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BOD and DO modeling for Tigris River at Baghdad city portion using QUAL2K model

نمذجة المطلب الحيوي للأوكسجين والأوكسجين المذاب لمياه نهر دجلة في مدينة بغداد باستخدام QUAL2K موديل

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Abstract:
This study was conducted within Baghdad portion of Tigris River, which is significant due to the presence of various drains joining the river. Water samples have been collected from Tigris River along different points between Alfahama to Al-Zafarania and were analyzed for various water quality parameters during low flow season (November). The study involves application of QUAL2K model to simulate and predict the dissolved oxygen (DO) and biochemical oxygen demand (BOD_5) profiles of Tigris River in a stretch of 49.97 kilometer. Remote sensing &GIS technique (ERDAS 9.2 & Global Mapper 11) used in this study as supported software to provide some QUAL2K input data related to the river geometric parameter. The simulation results were verified and showed that the predicted values were in agreement with the measured values. Model output showed that DO in the entire river was within limit of not less than 4 mg/L. For CBOD, the entire river may be divided into three reaches; first one is extended from AlFahama (0 km) to Alkadhmiah (9 km) and have CBOD concentration of 2 mg/L and the second reach has CBOD range (2–4) mg/L in which begins from Alkadhmiah and extend to near Aldora refinery. The third reach extends from Aldora refinery to Al-Zafaraniah (49.97) in the south before river confluence with Diyala River which has CBOD concentrations of more than 4 mg/L. The most polluted zone in the river located downstream of Aldora refinery and extend to the last segment due to the industrial discharge of pollutants to the river. Two strategies were suggested to control the level of CBOD in the river. First strategy suggest that the CBOD of the discharged effluent from industries should not exceed at least 50 mg/L to keep the CBOD of the entire river within limits of not more than 4 mg/L. While the second strategy does not give significant results in which the level of CBOD increase even with reduction in the pollution load (point source).
Key words: QUAL2K; Water quality modeling; Tigris River; BOD; DO; GIS.

المستخلص:
أختص هذا البحث بدراسة جزء من نهر دجلة والواقع في بغداد والذي تبرز اهميته نتيجة وجود عدة مصبات تصب في النهر. تم جمع العينات من نهر دجلة لعدة مواقع بين منطقة الفحامة والزعفرانية وتم أجراء بعض الفحوصات عليها خلال موسم جريان منخفض. وتضمنت هذه الدراسة تطبيق للموديل QUAL2K لمحاكاة وتوقع الاوكسجين المذاب والمطلب الحيوي للأوكسجين في مياه النهر بمسافة تقدر بحوالي 49.97 كيلومتر. أستخدمت تقنية التحسس النائي و نظم المعلومات الجغرافية في هذه الدراسة كبرنامج داعم لتجهيز بعض البيانات للموديل QUAL2K والمتعلقة بالمحددات الهندسية للنهر. تم التحقق من نتائج الموديل والتي أظهرت ان القيم المتوقعة كانت منسجمة مع القيم المقاسة. أظهرت نتائج الموديل بأن تركيز الأوكسجين المذاب في النهر يقع ضمن المواصفات لايقل عن 4 ملغم/لتر أما في حالة الـ BOD فيمكن تقسيم المنطقة المدروسة الى ثلاث اجزاء، الجزء الاول يمتد من الفحامة (0 كم) الى الكاظمية (9 كم) والذي له تركيز المطلب الحيوي للاوكسجين 2 ملغم/لتر،

والجزء الثاني يتراوح تركيز المطلب الحيوي للاوكسجين له بين 2-4 ويبدأ هذا الجزء من الكاظمية ويمتد الى مصفى الدورة تقريبا، أما الجزء الثالث فيمتد من أسفل مصفى الدورة الى الزعفرانية والذي له تراكيز BOD أعلى من 4 ملغم/لتر. ان اكثر مناطق النهر تلوثا هي تلك التي تقع اسفل التيار من مصفى الدورة لتمتد الى الزعفرانية بسبب طرح الملوثات الى النهر. تم اقتراح ستراتيجيتان للسيطرة على مستوى المطلب الحيوي للاوكسجين في النهر. الستراتيجية الاولى تقترح بأن تلتزم المصانع بطرح مخلفاتها مع ضمان عدم ارتفاع تركيز المطلب الحيوي للاوكسجين عن 50 ملغم/لتر لتبقى قيم المطلب الحيوي للاوكسجين في النهر ضمن الحدود المسموح بها وهي ان لايتجاوز 4 ملغم/لتر. بينما الستراتيجية الثانية لم تعطي نتائج مهمة، حيث يزداد تركيز المطلب الحيوي للأوكسجين حتى مع انخفاض التلوث من المصادر النقطية.

Abbreviations:

CBOD: carbonaceous biochemical oxygen demand
DO: dissolved oxygen
USEPA: united states environmental protection agency
GIS: geographic information systems
ETM: enhanced thematic mapper
DEM: digital elevation model

1. Introduction

The wastewater disposal generated from municipal and industrial sources without adequate treatment prior to discharge is current practice in most developing countries [1]. The population of Baghdad has been increased rapidly from 4.5 million in 1990 to 6.5 million in 2004 and wastewater generation in the city is about 1.2 m^3/day [2]. In Baghdad (capital of Iraq), wastewater disposal has been continuing over the history of civilization but as a result of population growth, serious problems of water quality are commonplace in water bodies of Baghdad [2]. The Tigris River is the main river in Baghdad in which entering the city divided into two parts Karkh and Rasafa. The river water in Baghdad is used for both abstractive and in-stream purposes. The water is used as raw water source for seven drinking water treatment plants, irrigation purposes and for cooling by industries. Effective management of this segment of the river is, therefore, of prime importance. In this context, computer-aided models have gained wide acceptance as a tools to predict the quality of water.

Strategy of the water quality management may involve a series of complex inter-disciplinary decisions based on expect responses of water quality to changing controls [3]. Mathematical models are described the complex relationships between waste loads from different sources and the resulting water qualities of the receiving waters [4]. A suitable water quality model which can simulate the river system is essential to the water quality management of Tigris River. The most widely used mathematical model for conventional pollutant impact evaluation is QUAL2E [5] developed by United States Environmental Protection Agency (US EPA). However, several limitations of the QUAL2E have been reported [6, 7]. One of the major inadequacies is the lack of provision for conversion of algal death to carbonaceous biochemical oxygen demand [6]. Now, USEPA has released a new version model, QUAL2K [8] to represent a modernized version of the QUAL2E model. QUAL2K model included the addition of new water quality interactions, such as conversion of algal death to BOD, denitrification, and DO change caused by fixed plants and, these new elements can overcome limitations of QUAL2E. Although, USEPA has released a new version model (QUAL2Kw) but this version is related to the QUAL2K model that was developed by [8] with including of some processes such as genetic algorithm and Monte Carlo simulation.

Paliwal [9] have simulated the BOD and DO concentration in Yamuna River at Delhi using QUAL2E model. They had showed four different pollution scenarios to manage the water quality in the river. Their results were wide acceptance with literature studies conducted on the river. Kannel [10] has used QUAL2Kw model to simulate various water quality management strategies during the critical period for Bagmati River in Kathmandu Valley (Nepal). They stated that the local oxygenation is effective to maintain minimum DO concentrations in the river.

QUAL2K is one-dimensional, steady flow stream water quality model and thus its application is limited to steady state flow condition. It has many new elements. It includes DO interaction with fixed plants, conversion of algal death to CBOD and reduction of amount of CBOD due to denitrification. It is useful in data limited conditions and is freely available (http://www.ecy.wa.gov/).

A real situation of a river can be represented more closely using complex models. However, the complex models, such as 2D or 3D, are highly sophisticated and are usually reserved for large (i.e. deep and wide) rivers/estuaries where the mixing patterns are complex and require large amount of data [11]. The Tigris River-reach being simulated is long with respect to the mixing length over the cross-section and the transport is dominated by longitudinal changes [12, 13]. Thus, the assumption of 1D process is valid. Hence QUAL2K was chosen as a framework of water quality modeling.

In this paper, the utilization of QUAL2K as a complete decision-making package has been studied to predict the DO and BOD_5 concentration in the Tigris river at Baghdad stretch.

2. Materials and Methods

Study Area:

The Tigris River is one of the largest rivers of the Middle East stretching for over 1,900 km, of which 1415 km are within Iraq, with a catchment area of 235000 km^2, sharing with Euphrates River as the main sources for man use, especially for drinking water since they pass the major cities in the country [14].

The Tigris River originates in the Toros mountains of southeastern Turkey; it passes through Turkey, Syria, and Iraq. There are many tributaries flow into the river; these include Botmanse, Kessora, A1-Khabur, the Greater and Lesser Zabs, and A1-Adhaim and Diyala Rivers [15].

Tigris River is the main source of drinking water for Baghdad, the capital of Iraq. Baghdad stretch of the Tigris River extends from Al-Fahama in the north to Al-Zafaraniah in the south before river confluence with Diyala River (Fig. 1). This reach is almost of 50 km length which considered for modeling the DO and BOD concentrations. The River divides the city into a right (Karkh) and left (Risafa) sections with a flow direction from north to south. The area is characterized by arid to semi-arid climate with dry hot summers and cold winters; the mean annual rainfall is about 151.8 mm [16].

Baghdad, with its 6.5 million people, is considered to be the most populated and industrialized city in Iraq. The majority of its municipal and industrial wastes are discharged directly into the river without adequate treatment which makes the river water polluted specially with organic substances [15, 17].

Remote sensing & GIS technique:

A Satellite image of Landsat7-ETM (2009) corrected by used ERDAS 9.2 has been used in this research as shown in (Fig. 2), the satellite data was visually interoperated and accuracy was checked on the ground. Digital Elevation Model (DEM) was created using Global Mapper.11 (Fig. 3), the satellite image and DEM pictures has been used to predict the hydraulic parameter for the Tigris River such as longitudinal slope, exacts location for the sample which inter them into QUAL2K model to get the result.

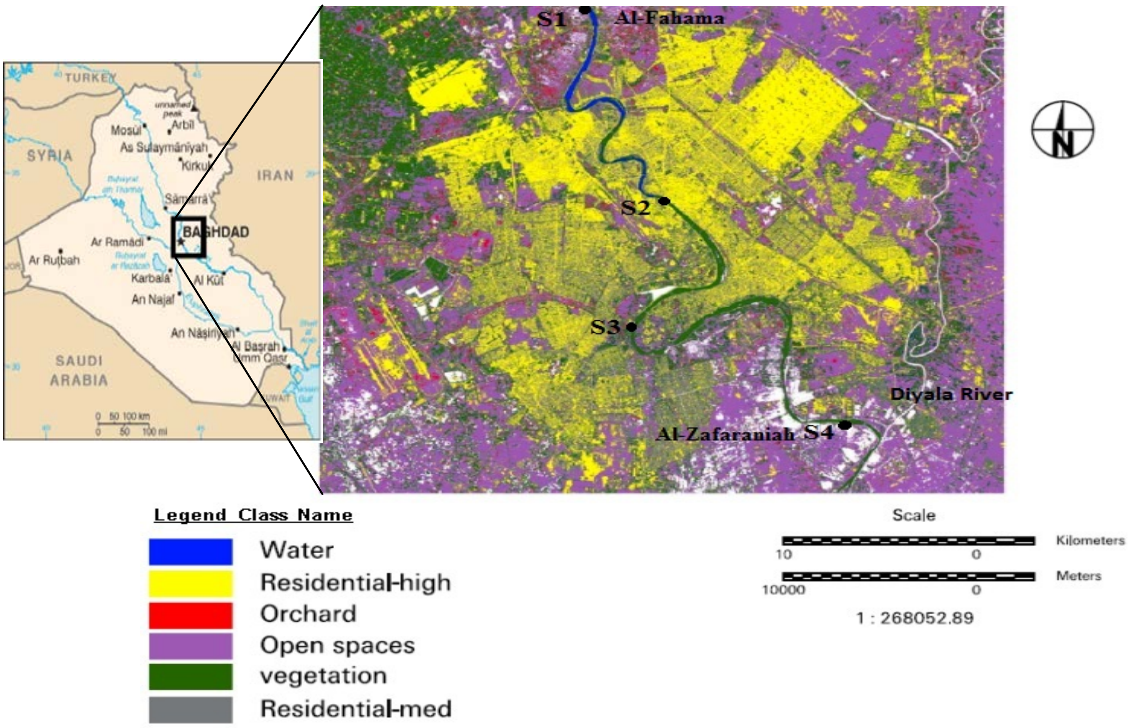

Figure 1: description of study area with sampling locations

Figure 2: Satellite images of Baghdad city from Landsat7-ETM (2009) corrected by used ERDAS 9.2

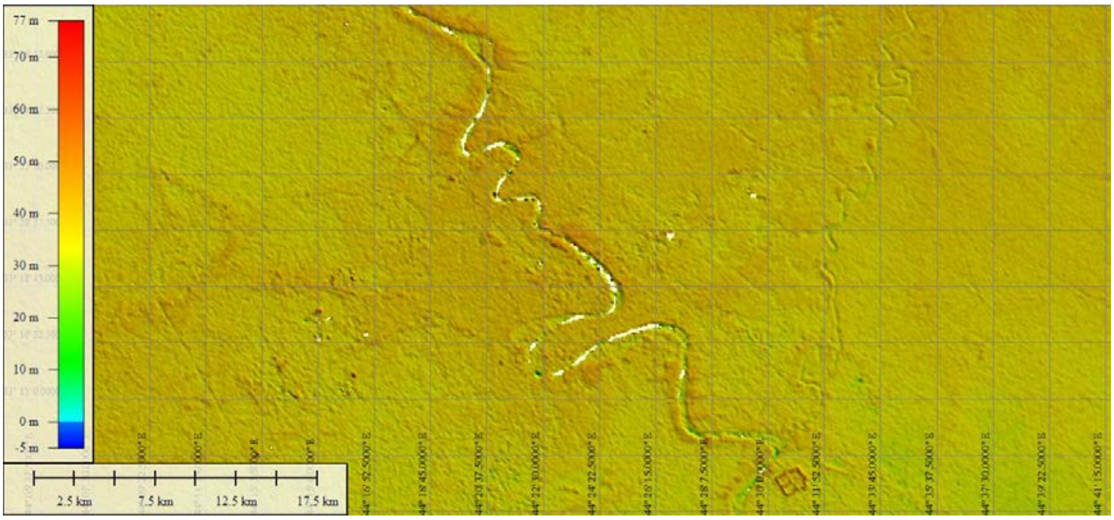

Figure 3: Digital elevation model (DEM) for Tigris River by Using Global Mapper.11

Model Description:

QUAL2K is a river and stream water quality model and is modernized version of the QUAL2E. The following features characterize QUAL2K: [8] (i) one dimensional (the channel is well-mixed vertically and laterally); (ii) steady-state hydraulics (non-uniform, steady flow is simulated); (iii) diurnal heat budget (the heat budget and temperature are simulated as a function of meteorology on a diurnal time scale); (iv) diurnal water-quality kinetics (all water-quality variables are simulated on a diurnal time scale); (v) Heat and mass inputs (point and non-point loads and abstractions are simulated).

In the QUAL2K model the River is divided into several reaches and each reach divided into segments. These segments are model's shortest parts of simulation. A steady-state flow balance is implemented for each model reach:

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{ab,i} \qquad (1)$$

where Q_i is outflow from reach i into reach i +1, m^3/d; Q_{i-1} is inflow from the upstream reach i-1, m^3/d; $Q_{in,i}$ is the total inflow into the reach from point and non-point sources, m^3/d; and $Q_{ab,i}$ is the total outflow from the reach due to point and non-point abstractions, m^3/d.

Once the outflow for each reach is computed, the depth and velocity are calculated in one of three ways: weirs, rating curves, and Manning equations. In this study, each river reach is idealized as a trapezoidal channel [17]. Under conditions of steady flow, the Manning equation can be used to express the relationship between flow and depth as:

$$Q = \frac{S_\circ^{1/2}}{n} \times \frac{A_c^{5/3}}{P^{2/3}} \qquad (2)$$

Where Q = flow [m^3/sec]; S_o = bottom longitudinal slope [m/m]; n = Manning roughness coefficient; A_c = cross sectional area [m^2]; and P = wetted perimeter [m].

This model can simulate fate and transport of so many parameters and contaminants including temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, various kinds of nutrients, phytoplankton and bottom algae. In this study, DO and BOD are considered for modeling their concentration in the river.

The modeling tool QUAL2K has a general mass balance equation for a constituent concentration (Fig. 4) in the water column of a reach i (the transport and loading terms are omitted from the mass balance equation for bottom algae modeling) as: [18]

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}C_{i-1} - \frac{Q_i}{V_i}C_i - \frac{Q_{ab,i}}{V_i}C_i + \frac{E_{i-1}}{V_i}(C_{i-1} - C_i) + \frac{E_i}{V_i}(C_{i-1} - C_i) + \frac{W_i}{V_i} + S_i \quad (3)$$

where Ci is variable concentration for reach i, g/m^3; t is time, d; Q_i is outflow from reach i into reach i +1, m^3/s or m^3/d; Vi is volume of ith reach (m^3); Ei is bulk dispersion coefficient between reaches i and i +1, m^3/d; Wi is external loading of the constituent to reach i, g/d or mg/d; and S_i is sources and sinks of the constituent due to reactions and mass transfer mechanisms, g/m^3/d or mg/m^3/d. For bottom algae the transport and loading terms are omitted.

The QUAL2K employed hydraulics based formula to determine the longitudinal dispersion for a boundary between two reaches (internally compute dispersion based on the channel's hydraulics): [8]

$$E_{p,i} = 0.011\frac{U_i^2 B_i^2}{H_i U_i^*} \quad (4)$$

$$U_i^* = \sqrt{gH_iS_i} \quad (5)$$

where $E_{p,i}$ is the longitudinal dispersion between reaches i and i + 1 [m^2/s], U_i is velocity [m/s], B_i is width [m], H_i is mean depth [m], and U_i^* is shear velocity [m/s], g is acceleration due to gravity [= 9.81 m/s^2] and S is channel longitudinal slope.

Model requires input of these characteristics: geographic characteristics (geographical longitude and latitude, elevation), meteorological characteristics (air temperature, dew point, wind speed, cloud cover, shade), physical-chemical and biological parameters of waste water, hydraulic (morphological elements, Manning roughness coefficient, flow curve).

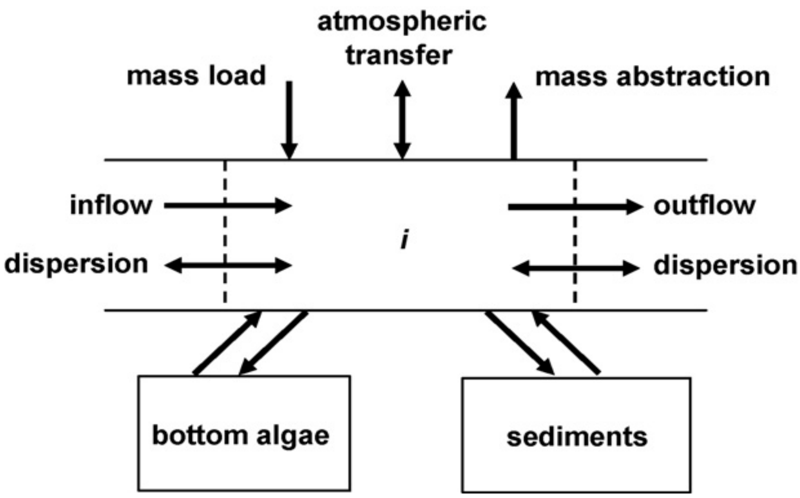

Figure 4: Mass balance in a reach segment i.

Sampling:

For model calibration and verification, four sampling stations were selected on Tigris River namely Al-Muthana bridge (S1), Medical City bridge (S2), Al-Jadriyah Bridge (S3), and Al-Zafarania (S4) (Fig. 1). To provide data for head water, sampling from Alfahama station also done and were analyzed. The technical methods used for the analysis of the sampling are summarized in Table 1. The monitoring works were performed at low flow conditions for applicability of the steady flow model QUAL2K. Water samples were collected in polypropylene bottles from sampling sites in January 2011 and January 2012. Grab sampling procedure was adopted for the analysis of various water quality parameters as recommended by standard methods [19]. The polypropylene bottles were used for water quality parameter analysis. Water samples for BOD estimation were collected in BOD bottles (non-reactive borosilicate glass bottles of 300 ml capacity). Analysis of water samples was started as soon as possible after collection to avoid unpredictable changes. The bottles were kept at +4°C and analyzed within approximately 24 h. The analysis of the samples was done at chemical laboratory of water resource techniques department, institute of technology. The selected parameters included water Temperature, pH, electrical conductivity (EC), five days biochemical oxygen demand (BOD_5), Dissolved oxygen (DO), total alkalinity (TA).

Table 1: Analytical method for various parameters

Parameter	Units	Instruments / technique used
pH	-	Digital pH meter
Temperature,	°C	Mercury Thermometer
Dissolved oxygen	mg/L	Winkler’s method
Biochemical oxygen demand	mg/L	Winkler’s method, incubation for 5 days at 20°C
Total Alkalinity	mg/L	Titration method
Electrical conductivity	µs/cm	Measured by conductivity meter

Model Calibration

The QUAL2Kmodel was calibrated and confirmation using measured data, before it was used for simulating the water quality. Calibration was accomplished by adjustment of model coefficients during successive/iterative model runs, until the best goodness of fit between predicted and observed data is achieved. In general, the model was calibrated with the goal of minimizing the error for BOD and DO. Two sets of data were used for model calibration and confirmation. QUAL2K was calibrated for the month of November representing a low-flow period [20]. The model was operated as a one-dimensional steady state and completely mixed system. The 49.97 km stretch from Al-Fahama to Al-Zafarania was divided into four reaches with further segmentation. Figure 5 shows the river system segmentation along with the locations of point sources of pollution loads and abstractions.

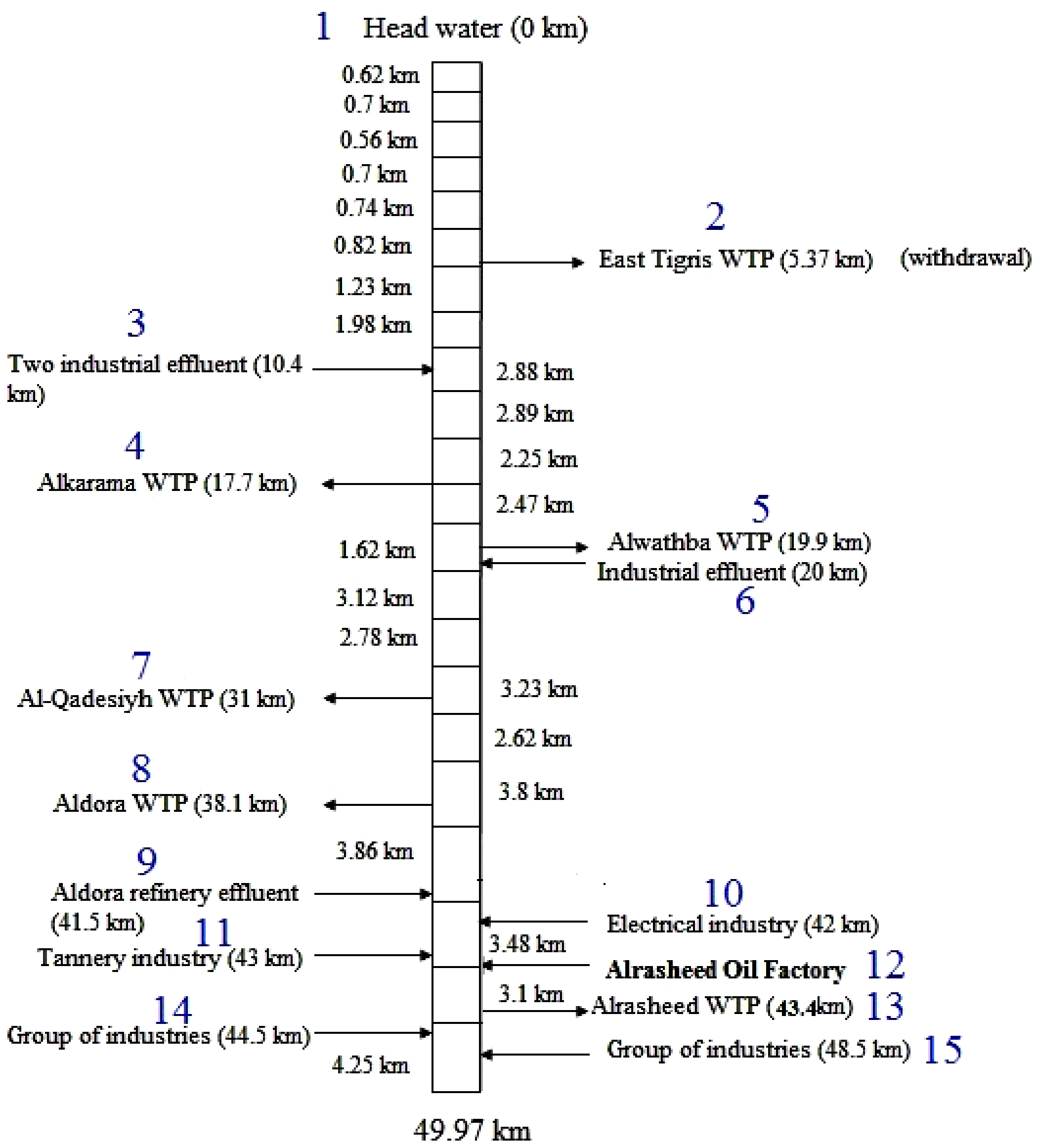

Figure 5: The schematic diagram of the study region

Certain geometric and hydraulic data has been obtained from [20] and others were provided by (ERDAS 9.2 & Global Mapper 11). Hydraulic constants simulate the transport of constituents, i.e., pollutants, in the water system [9]. Manning equation was used to express the relationship between flow and depth. The Tigris River is a natural stream channel; some reachs are clean and straight and other are clean, winding and some weeds. Thus, Manning’s coefficient is taken range between 0.024 and 0.03 [21] (Table 2).

Table 2: Input values of Manning's coefficient in different reach of the Tigris River with their GPS locations [21].

Downstream location (km)	Manning n	Downstream					
		Latitude			Longitude		
		Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
0	0.0300	33	27	21	44	19	12
0.62	0.0300	33	27	10	44	19	32
1.32	0.0300	33	26	54	44	19	51
1.88	0.0300	33	26	40	44	20	5
2.58	0.0300	33	26	23	44	20	22
3.32	0.0300	33	26	2	44	20	37
4.14	0.0300	33	25	36	44	20	44
5.37	0.0290	33	24	56	44	20	35
7.35	0.0290	33	23	58	44	20	2
10.23	0.0290	33	23	23	44	20	41
13.12	0.0290	33	22	35	44	21	25
15.37	0.0290	33	21	33	44	21	10
17.84	0.0290	33	21	16	44	22	23
19.46	0.0290	33	20	34	44	22	37
22.58	0.0290	33	19	33	44	24	11
25.36	0.0290	33	18	14	44	24	58
28.59	0.0240	33	17	32	44	23	11
31.21	0.0240	33	16	31	44	22	1
35.01	0.0240	33	16	17	44	23	42
38.87	0.0240	33	17	19	44	25	48
42.35	0.0240	33	16	28	44	27	14
45.45	0.0240	33	14	48	44	27	6
49.97	0.0240	33	13	45	44	29	7

As the model simulates ultimate CBOD, the measured 5 day CBOD ($CBOD_5$) was transferred to ultimate CBOD ($CBOD_u$) using the following relationship (k = the CBOD decomposition in the bottle, 1/day) [10]:

$$CBOD_U = \frac{CBOD_5}{1-e^{-5k}} \qquad (6)$$

The bottle rates for sewage derived organic carbons are on the order of 0.05–0.3 day^{-1} [21]. As the average COD/$CBOD_5$ ratio was 1.83 in some part of the river [22], ratio CBODu/$CBOD_5$ was assumed as 1.5 [23], which results in rate coefficient as 0.22.

The water quality input parameters included in the model are temperature, DO, CBOD, pH, Alkalinity and Electrical conductivity while other input parameters were not measured and the inputs were left blank. The water qualities for the wastewater and abstraction were the other point pollutions input to the model (Table 3) in which collected from various literatures. The algae and bottom sediment oxygen demand coverage were assumed 50%.

Table 3: The input water qualities data for head water, point source and abstraction.

No	Drain/Discharge	Location (km)	Flow m^3/s	DO mg/L	BOD mg/L
1	Headwater (Al-Fahama)	0.0	298[b]	5	2
2	East Tigris WTP	5.37	-2.47[c]	6.5	2.3
3	Two industrial effluent	10.4	0.01[d]	1.5	110
4	Alkarama WTP	17.7	-8.2[a]	7.2	2
5	Alwathba WTP	19.9	-13.889[a]	7.2	2
6	Industrial effluent	20	0.01[d]	1	120
7	AlQadesiya WTP	31	-4.37[c]	5	4
8	Aldora WTP	38.1	-4.37[c]	5.5	5.2
9	Aldora refinery effluent	41.5	0.01[d]	0	150
10	Thermal power plant	42	0.013[d]	0	144
11	Tannery industry	43	0.120[d]	0	168
12	Alrashed oil factory	43.2	0.013[d]	0	220
13	Alrashed WTP	43.4	-2.47[C]	7.6	4
14	Group of industries	44.5	0.2[d]	0	160
15	Group of industries	48.5	0.2[d]	0	160

Negative sign signifies withdrawal.
Source: data in the table was extracted from various sources
a- (Abdul Razzak et al, 2009) [24]
b- (Ali et al, 2012) [20]
c- (AL-Rawi and Razuki, 2010) [25]
d- (Tawfik, 2007) [26]

Model parameters
All the parameters were set as default in QUAL2K with some exception. Some of model rate parameters required by QUAL2K were obtained from QUAL2K user manual [8]. To calculate re-aeration rate, Owens–Gibbs formula [27] was applied. Exponential model was chosen for oxygen inhibition for CBOD oxidation, nitrification and de-nitrification. Table 4 shows the model parameters used in this study.

Model validation
Two sets of data were used for model calibration and validation. After giving all inputs, a number of trials were made to ensure matching of observed and simulated values of BOD and DO. Errors in simulations are estimated as the difference between model forecasted values and observed data. The relative error for BOD was 23%, 14%, 4%, 13 % at Al-Muthana bridge (S1), Medical City bridge (S2), Al-Jadriyah Bridge (S3), and Al-Zafarania (S4) respectively while for DO was 10%, 15%, 11%, 8 % at Al-Muthana bridge (S1), Medical City bridge (S2), Al-Jadriyah Bridge (S3), and Al-Zafarania (S4) respectively.

Table 4: Model parameters considered as inputs in QUAL2K model

Parameter	Units	Symbol	Range	Calibrated
Temperature correction	-	□□	-	1.024
O_2 for carbon oxidation	gO_2/gC	r_{oc}	-	2.69
O_2 for NH4 nitrification	gO_2/gN	r_{on}	-	4.57
Oxygen inhib CBOD oxidation	L/mgO_2	K_{socf}	-	0.60
Oxygen inhib nitrification parameter	L/mgO_2	K_{sona}	-	0.60
CBOD Hydrolysis rate	/d	k_{hc}	0.02-5.6	2
CBOD Oxidation rate	/d	k_{dc}	0.02-5.6	4
Partial pressure of carbon dioxide	ppm	P_{co2}	-	347
Photosynthetically Available Radiation	-	-	-	0.47
Background light extinction	/m	-	-	0.2
Linear chlorophyll light extinction	1/m-(ugA/L)	a_p	-	0.0088

3. Results and Discussions

The results for the water quality parameters that used as input data for head water are shown in Table 5 while Table 6 shows the measurement data in different stations along river for comparison with predicted values.

Table 5: Input data for head water

Parameters	Unit	Head water (Alfahama)
Temperature	°C	12
pH	-	7.55
Electrical conductivity	µs/cm	818
Dissolved Oxygen	mg/L	5
BOD	mg/L	2
Total Alkalinity	mg/L	118

From model output (Figure 6), it can be seen that DO concentrations for the entire river are meet the targeted quality criteria for survival of fisheries: minimum DO at or above 4 mg/L [21]. In case of CBOD (Figure 7), it can be noticed that the Tigris River CBOD could be divided into three main reaches; the first one is extended from Alfahama (0 km) to Alkadhmiah (9 km) and have CBOD concentration of 2 mg/L and the second reach have CBOD range (2–4) mg/L in which begin from Alkadhmiah and extend to near Aldora refinery. The third reach extends from Aldora refinery to Al-Zafaraniah in the south before river confluence with Diyala River which has CBOD concentrations of more than 4 mg/L. BOD level in rivers should not exceed 4 mg/L [21].

Table 6: water quality data along river

Sampling Station	Dissolved Oxygen (mg/L)	BOD (mg/L)
Al-Muthana bridge (S1)	7	1.5
Medical City bridge (S2)	8	4.5
Al-Jadriyah Bridge (S3)	8.5	3.9
Al-Zafarania (S4)	8.7	6.6

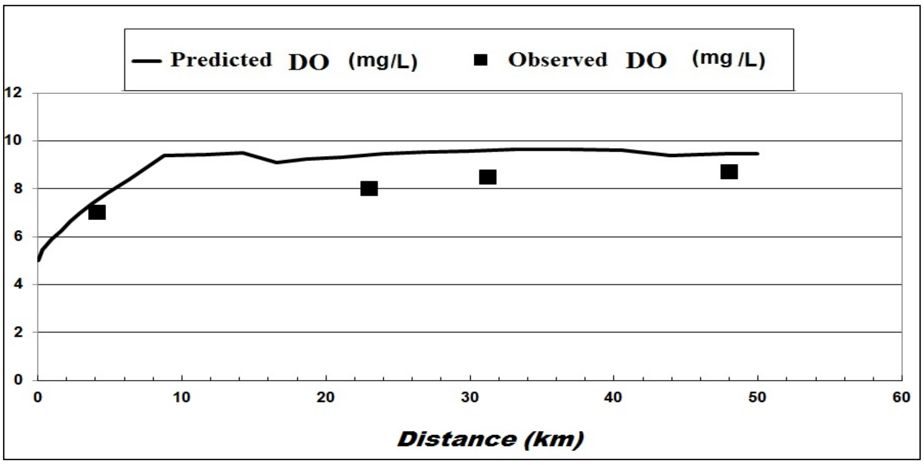

Figure 6: The confirmation results in November (comparison of observed and predicted DO values).

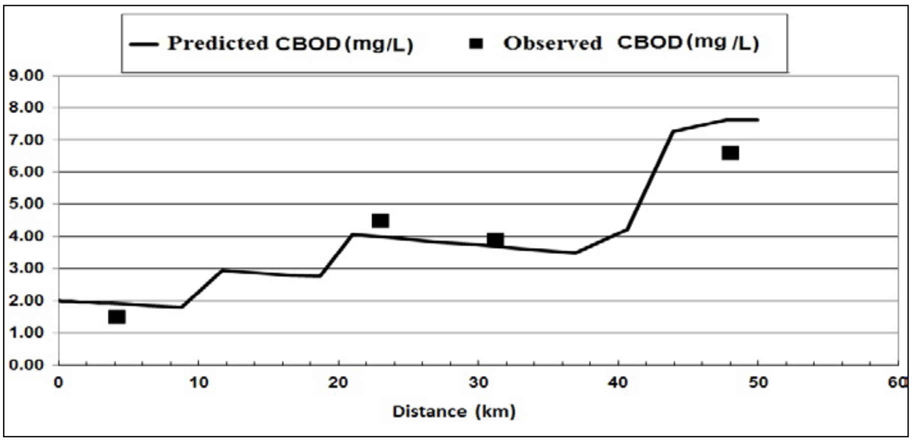

Figure 7: The confirmation results in November (comparison of observed and predicted CBOD values).

The high level of CBOD in the third reach of the river may due to discharges of untreated wastewater from different industries [28]. At 25 km distance near Alsink bridge, it can be readily seen that CBOD level slightly decreases due to self-purification of the river. In general, The Tigris River upstream of Al-Jadriyah Bridge is not heavily polluted organically. The most polluted zone in the river located downstream of Aldora refinery because of the discharge of pollutants. In case of dissolved oxygen, the DO in surface water should not be less 4 mg/L; the entire Tigris River is within standard of 4 mg/L. the low DO concentration in headwater may due to agricultures activities upstream of Alfahama (Figure 6).

Strategies for control the quality of the Tigris river water

In this study, we examine different strategies to control the level of CBOD in the river and keep it within standard. Illustrations of DO concentrations in these strategies were neglected due to fact that DO levels in the river was within limits and only CBOD was considered. The strategies of cleanup of the Tigris River are based on the fact that the modification of the point sources representing the effluent discharged to the Tigris River is possible after enforcement of policies and acts.

Strategy 1: control of Pollution loads modification

This strategy suggests the control of pollution load (point sources pollution), for this purpose, it was fixed trial values of CBOD as 70, 50 and 30 mg/L for point sources (see Table 7). Figures 8-10 shows CBOD profiles obtained by simulation.

Table 3 set of fixed trial values of CBOD as 70, 50 and 30 mg/L for point sources

No	Drain/Discharge	Location (km)	BOD mg/L 1st case	BOD mg/L 2nd case	BOD mg/L 3rd case
1	Headwater (Al-Fahama)	0.0	2	2	2
2	East Tigris WTP	5.37	2.3	2.3	2.3
3	Two industrial effluent	10.4	70	50	30
4	Alkarama WTP	17.7	2	2	2
5	Alwathba WTP	19.9	2	2	2
6	Industrial effluent	20	70	50	30
7	AlQadesiya WTP	31	4	4	4
8	Aldora WTP	38.1	5.2	5.2	5.2
9	Aldora refinery effluent	41.5	70	50	30
10	Thermal power plant	42	70	50	30
11	Tannery industry	43	70	50	30
12	Alrashed oil factory	43.2	70	50	30
13	Alrashed WTP	43.4	4	4	4
14	Group of industries	44.5	70	50	30
15	Group of industries	48.5	70	50	30

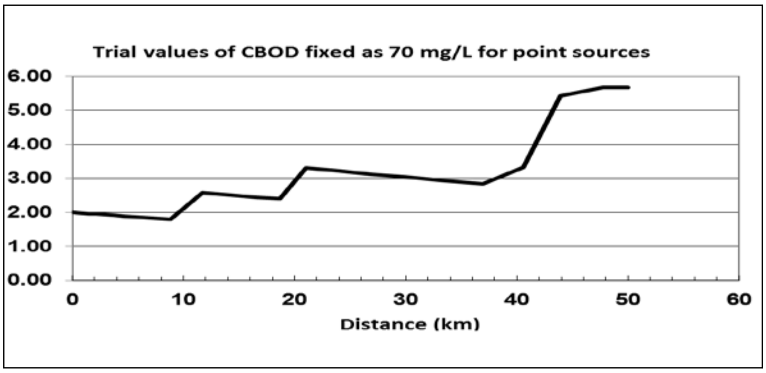

Figure 8: CBOD concentrations along Tigris River in case of control the discharges of point sources as 70 mg/L BOD.

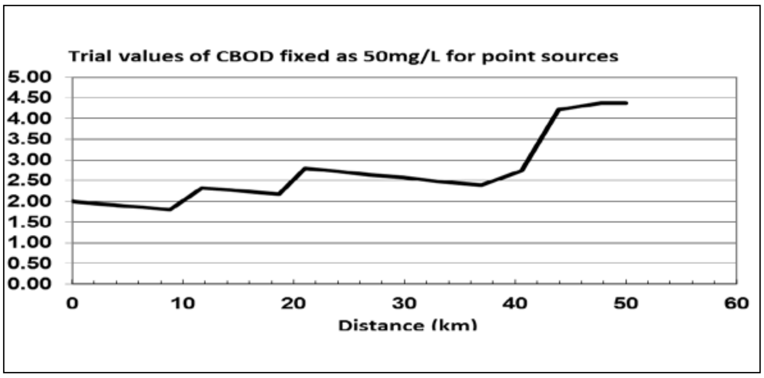

Figure 9: CBOD concentrations along Tigris River in case of control the discharges of point sources as 50 mg/L BOD.

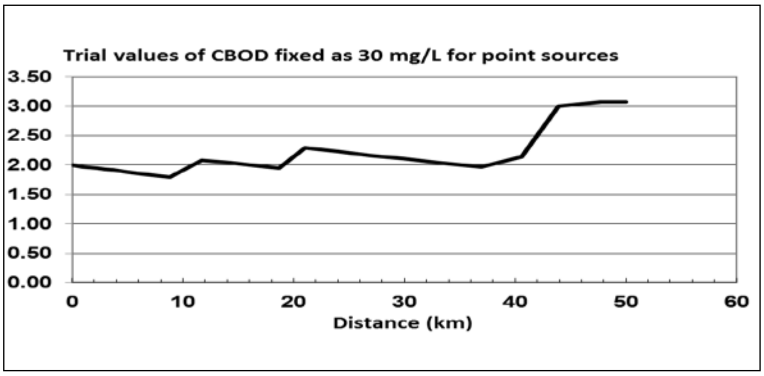

Figure 10: CBOD concentrations along Tigris River in case of control the discharges of point sources as 30 mg/L BOD.

Figure 8 shows CBOD concentrations along Tigris River in case of control the discharges of point sources as 70 mg/L of BOD. It can be noticed that the third polluted reach still exceeds 4 mg/L at 42 km distance of the river near Alrasheed water treatment plant. While Figure 9 shows CBOD concentrations along Tigris River in case of control the discharges of point sources as 50 mg/L BOD, in this case (2nd case) it can be seen that CBOD concentrations in the river are almost within limits. As shown in Figure 10, best results of CBOD were noticed, this case (3rd case) suggest that the point source pollution (effluent discharge to the river) should not exceed 30 mg/L of BOD. The concentrations of CBOD in the range of (2 - 3) along the Tigris River (see Figure 10).

Strategy 2: Flow augmentation with control of Pollution loads modification

To examine the flow augmentation of Tigris River with control of point source pollution, same fixed trial values of CBOD as 70, 50 and 30 mg/L for point sources with 20 m^3/s flow augmentation in head water Figures 11-13 shows the CBOD profiles along Tigris river for 20 m^3/s flow augmentation in addition to wastewater reductions.

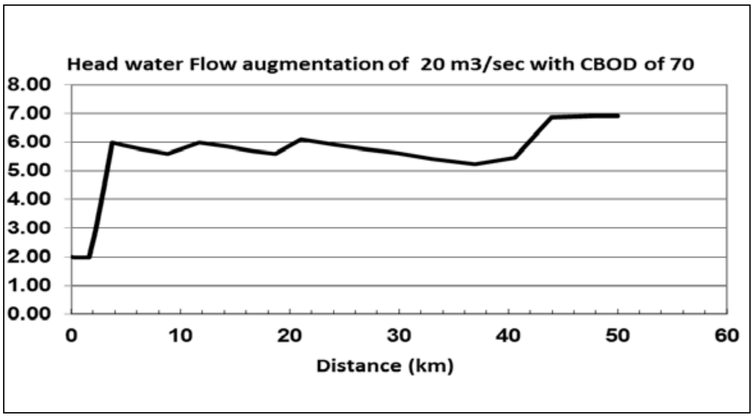

Figure 11: CBOD concentrations along Tigris River in case of control the discharges of point sources as 70 mg/L BOD with flow 20 m^3/s.

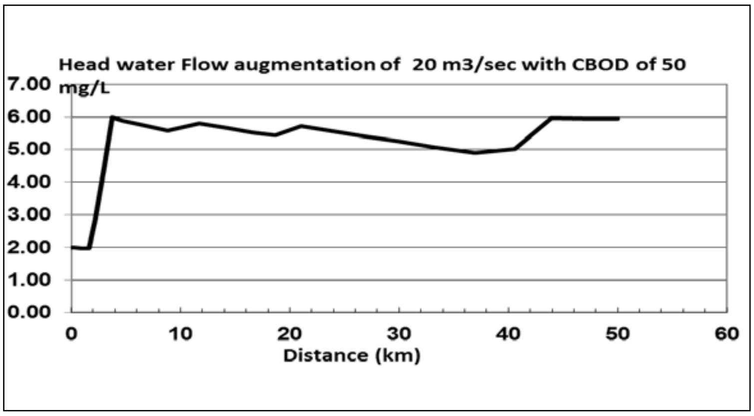

Figure 12: CBOD concentrations along Tigris River in case of control the discharges of point sources as 50 mg/L BOD with flow 20 m^3/s.

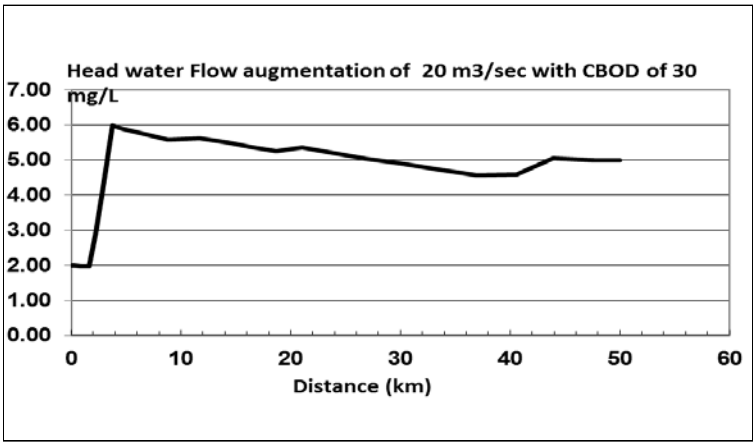

Figure 12: CBOD concentrations along Tigris River in case of control the discharges of point sources as 30 mg/L BOD with flow 20 m^3/s.

Flow augmentation in strategy 2 does not give significant results as shown in the Figures 11-13, in which the level of CBOD increase even with reduction in the pollution load (point source).

4. Conclusions

A stream water quality model, QUAL2K, was calibrated for the Tigris River through assessment of phsico-chemical parameters and using the data collected from several literatures. The model was applied to simulate the dissolved oxygen (DO) and biochemical oxygen demand ($CBOD_5$) profiles of the river during low flow period. Remote sensing & GIS techniques were also used to provide some QUAL2K input data that related with Tigris River geometric and hydraulic characteristics. From model results, it can be concluded that the river water is within the standard quality criteria of DO above 4 mg/L. The third reach of the river which begins from Aldora and extends to Al-Zafarania is the most polluted reach in the river. From strategy 1, it could be stated that authorities should monitors the industries that discharged their effluent without adequate treatment to the river and BOD in the discharged effluent should be kept at least 50 mg/L to maintain BOD below 4 mg/L in the Tigris river water. Strategy 2 (flow augmentation) does not gave significant vision. Water quality modeling provides better understanding of the physical and chemical processes. Since, models are able to realistically represent surface waters; they can be used to support water quality management and decision-making. This reasonable modeling application guarantees the use of QUAL2K for future river water quality policy options.

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