P.S.
Sec 11	45.40	Basin 6	112,670	Nemra 3 & Nemra 4 Drain & P.S.
Sec 12	49.00	-	-	Main Drain
Sec 13	56.50	-	-	Main Drain
Total			382,440	

*Beginning of Kitchener drain

2.3 Water Quality Modeling

River Pollutant (RP) modeling was used to simulate pollutant transport in Kitchenerdrainfor Segaaia pumping station to Khashaa weir (Mostafa, 2014; Mostafa et al., 2015; Mostafa, 2015a; Mostafa, 2015b). The simulated parameters include COD, TSS,TN, and TP.Exponential and mass balance equations were used to estimate the targeted water quality parameters along Gharbia Main drain. The inputs to the modeling include the water flow at the beginning of the drain, inflows along its length, cross-sectional area of the drain, concentration of the selected parameters at the mouth of the drain and each point source along the drain, decay coefficient for each parameter, and withdrawal locations and flows. The expected outputs from the drain include the total flow at the end of the drain and the concentration of the selected parameters along the study area. The decay coefficient for each parameter was calculated from published paper using the exponential equation to accurately simulate water quality at Gharbia Main drain (Shaban et al., 2010). The calculated decay coefficient for COD, TSS, TN, and TP was 0.19, 0.38, 0.2, and 0.0367 day^{-1}, respectively. Model validation were performed between model estimation and actual data. Correlation coefficients were obtained between the natural and modeling data to help identifying the accuracy of the RP modeling.Then,a comparison was conducted between the current situation and two proposed scenarios of improving water quality at most critical basins through reducing the load of the domestic wastewater.

3 RESULTS AND DISCUSSION

The total, domestic, agricultural, and industrial wastewater quantity in the six basins was 522,757, 3,195,616, and 133,567m^3/day. Table 2 presents the total organic loads from the domestic wastewater. For agricultural flows, the main pollutants are TN and TP. Table 3 shows summary of the total phosphorus and nitrogen loads at selected sections. Table 4 shows the load of different parameters in the selected sections.

Table 2. Average estimated domestic wastewater loads for COD, TSS, TN, and TP

Basin number	Main drain	Station	WWTP number	Population calculated, capita	Discharge calculate, m^3/day	Flow Ratio, %	Total load, ton/day			
				2017	2017	2017	COD	TSS	TN	TP
Basin 1	Zifta Al-Bahri	Sec 1	8	1,371,628	170,280	32.6	128	64	13	0.9
Basin 2	Tahwilat Samatay	Sec 2	8	897,374	125,498	24.0	79	39	8	0.6
Basin 3	Samatay Al Asfal	Sec 4	3	524,503	79,252	15.2	55	27	5	0.35
Basin 4	Nemra 5	Sec 6	9	465,785	48,228	9.2	52	26	5	0.32
Basin 5	Nemra 6	Sec 8	2	187,838	22,589	4.3	17	9	2	0.12
Basin 6	Nemra 4	Sec 11	8	637,388	76,910	14.7	73	36	7	0.43
Total			38	4,084,516	522,757	100	404	202	40	2.8

Table 3.Estimated TN and TP Loads from drainage water at each basin

Basin number	Main drain	Station	Station (km)	Estimated drainage water, m^3/day	Total load, ton/day	
					TN	TP
Basin 1	Zifta Al-Bahri	Sec 1	69.00	365,753	6.14	0.64
Basin 2	Tahwilat Samatay	Sec 2	69.00	450,685	7.70	0.86
Basin 3	Samatay Al Asfal	Sec 4	57.50	582,466	11.67	0.99
Basin 4	Nemra 5	Sec 6	46.80	466,027	8.34	0.87
Basin 5	Nemra 6	Sec 8	33.25	383,562	4.38	0.58
Basin 6	Nemra 4	Sec 11	23.6	947,123	8.72	0.92
	Total			3,195,616	46.94	4.86

Table 4. Estimated loads of industrial pollution on each basin

Basin number	Main drain	Section	Industrial discharge m^3/day		Total load, ton/day			
					Direct pollution			Indirect pollution
			Direct	Indirect	COD	TSS	TN	COD
Basin 1	Zifta Al-Bahri	Sec 1	-	53,637	-	-	-	23.15
Basin 2	Tahwilat Samatay	Sec 2	1,560	-	0.4	-	-	-
Basin 3	Samatay Al Asfal	Sec 4	-	-	-	-	-	-
Basin 4	Nemra 5	Sec 6	67,870	-	20.9	1.8	0.76	-
Basin 5	Nemra 6	Sec 8	10,500	-	11.5	0.16	-	-
Basin 6	Nemra 4	Sec 11	-	-	-	-	-	-
Total			79,930	53,637	32.8	1.96	0.76	23.15

3.1 Assessment of Pollution Load in the Kitchener Drain

The load of each parameter was calculated in each basin, as shown in Figure 2. The highest COD, TSS, TN, and TP loads were recorded in basins No. 1, 2, 3, and 6. It was concluded that these four basins are the most critical basins when compared with the other basins and this is mainly due to the huge water quantities at these basins. The huge loads at these basins have adversely affected the water quality at Gharbia Main drain. From an economic point of view, it is recommended to apply the depollution projects in the most critical basins.

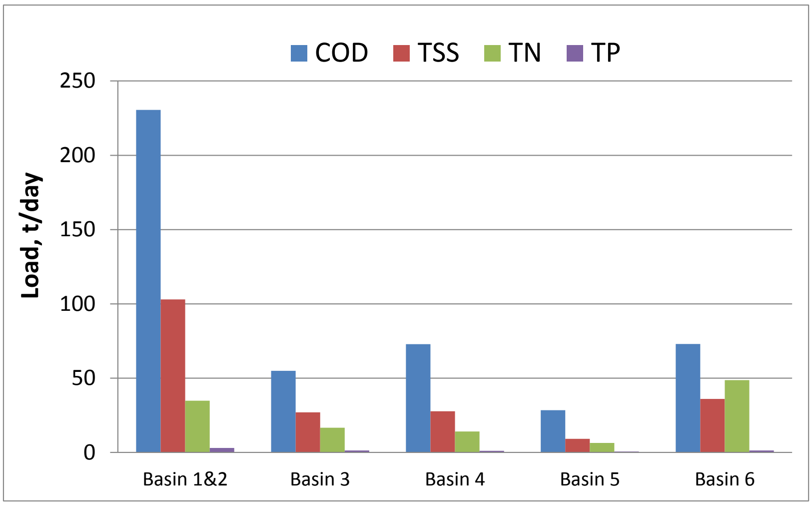

Figure 2. COD, TSS, TN, and TP load in each basin along Gharbia Main drain

3.2 The Proposed Scenarios

Three scenarios were proposed to reduce pollution load in Gharbia Main drain by constructing new WWTPs and improve the efficiency of the existing WWTPs. First scenario is to reduce the domestic wastewater load at basins No. 1, 2, and 6.Second scenario involves reducing the domestic wastewater load at basins No. 1, 2, 3, and 6. Third scenario is to reduce the domestic wastewater load at basins No. 1, 2, 4, and 6.

3.3 Water Samples Analysis and Boxplot

Table 5 shows analysis of water samples collected from Kitchener drain for different labs along with the calculated and historical data. The box plot was performed for the results reported at the beginning of the study area (section 3). As shown in Figure 3, the box plot for all four parameters is tall. This suggests that the labs and the historical data hold quite different results for the four selected parameters. For COD,TSS, TN, and TP, most of the results are on the low end of the scale (skewed right), while for TP, most of the results are on the high end of the scale (skewed left). The interquartile range for COD, TSS, TN, and TP is 198.3, 93.75,22.05, and 1.115, respectively.The median for COD, TSS, TN, and TP is 158, 93.5, 22.86, and 2.1 mg/L, respectively. The box plot results also indicated that the historical and thecalculated data are the most reliable data because they are more close to the median when compared with the results from the three labs.

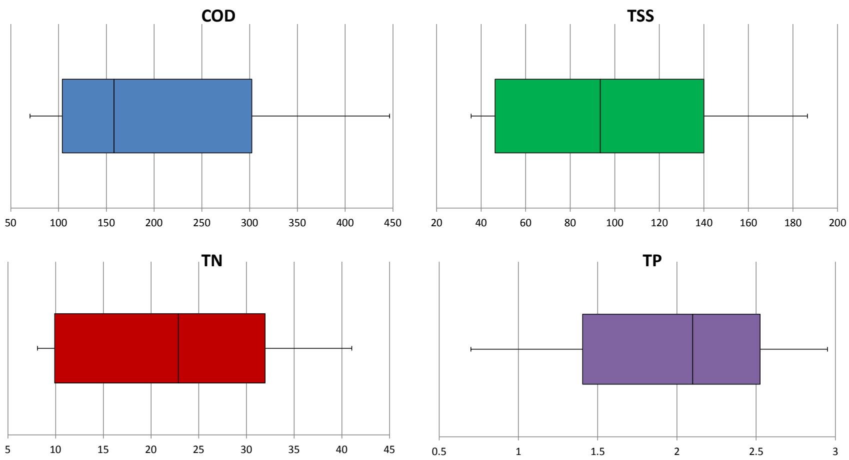

Figure 3. Box plot for COD, TSS, TN, and TP

Table 5.Analysis of water samples collected along the drain

Section/ parameter	National Research Centre	Soil and Water Laboratory	Environmental Monitoring Center - Ministry of Health and Population (1st day)	Environmental Monitoring Center - Ministry of Health and Population (2nd day)	Historical data*	Egyptian Environmental Affairs Agency	Calculated data
COD, mg/L							
Section 3	70	158	269	115.2	266	402	198
Section 5	15	-	-	58.8	131.3	-	-
Section 9	45	-	-	56.8	101.7	-	-
Section 12	-	-	-	95.2	90.6	-	-
Section 13	54	-	-	-	82.3	-	-
TSS, mg/L							
Section 3	35.5	-	57	130	148	150	88
Section 5	28.5	-	-	118	70.4	-	-
Section 9	29	-	-	190	50	-	-
Section 12	-	-	-	126	41.4	-	-
Section 13	40	-	-	-	37.8	-	-
TN, mg/L							
Section 3	37.8	10.5	29.7	16.02	38.5	8.1	30
Section 5	20.8	8.62	-	9.96	20.6	-	-
Section 9	20	8	-	9	17.2	-	-
Section 12	-	-	-	6	10.5	-	-
Section 13	12	7	-	-	7.8	-	-
TP, mg/L							
Section 3	2.5	2.2	2	0.7	2.5	1.64	2.6
Section 5	1.85	1.3	-	0.3	1.7	-	-
Section 9	2	1.4	-	0.2	1.51	-	-
Section 12	-	-	-	0.2	1.25	-	-
Section 13	2.23	0.9	-	-	1.1	-	-

*Shaban et al., 2010

3.4 Modeling Validation and Results

The created modeling was validated by comparing the modeling results and the actual data for the current situation. The modeling was found to be efficient, where a significant coefficient of determination values were obtained between the actual and predicted valuesfor the four studied parameters. The R^2 for COD, TSS, TN, and TP was recorded as 0.89, 0.98, 0.87, and 0.95, respectively.

Table 6 presents the input data required to run the created modelling. The concentrations of COD, TSS, TN, and TP at Basins 1, 2, 3, 4, and 6 were adjusted for the proposed scenarios according to the expected reduction in the domestic pollution loads after applying the proposed depollution projects.Based on the current operating conditions, the COD, TSS, TN, and TP concentartions along the study area clearly exceeded the permissible limits specified in Egyptian Law 48/1982 (COD ≤ 80 mg/L, TSS ≤ 30 mg/L, TN ≤ 10 mg/L, TP ≤ 2 mg/L), as presented in Figures 4 through 6.The COD, TSS, TN, and TP concentartions along the study area is expected to reduce significantly after improving the water quality at basins 1, 2, and 6 (first scenario), and expected to reduce further after applying the second or the third scenario. The COD concentration is expected not to exceed the allowable limits when applying the first scenario, as presented in Figure 4.The TSS concentration is expected to slightly exceed the allowable limits at km 11.5 and km 20.17 when applying the first scenario, as presented in Figure 5. This is mainly attributed to high TSS load discharged from basins 3 and 4 to the drain. The main sources of TSS load in these basins are the domestic wastewaterand the solid wastes.The TSS concentration is expected not to exceed the allowable limits when applying the second or the third scenario.The TN concentrationis expected to exceed the allowable limit from km 11.5 till the end of the study area even after applying the first scenario due to the the excessive use of fertlizers in the agricultural lands of basins3 and 4, as presented in Figure 6.The TN concentration is expected slightly exceed the allowable limits from km 20.17 to km 44.1 even after applying the second or the third scenario. The TP concentration is expected not to exceed the allowable limits when applying the first scenario, as presented in Figure 7.

The model results showed that applying the second or the third scenario is more preferable than applying the first scenario since it is expected to significanlty improve water quality at Kitchener Drain. But, from an economic point of view, it may be preferable to apply the first scenario and improve water quality at only three basins. Improving water quality at Basins No. 1, 2, and 6 is expected to reduce COD, TSS, TN, and TPloads in Kitchener drain by about 72.3, 77.8, 58.2, and 60.8%,respectively.

Table 6. Input data required to simulate the Pollutants Transport in the Drain

Current situation	**Basin1&2**	**Basin3**	**Basin4**	**Basin5**	**Basin6**
Parameter/flow (m^3/day)	1,167,413	661,718	582,125	416,651	1,024,033
COD, mg/L	198	84	125	70	71
TSS, mg/L	88	41	48.5	22	35.5
TN, mg/L	30	25.7	24	15.4	15.5
TP, mg/L	2.6	1.5	1.5	1.4	0.9
First proposed scenario (Improve basins 1,2 &6)	**Basin1&2**	**Basin3**	**Basin4**	**Basin5**	**Basin6**
Parameter/flow (m^3/day)	1,167,413	661,718	582,125	416,651	1,024,033
COD, mg/L	50	84	125	70	50
TSS, mg/L	30	41	48.5	22	30
TN, mg/L	10	25.7	24	15.4	10
TP, mg/L	1.9	1.5	1.5	1.4	0.7
Second proposed scenario (Improve basins 1,2,3 & 6)	**Basin1&2**	**Basin3**	**Basin4**	**Basin5**	**Basin6**
Parameter/flow (m^3/day)	1,167,413	661,718	582,125	416,651	1,024,033
COD, mg/L	50	50	125	70	50
TSS, mg/L	30	30	48.5	22	30
TN, mg/L	10	10	24	15.4	10
TP, mg/L	1.9	1.3	1.5	1.4	0.7
Third proposed scenario (Improve basins 1,2, 4&6)	**Basin1&2**	**Basin3**	**Basin4**	**Basin5**	**Basin6**
Parameter/flow (m^3/day)	1,167,413	661,718	582,125	416,651	1,024,033
COD, mg/L	50	84	50	70	50
TSS, mg/L	30	41	30	22	30
TN, mg/L	10	25.7	10	15.4	10
TP, mg/L	1.9	1.5	1	1.4	0.7

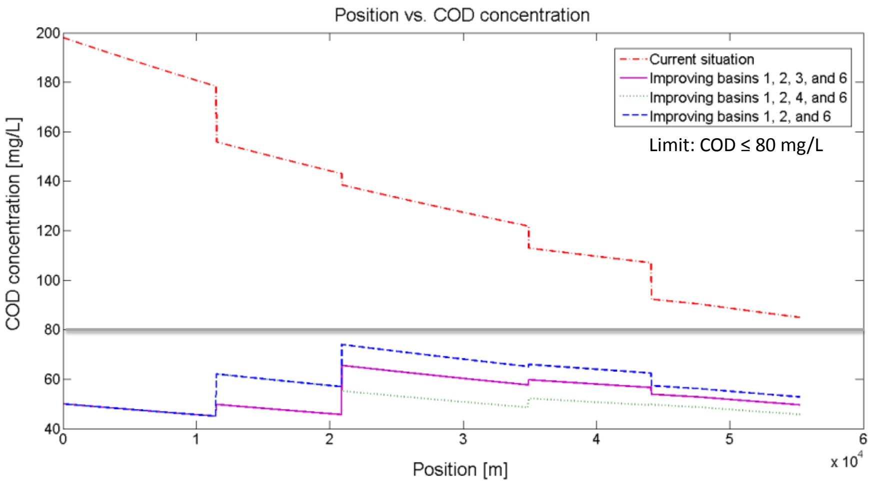

Figure 4. CODconcentration along Kitchener drain for the current situation and proposed depollution scenarios

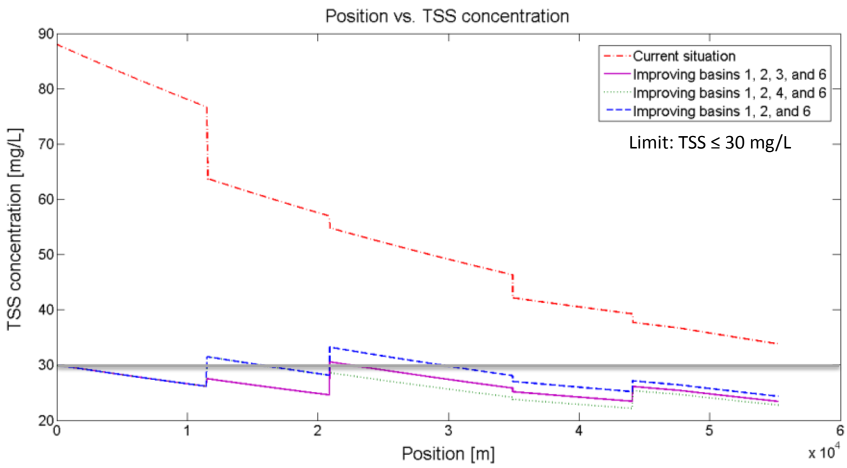

Figure 5.TSS concentration along Kitchener drain for the current situation and proposed depollution scenarios

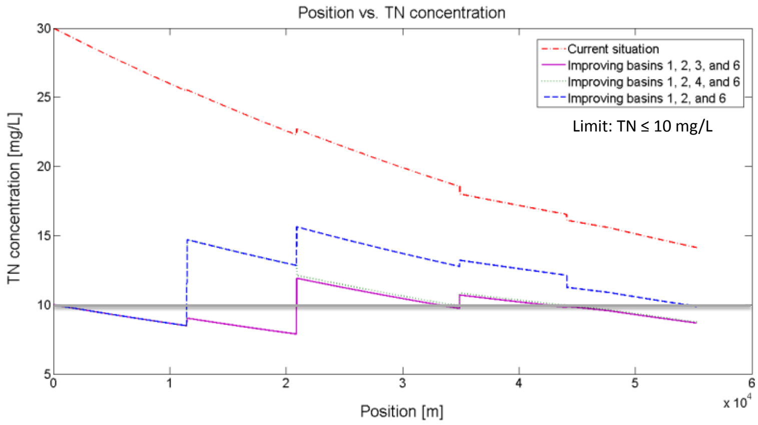

Figure 6.TN concentration along Kitchener drain for the current situation and proposed depollution scenarios

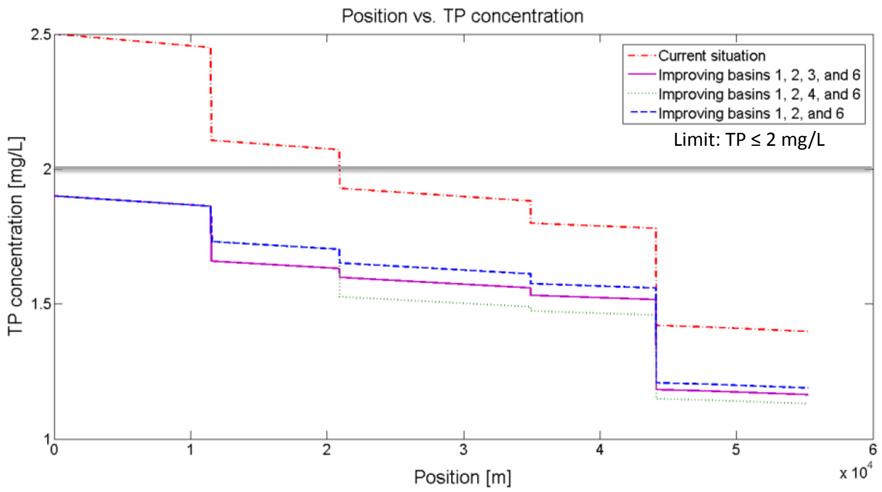

Figure 7. TP concentration along Kitchener drain for the current situation and proposed depollution scenarios

4 CONCLUSIONS

The water quality on Kitchener drain is adversely affected by the discharge of domestic, industrial, and agricultural wastewater.The highest pollutants loads were recorded in basins No. 1, 2, and 6. Domestic wastewater has the highest contribution in increasing the pollution load in the drain due to the low efficiency of the existing WWTPs located in these basins.Since, this study aims to manage water quality at the drain at the lowest cost.A comparison was conducted between three scenarios: (1) reduce domestic wastewater load at basins 1, 2, and 6; (2) reduce domestic wastewater load at basins 1, 2, 3, and 6; and (3) reduce domestic wastewater load at basins 1, 2, 4, and 6. First, the created model was validated and good coefficients of determination values were obtained between the actual and predicted values. The R^2 for COD, TSS, TN, and TP was recorded as 0.89, 0.98, 0.87, and 0.95, respectively. The model results showed that applying the second or the third scenario will significantly reduce pollutants loads in the drain, and thus improve its water quality.But, from an economic point of view, it may be preferable to apply the first scenario. The domestic wastewater load at the selected basins can be reduced through improve the efficiency of the existing WWTPs and constructing new WWTPs. This will help meeting the criteria for the irrigation of all crop classes.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Mohamed El-Shourbagy of Chemonics Egypt Consultants for his assistance in the laboratory analysis.

ABBREVIATIONS

BOD	Biological oxygen demand
COD	Chemical oxygen demand
FAO	Food & Agriculture Organization of the United Nation
NRC	National Research Center
PS	Pumping stations
TN	Total nitrogen
TSS	Total suspended solids
TP	Total phosphorus
WWTP	Waste Water treatment plant

REFERENCES

Balkhair, K.S. & Muhammad, A.A. (2016) Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. *Saudi Journal of Biological Sciences*, 23, pp.S33-S44, doi:10.1016/j.sjbs.2015.09.023

EL Gammal, H.A.A., Hatem, M.M.A. & Aly, N.E.(2009) Assessment of Water Reuse as a Non-Conventional Water Resource in Egypt case study: Gharbia drain, Nile Delta. *Thirteenth International Water Technology Conference*, IWTC13 2009, Hurghada, Egypt, pp. 1581-1593

FAO (1992) Wastewater Treatment and Use in Agriculture. Food and Agriculture Organization, Irrigation and Drainage Paper 47, Rome, Italy

Goyal, M.R. (2016) Wastewater Management for Irrigation: Principles and Practices.*Apple Academic Press, Inc.*, Boca Raton, FL, USA: CRC Press, Ttaylor& Francis Group, pp. 12-18

Ministry of Water Resources and Irrigation (2002) Survey of Nile System Pollution Sources. Report No. 64, United States Agency for International Development/Egypt

Ministry of Water Resources and Irrigation (2003) Nile River Water Quality Management Study.Report No. 67, United States Agency for International Development/Egypt

Mostafa, M. (2014) Modeling of Pollutant Transport in the Nile Delta, Egypt. PhD Dissertation, Department of Civil, Construction, and Environmental Engineering, University of Alabama at Birmingham, Birmingham

Mostafa, M., Elshafei, M. & Peters, R. (2015) Improve Water Quality at the El-Rahawy Drain and the Rosetta Branch, Egypt. *Journal of Environmental Protection*, 6, 1139-1148. doi: 10.4236/jep.2015.610101

Mostafa, M. (2015a) Simulating the Effect of Improving Water Quality at the El-Rahawy and the Tala Drains in the Rosetta Branch Water Quality. *Journal of Water Resource and Protection*, 7, 1271-1279.doi: 10.4236/jwarp.2015.716103

Mostafa, M.K. (2015b) Impact of Improving Water Quality at the Tala Drain on the Rosetta Branch Water Quality. *Journal of Environmental Protection*, 6, 1149-1157. doi: 10.4236/jep.2015.610102

Navidi, W., (2010), Statistics for Engineers and Scientists, New York, NY, United States of America: McGraw-Hill

Shaban, M., Urban, B., El Saadi, A. & Faisal, M. (2010) Detection and mapping of water pollution variation in the Nile Delta using multivariate clustering and GIS techniques. *Journal of Environmental Management*, 91, pp. 1785-1793, doi:10.1016/j.jenvman.2010.03.020