Application of QUAL2K for Water Quality Modeling and Management in the lower reach of the Diyala river

Ayad S. Mustafa[1] **Sadeq O. Sulaiman**[2] **Sabreen H. Shahooth**[3]

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Abstract

The current study includes application of QUAL2K model to predict the dissolved oxygen (DO) and Biochemical Oxygen Demand (BOD5) of lower reach of the Diyala River in a stretch of 16.90km using hydraulic and water quality data collected from Ministry of Water Resources for the period (January-April 2014). Google Earth and Arc-GIS technique were used in this study as supported tools to provide some QUAL2K input hydro-geometric data. The model parameters were calibrated for the dry flow period by trial and error until the simulated results agreed well with the observed data. The model performance was measured using different statistical criteria such as mean absolute error (MAE), root mean square error (RMSE) and relative error (RE). The results showed that the simulated values were in good agreement with the observed values. Model output for calibration showed that DO and CBOD concentration were not within the allowable limits for preserving the ecological health of the river with range values (2.51 - 4.80 mg/L) and (18.75 – 25.10 mg/L) respectively. Moreover, QUAL2K was used to simulate different scenarios (pollution loads modification, flow augmentation and local oxygenation) in order to manage the water quality during critical period (low flow), and to preserve the minimum requirement of DO concentration in the river. The scenarios results showed the pollution loads modification and local oxygenation are effective in raising DO levels. While flow augmentation does not give significant results in which the level of DO decrease even with reduction in the BOD5 for point sources. The combination of wastewater modification and local oxygenation (BOD5 of the discharged effluent from point sources should not exceed 15 mg/L and weir construction at critical positions 6.67km from the beginning of the study region with 1m height) is necessary to ensure minimum DO concentrations.

Key Words: Water quality modeling, QUAL2K, GIS, Diyala River; BOD; DO.

تطبيق QUAL2K لنمذجة والسيطرة على نوعية المياه للمجرى الأسفل لنهر ديالى

د. أياد صليبي مصطفى د.صادق عليوي سليمان صابرين حمدي شاحوذ

الخلاصة

تتضمن الدراسة الحالية تطبيق نموذج (QUAL2K) لمحاكاة الأوكسجين المذاب (DO) والمتطلب الحيوي للأوكسجين (BOD5) للجزء الأسفل لنهر ديالى لمسافة (16.90km) باستخدام بيانات تم جمعها من وزارة الموارد المائية للفترة (كانون الثاني - نيسان 2014). استخدم Google Earth ونظم المعلومات الجغرافية (Arc-GIS) في هذه الدراسة كأدوات داعمة لتوفير بعض البيانات الداخلة بنموذج QUAL2K. تم معايرة معاملات الموديل باستخدام بيانات موسم الجريان المنخفض عن طريق المحاولة والخطأ إلى حصول على توافق بين نتائج المحاكاة والقيم المقاسة. تقييم أداء النموذج تم باستخدام المعايير الإحصائية، معدل الخطأ المطلق (MAE) ، جذر متوسط لمربع الخطأ (RMSE) والخطأ المطلق (RE). تبين من النتائج المستحصلة أن القيم التي تنبأ بها النموذج متوافقة مع القيم المقاسة.

[1] *Professor at the Department of Civil Engineering, University of Anbar.*

[2] *Assistant Professor at the Department of Dams and Water Resources Engineering, University of Anbar.*

[3] *Student at the Department of Civil Engineering, University of Anbar.*

وأظهرت النتائج أن تراكيز DO و CBOD كانتا أعلى من الحدود المسموح بها لإدامة الحياة المائية حيث كانت (2.51 - 4.80mg/L) و (18.75 - 25.10mg/L) على التوالي .بالإضافة لذلك تم تطبيق QUAL2K لمحاكاة سيناريوهات مختلفة(تعديل أحمال التلوث ، زيادة تصريف النهر وإنشاء الهدار المائي (weir)) لإدارة نوعية المياه خلال الفترة الحرجة (الجريان المنخفض) وللحفاظ على معايير نوعيه المياه ضمن الحد المسموح (الحد الأدنى ل DO اكبر أو مساوي 4mg/L).

أظهرت نتائج السيناريوهات أن تعديل أحمال التلوث المتمثلة ب BOD_5 لمياه الصرف الصحي للمصادر النقطية وإنشاء الهدار المائي فعالتان لرفع تركيز DO للنهر بينما زيادة تصريف النهر لا تعطي نتائج مفيدة حيث أن تركيز DO يقل حتى وان تم تخفيض تركيز BOD_5 للمصادر النقطية. أن تعديل أحمال الملوثات وإنشاء الهدار المائي معا بنفس الوقت ضروري لجعل تركيز DO للنهر ضمن المستوى المطلوب لذلك يجب أن يكون تركيز BOD_5 المطروح للنهر من المصادر النقطية لا يزيد عن (15mg/L) مع إنشاء هدار مائي(weir) بارتفاع 1m عند مسافة 6.67km من بداية منطقه الدراسة .

1. Introduction

Surface waters are confronting an increasing problem through the contaminated water disposal due to the quick growth of municipal and industrial activities because of the increasing of population growth as well as the increase of land drainage due to agrarian activities. So, there has been an increasing worry about water quality all over the world [1].

The number of inhabitants in Baghdad city has been increased quickly from 4.5 million in 1990 to 6.5 million in 2004 and wastewater generation in this city is about 1.2 m^3/day [2]. One of the biggest rivers of the Middle East is Tigris river, extending for more 1,900 km of which 1415 km are inside Iraq, with a catchment area of 235000 km^2 [3]. The rivers tributaries have direct impact on physic-chemical and biological properties of the rivers itself.

Diyala River is the more important easterly tributary of Tigris River. It covers distance of 445 km of which 386 km in Iraq [4]. Along its path it affected by different type of industrial wastes ,agricultural , human activities, all these factors effect on the hydrochemical and physical properties of the stream that undoubtedly will effect on organisms [5].

Control of water contamination has reached essential significance in developed and a number of developing countries. The complex relationships between waste loads from various sources and the resulting water quality of the receiving waters should to be characterized. The most effective way to describe these relationships is the mathematical models [6].

There are many type of water quality model, each of these requires a different level of confidence in the model output. QUAL2E is the most common mathematical model that can be used for traditional contaminant impact assessment [7]. This model has been developed by United States Environmental Protection Agency (US EPA). QUAL2E have some limitations such as the lack of provision for transformation of algal death to carbonaceous biochemical oxygen demand (CBOD) [8]. USEPA has released a new version model, QUAL2K [9] to represent a modernized version of the QUAL2E model.

QUAL2K is one-dimensional, steady flow stream water quality model. It included the simulation of new water quality interactions such as translation of algal death to BOD, denitrification process, and DO change caused by fixed plants . These new elements can overcome limitations of QUAL2E [8, 10]. It is useful in data limited conditions and is available as a free software (http://www.ecy.wa.gov/).

The main objective of the present study is to predict water quality parameters : DO and BOD5 along the lower reach of Diyala River using the QUAL2K model and to develop hypothetical scenarios to maintain the DO concentration of the Diyala River within the allowable limits.

2. Materials and Methods

2.1 Study Area

In Iraq, Diyala River is considered one of most important tributaries of Tigris River. It originates near Sanandaj in the Zagros Mountains in Iran with a total length of 574 km and a drainage area of 33,240 km^2, of which 25% are located in Iran and 75% in Iraq . The Diyala joins the Tigris at about 15km south of Baghdad[11].

The study area lies in Baghdad city and it covers (16.90km) length of the lower part of Diyala River Figure (1). The study reach began from 2km upstream of AL-Rustimiyah third expansion plant (R3) at directions (33°18'34.2"N, 44°32'13.8"E) and extended to the confluence of the Tigris-Diyala Rivers at directions(33°13'13.49"N, 44°30'21.81"E).

Within the study area there are five outfalls have been taken as point sources of pollution, which are receiving contaminated water into the Diyala River continuously and thus into the Tigris River. These outfalls are Army Canal , old Rustimiyah project (R01 , R2) and new Rustimiyah project (R3A , R3B) that discharged at various locations along the lower reach of Diyala River, as shown in Figure (1).

AL-Rustimiyah wastewater treatment plant (WWTP) is situated on the right bank of Diyala River at about14km before to the confluent of Tigris River south of Baghdad city [12]. The plant designed to serve the east part of the city (Rusafa). The plant is considered one of the major projects in Iraq that treats domestic wastewater, it consists of: (1) The old Rustimiyah project (Al-Rustamiya South plant) working since1963 . It includes three integrated projects: : zero expansion (R0) , first expansion (R1) and second expansion (R2) with a designed capacity of 175,000 m^3/day while the actual flow reaches 300,000 m^3/day.

This plant serves 1,500,000 inhabitants on the eastern side of Baghdad. (2) The new Rustimiyah project (Al-Rustimiyah North plant) third expansion (R3) working since 1984. This plant serves 1,500,000 inhabitants on the eastern side of Baghdad with a designed capacity of 300,000m^3/day while the actual flow reaches 450,000 m^3/day [13].

The Army Canal, 24 km length and 2 to 2.5m depth, recharges from the Tigris River in the northern part of the Baghdad city and terminates in the southern part of Diyala River [14]. One of the main contamination sources that is released directly into Diyala river and thusly to the Tigris river is Army canal. Usually, the canal total discharge is (14m^3/sec) which is provided from seven lifting pumps , each one has (2m^3/sec) of capacity. Indeed the adopted maximum capacity of canal in present continuously is may be (1m^3/sec), and it supplies water to some farms, gardens and nurseries along its bank [15].

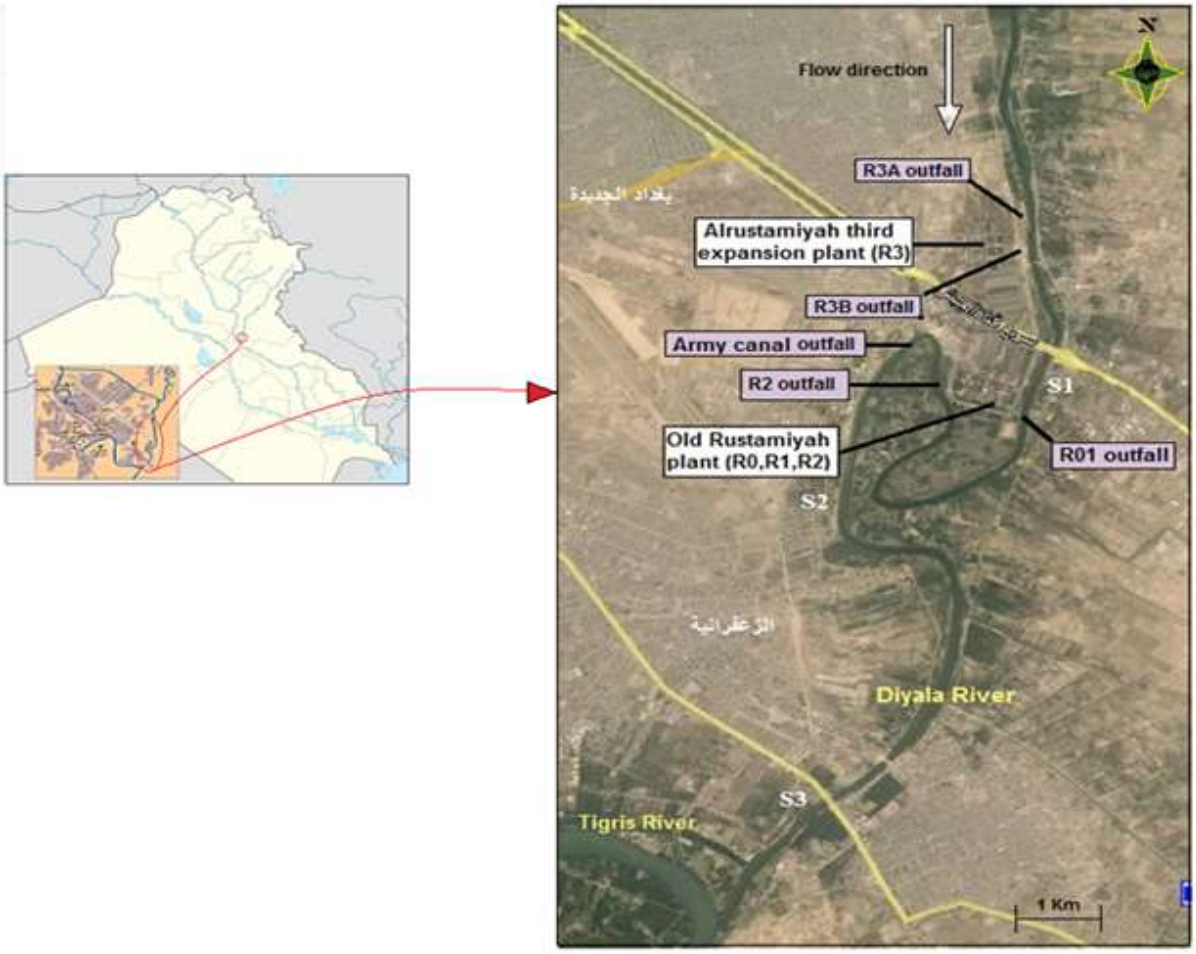

Figure 1. General layouts of the study reach

2.2 Sampling Sites

Depending on Ministry of Water Resources of Iraq ,three sampling stations are selected on the Diyala River with the study area for two set of data for model calibration and validation for the period (January -April 2014) .The samples are analyzed for Dissolved oxygen (DO) and five days biochemical oxygen demand (BOD5). The sampling locations are shown in Figure (1).

2.3 QUAL2K Model Description

QUAL2K (or Q2K) is a river and stream water quality model and is a modernized version of the QUAL2E model. The QUAL2K characterize as following : [9] (i) One dimensional, steady state hydraulics (the model considers the channel is well-mixed vertically and laterally under steady flow, non-uniform.); (ii) Diurnal water-quality kinetics and heat budget (the model simulates all water quality variables, temperature and heat budget on a diurnal time scale); (iii) Mass and heat inputs (the model can simulate the point and diffuse loads and abstractions).

In the QUAL2K model the study river is divided into several “reaches” and each reach is divided into “segments”. These segments are model’s shortest parts of simulation. A steady state flow balance is implemented for each model segment, as :

$$Qi = Q_{i-1} + Q_{in,i} - Q_{ab,i} \tag{1}$$

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

The outflow for each segment is calculated, the velocity and depth are calculated in one of three ways: rating curves, weirs, and Manning equations. Each segment is idealized as a trapezoidal channel. Under the conditions of steady flow, Manning equation was used to express the relationship between depth and flow as:

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

where Q = flow (m^3/d), n = the Manning roughness coefficient , S∘ = bottom slope (m/m), Ac = cross - sectional area (m^2) and P = the wetted perimeter (m)[9].

QUAL2K has at its core a one-dimensional advection-dispersion equation as the governing equation[16].

$$V\frac{\partial c}{\partial t}=\frac{\partial\left(A_cE\frac{\partial c}{\partial x}\right)}{\partial x}dx-\frac{\partial(A_cUC)}{\partial x}dx+V\frac{dc}{dt}+S \qquad (3)$$

Where U = averaged velocity (m/d), Ac = cross sectional area (m^2), E = longitudinal dispersion coefficient (m^2/d), c is concentration (g/m^3), V = volume (m^3), x = distance (m) and S = sources and sinks of the constituent due to reactions and mass transfer mechanisms (g/m^3/d).

QUAL2K solves this governing equation in a steady-state condition for a water quality parameter concentration ci in the water column of segment i Figure (2). This gives in a general mass balance equation that can be expressed as:[9]

$$\frac{d_{ci}}{dt}=\frac{Q_{i-1}}{Vi}C_{i-1}-\frac{Qi}{Vi}Ci-\frac{Q_{ab,i}}{Vi}Ci+\frac{\dot{E}_{i-1}}{Vi}(C_{i-1}-Ci)+\frac{\dot{E}_i}{Vi}(C_{i+1}-Ci)+\frac{Wi}{Vi}+Si \qquad (4)$$

where Ci = variable concentration for segment i, (g/m^3), Vi = volume of the segment i (m^3), Wi = external loading of the constituent to segment i (g/d or mg/d), t = time (d), Qi = outflow from segment i into segment i +1, (m^3/d) and $\dot{E}_i$ =bulk dispersion coefficient between segments i and i +1 (m^3/d) .

The complete description of processes and mathematical representations of the interacting water quality state variables and sources and sinks of the constituent due to reactions and mass transfer mechanisms, are available in Model user's manual[9].

The QUAL2K employed hydraulics based formula to internally compute the longitudinal dispersion for a boundary between two segments based on the channel’s hydraulics: [17]

$$E_{P,i}=0.011\frac{U_i^2\,B_i^2}{H_i\,U_i^*} \qquad (5)$$

where $E_{P,i}$= the longitudinal dispersion coefficient between segments i and i + 1 [m^2/d] ,U_i = velocity [m/d], B_i = width [m], H_i= mean depth [m], and U_i^* = shear velocity [m/d], which is related to more fundamental characteristics by:

$$U_i^*=\sqrt{gH_iS_i} \qquad (6)$$

Where g = acceleration due to gravity = [9.81 m/s^2] and S = channel slope [dimensionless].

2.4 Implementation of The Model

2.4.1 River descretization

The 16.90km stretcher of Diyala River from 2km upstream of Rustimiyah third expansion plant (R3) to the Tigris-Diyala Rivers confluence was divided into four reaches with further segmentation (26 segment), all with a length less than 1km. Figure (3) shows along of the river system segmentation with the locations of point sources.

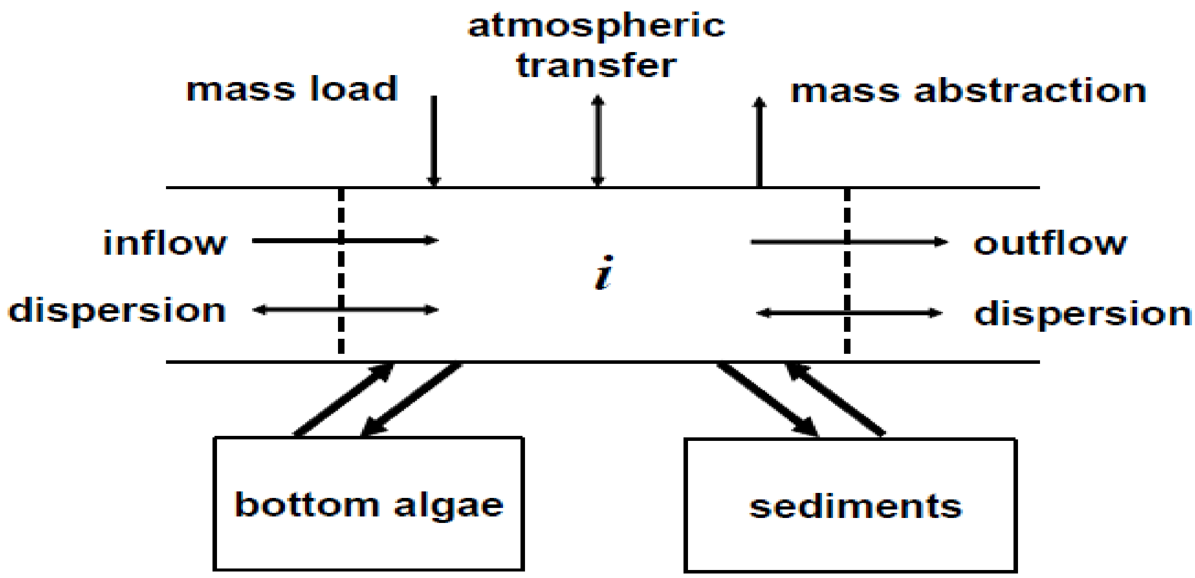

Figure **2**. Mass balance in a segment i

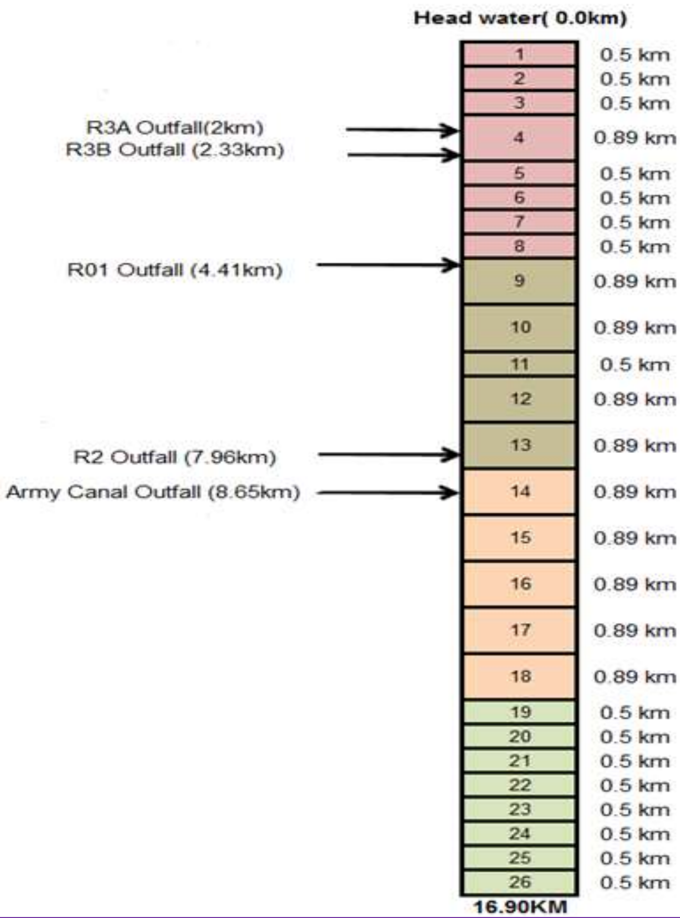

Figure 3.System segmentation with location of pollution sources along a lower reach of Diyala River

2.4.2 Input data

The model required input data includes: geographic characteristics (elevation, geographical longitude and latitude), meteorological characteristics (air temperature, wind speed, dew point, shade ,cloud cover), Hydraulic characteristics (morphological elements, Manning roughness coefficient, flow curve) and physical-chemical and biological parameters of river and point sources.

Google Earth has been used in this study to calculate the reach segment lengths and geographical longitude and latitude. Table (1) , shows the input model segmentation, location, and length of each segment.

Table 1. Model segmentation, location and length of each segment.

Reach	Downstream	Downstream					
	location	Latitude			Longitude		
	(km)	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
Reach 1 (New Diyala bridge)	0	33	18	34.2	44	32	13.8
	0.5	33	18	18.02	44	32	10.11
	1	33	18	2.22	44	32	11.89
	1.5	33	17	46.6	44	32	15.92
	2.39	33	17	17.78	44	32	18.43
	2.89	33	17	1.68	44	32	20.94
	3.39	33	16	46.19	44	32	26.65
	3.89	33	16	31.41	44	32	19.61
	4.39	33	16	16.18	44	32	13.01
Reach 2 (Old Rustimia plant)	5.28	33	15	52.79	44	31	57.49
	6.17	33	15	44.22	44	31	25.45
	6.67	33	15	55.44	44	31	20.37
	7.56	33	16	13.44	44	31	46.15
	8.45	33	16	41.43	44	31	41.79
Reach 3 (Army canal)	9.34	33	16	30.7	44	31	19.38
	10.23	33	16	3.63	44	31	9.07
	11.12	33	15	35.1	44	31	5.88
	12.01	33	15	26.34	44	31	37.71
	12.9	33	14	59.79	44	31	45.79
Reach 4 (Old Diyala bridge)	13.4	33	14	44	44	31	42.12
	13.9	33	14	28.78	44	31	35.23
	14.4	33	14	15.26	44	31	24.69
	14.9	33	14	3.92	44	31	10.85
	15.4	33	13	54.26	44	30	54.96
	15.9	33	13	41.56	44	30	43.1
	16.4	33	13	29	44	30	39.92
	16.9	33	13	13.49	44	30	21.81

A Digital Elevation Model (DEM), Figure (4) has been used to obtain some hydro-geometric data for the Diyala River segments that required for inputs parameters for Manning formula such as side slope, longitudinal slope, width and elevation of the study location from sea level .

This model was created using Arc Geographical Information Systems (Arc-GIS) [18]. Manning's coefficient was taken as 0.027 from [19]. The inputs parameters for Manning formula and elevation for each segment are shown in the Table (2).

Table 2. Manning formula parameters and elevation for Diyala River segments.

Downstream	Elevation		Manning formula				
Location	Upstream	Downstream	Width	Side slope	Side slope	Channel	Manning
(km)	(m)	(m)	(m)	Left	Right	Slope	n
0		32	43	0.150	0.190	0.00080	0.0270
0.5	32	31.6	41	0.085	0.065	0.00020	0.0270
1	31.6	31.5	42	0.122	0.120	0.00040	0.0270
1.5	31.5	31.3	48.7	0.090	0.126	0.00022	0.0270
2.39	31.3	31.1	53.9	0.066	0.083	0.00020	0.0270
2.89	31.1	31	47.1	0.106	0.086	0.00020	0.0270
3.39	31	30.9	54.6	0.200	0.021	0.00020	0.0270
3.89	30.9	30.8	43.3	0.180	0.064	0.00040	0.0270
4.39	30.8	30.6	44.9	0.126	0.020	0.00011	0.0270
5.28	30.6	30.5	44.2	0.068	0.110	0.00044	0.0270
6.17	30.5	30.1	44.2	0.123	0.125	0.00060	0.0270
6.67	30.1	29.8	41.2	0.081	0.149	0.00011	0.0270
7.56	29.8	29.7	47.3	0.150	0.215	0.00011	0.0270
8.45	29.7	29.6	51.7	0.090	0.198	0.00011	0.0270
9.34	29.6	29.5	48.8	0.178	0.219	0.00011	0.0270
10.23	29.5	29.4	49.7	0.190	0.114	0.00011	0.0270
11.12	29.4	29.3	48.7	0.290	0.142	0.00011	0.0270
12.01	29.3	29.2	59.5	0.119	0.244	0.00022	0.0270
12.9	29.2	29	50.8	0.230	0.193	0.00020	0.0270
13.4	29	28.9	70.8	0.149	0.164	0.00040	0.0270
13.9	28.9	28.7	63.5	0.280	0.340	0.00020	0.0270
14.4	28.7	28.6	66.1	0.220	0.180	0.00040	0.0270
14.9	28.6	28.4	72.5	0.133	0.154	0.00040	0.0270
15.4	28.4	28.2	59.2	0.220	0.420	0.00040	0.0270
15.9	28.2	28	53.7	0.169	0.151	0.00060	0.0270
16.4	28	27.7	59.7	0.062	0.105	0.00080	0.0270
16.9	27.7	27.3	58.8	0.020	0.03	0.00040	0.0270

Different data groups were used for QUAL2K model to describe model boundary conditions. It uses headwater data group to define upstream boundary conditions of the model domain. Downstream boundary conditions can be computed internally. The point source data group defines the condition of point source discharges that enter simulated river segments. The input water quality parameters in the model are Dissolved oxygen (DO), biochemical oxygen demand (CBOD), pH, electrical conductivity (EC), total suspended soiled (TSS), total alkalinity (TA) and water temperature (Temp). The monthly input water quality and flow rate data for headwater and point sources are collected from previous technical reports and researches related to Diyala River for the period (January -April 2014).

As the QUAL2K model simulates ultimate CBOD (CBODu) , the measured BOD5 was converted to CBODu using the following relationship :

$$CBOD_U = \frac{CBOD_5}{1-e^{-5\,k}} \quad (7)$$

Where k = the kinetic rate of decomposition of CBOD (day^{-1}) [20].

The bottle rates for sewage derived organic carbons are on the request of 0.05–0.3 day^{-1} [21]. Ratio CBODu/CBOD5 was assumed as 1.5 [22,23] , which results in rate coefficient as 0.22 .The algae and bottom sediment oxygen demand coverage were assumed 50% [22, 23].

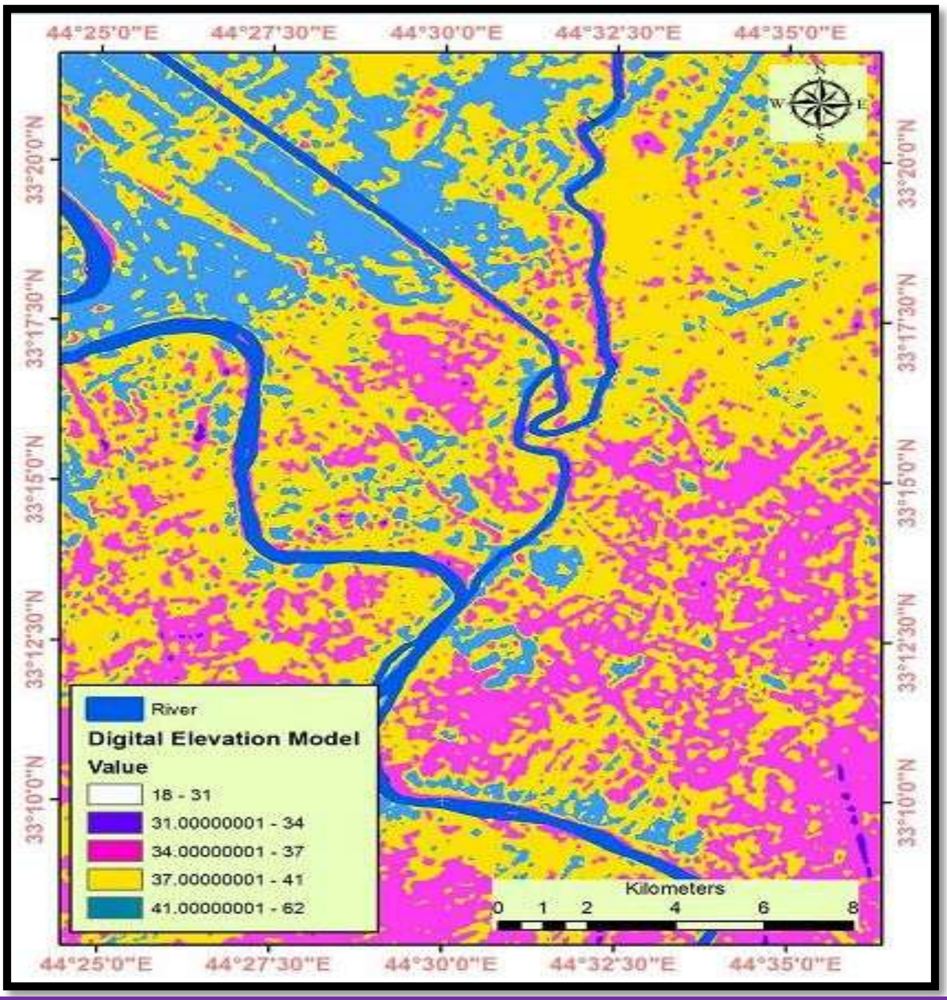

Figure 4. Digital elevation model (DEM) for Baghdad city.

2.4.3 Model calibration

QUAL2K model solves the governing equation using a finite-difference (implicit backward method) and is set up as a one-dimensional steady-state and completely mixed system. It was calibrated with low flow data (April 2014) and the calibration was accomplished by adjustment of model parameters during successive/iterative model runs, until the better goodness of fit between predicted and observed data is achieved. In general, the model was calibrated with the objective of minimizing the error for DO and BOD.

2.4.4 System parameters

All the parameters were set as default in QUAL2K parameters that required by QUAL2K were with some exception. The ranges of model rate obtained from different literatures including: Model user manual [9] , and Environment Protection Agency (EPA) guidance document [24]. To calculate reaeration coefficient for Diyala river, O'Connor-Dobbins was applied [25]. Table (3) shows the model parameters used in this study.

Table 3. Model parameters considered as inputs in QUAL2K model.

Parameter	Units	Symbol	Range	Calibrated
Stoichiometry:				
Carbon	mgC	gC	-	40
Nitrogen	mgN	gN	-	7.2
Phosphorus	mgP	gP	-	1
Dry weight	mgD	gD	-	100
Chlorophyll	mgA	gA	-	1
Inorganic suspended solids:				
Settling velocity	m/d	vi	0 - 2	0.01
Oxygen:				
Reaeration model	-	-	O'Connor-Dobbins	
Temperature correction	-	θa	-	1.024
O2 for carbon oxidation	gO2/gC	roc	-	2.69
O2 for NH4 nitrification	gO2/gN	ron	-	4.57
Oxygen inhib CBOD oxidation parameter	L/mgO2	Ksocf	-	0.6
Oxygen inhib nitrification parameter	L/mgO2	Ksona	-	0.6
Oxygen enhance denitrification parameter	L/mgO2	Ksodn	-	0.6
CBOD:				
CBOD Hydrolysis rate	/d	khc	0.04 - 4.2	1.5
CBOD Oxidation rate	/d	kdc	0.04 - 4.2	1.62
pH:				
Partial pressure of carbon dioxide	ppm	Pco2	-	347
Light and heat:				
Photosynthetically Available Radiation	-	-	-	0.47
Background light extinction	/m	keb	-	0.2
Linear chlorophyll light extinction	1/m-(ugA/L)	ap	-	0.0088
atmospheric turbidity coefficient	-	nfac	2=clear, 5=smoggy, default=2	2
atmospheric transmission coefficient	-	atc	0.70 - 0.91	0.8

2.4.5 Model validation

It is the testing of the calibrated model against the extra set of data preferably under various environmental conditions (river flow, water quality parameters concentration etc.), to ensure that the model can predict real situations in a dependable manner [26].The model parameters used were the same as in the calibrated model and only different input additional sets of measured data in high flow data (January 2014) were used to validate the model.

3. Results and Discussion

3.1 Model Calibration And Validation

The results of CBOD and DO predicted by the model for calibration and validation are shown in Figure (5) and Figure (6) respectively.

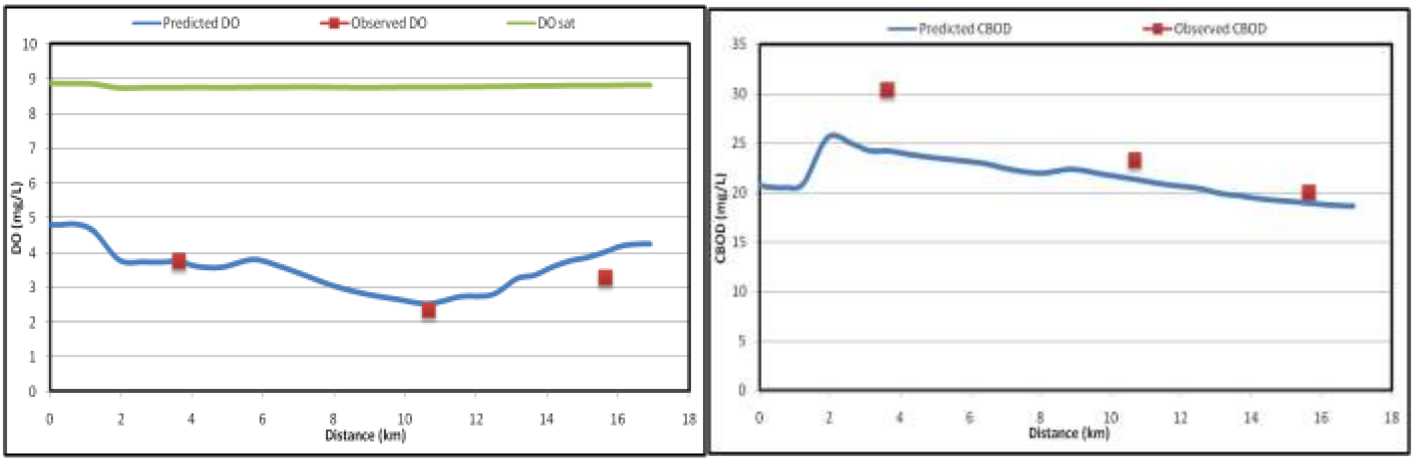

Figure 5.Simulated DO and CBOD along lower reach of Diyala River for model calibration in April,2014.

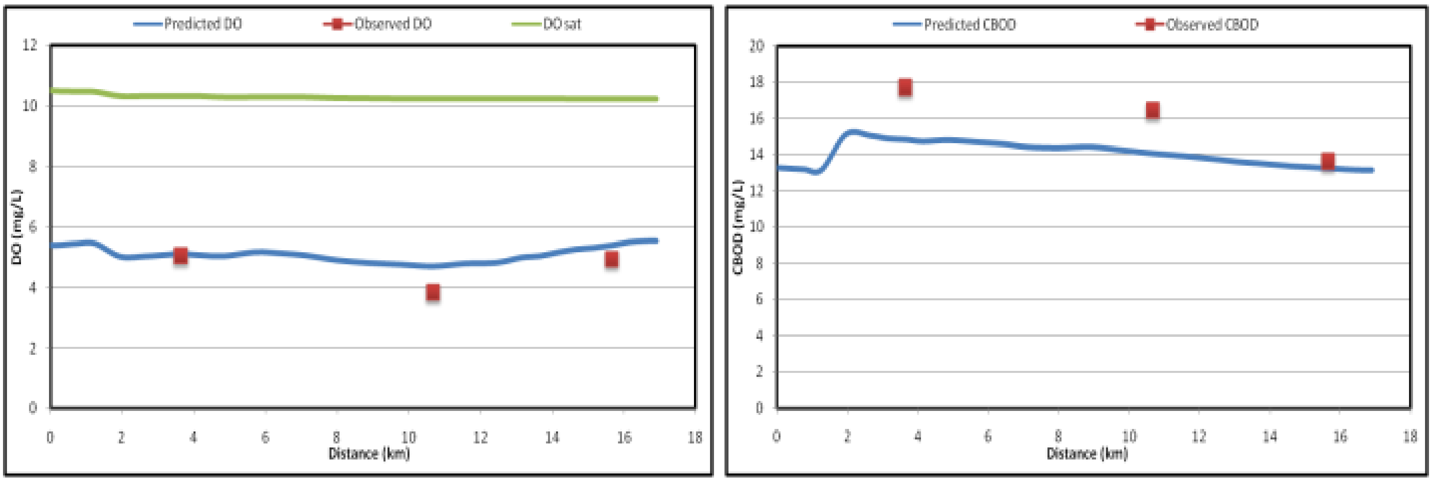

Figure 6. Simulated DO and CBOD along lower reach of Diyala River for model validation in January,2014

From the results obtained for calibration and validation, the performance of the model was measured using statistical criteria such as :mean absolute error (MAE) , root mean square error (RMS) and relative error (RE). The Error between the predicted and observed values for DO and CBOD computed for both calibration and validation are given in Table (4) . The results of RE, showed a good fit between observed and predicted values of DO and BOD. Similarly, the values of MAE and RMS also indicate that there is not much variation in these values between calibration and validation. The acceptable error values show that QUAL2K model can be used as an effective tool to predict the river water quality and can be used to support water quality management and decision-making especially for the developing countries where the higher accuracy data analysis and financial resources for frequent monitoring campaigns are very limited[27].

Table 4. Error values of DO and CBOD for Model Calibration and validation.

Parameters	Mean absolute error (MAE)		Root mean square error (RMS)		Relative error (RE)%	
	Calibration	validation	Calibration	validation	Calibration	validation
DO (mg/L)	0.31	0.44	0.44	0.54	9.80	9.60
CBOD (mg/L)	4.44	2.82	5.65	3.25	12.32	11.72

From model output Figure (5), it can be seen that DO and CBOD are exceed the allowable limits for preserving the ecological health of the river : minimum DO at or above 4 mg/L , BOD5 should not exceed 4 mg/L[21, 22, 23] and it can be noticed that the Diyala River DO and CBOD could be divided into two main reaches; the first one is extended from headwater (0km) to (10.68km) downstream of headwater which have DO concentration range (2.51 - 4.80) mg/L and CBOD range (21.38 – 25.10) mg/L. The second reach have DO range (2.51– 4.28) mg/L and CBOD range (18.75 –21.38) mg/L in which begin from (10.68km) to (16.90km) downstream of headwater. The gradually DO concentration decreases and CBOD concentration increases at the first reach may be due to the high level of organic matter load from polluted point sources : Army canal and Rustimiyah third expansion plant (R3) , old Rustimiyah plant (R01 and R2) that discharged without adequate treatment to the river. At the second reach DO concentration increases and CBOD concentration decreases due to, no contaminated source at this distance and self-purification of the river.

From model output Figure (6), it can be seen that DO concentrations for the entire river are to meet the targeted quality criteria for : minimum DO at or above 4 mg/L and CBOD concentrations decrease in wet season, this may be due to the increase aeration because increase river discharge from 10.2 m^3/s in dry season to 26.1 m^3/s in wet season due to rainfall and high flow velocity. A large volume of flow dilutes concentrations of contaminants that are released into the river , high flow velocity increases mixing in the river, enhances the river absorptive capability, and reduces gradients of pollutant concentration [28]. In addition the decrease of temperature for headwater from 21°C to13°C in wet seasons that increase the oxygen solubility [29].

3.2 Scenarios for water quality control

From simulation results for calibration during critical period (low flow), it can be said that the Diyala River water is not suitable for fisheries survival in which the minimum DO concentration is 4 mg/L and BOD5 concentration in rivers should not exceed 4 mg/L .Therefore we examined different scenario to keep the concentration of DO within the limit level.

The three proposed scenario involves the following:

1- Pollution loads modification : It was assumed that the BOD5 concentration of point sources pollution as 20, 15, 10 and 5 mg/L along the lower reach of Diyala River. The River flow is 10.2 m^3/s.From the first scenario result as shown in Figure (7), it can be noticed that the pollution loads modification is effective in raising the DO levels but all DO profiles do not completely meet the minimum oxygen concentrations of 4 mg/L.

2- Flow augmentation: It was assumed that the same fixed trial values of BOD5 are 20,15, 10 and 5mg/L for point sources and flow increases in headwater to 26.1 m^3/s.From Figure (8),it can be seen that scenario 2 does not give significant results , the DO level decrease even with reduction in the pollution load (BOD5) for point source.

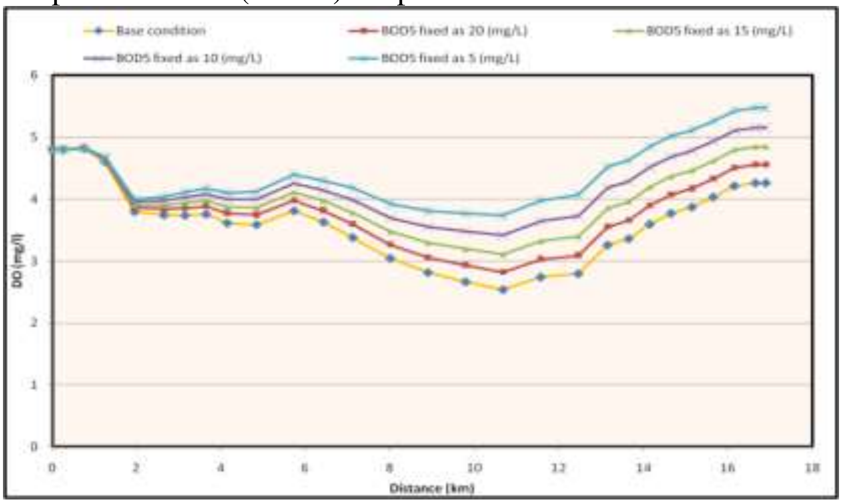

Figure 7. DO concentrations along the lower reach of Diyala River with different BOD5 concentrations for point sources.

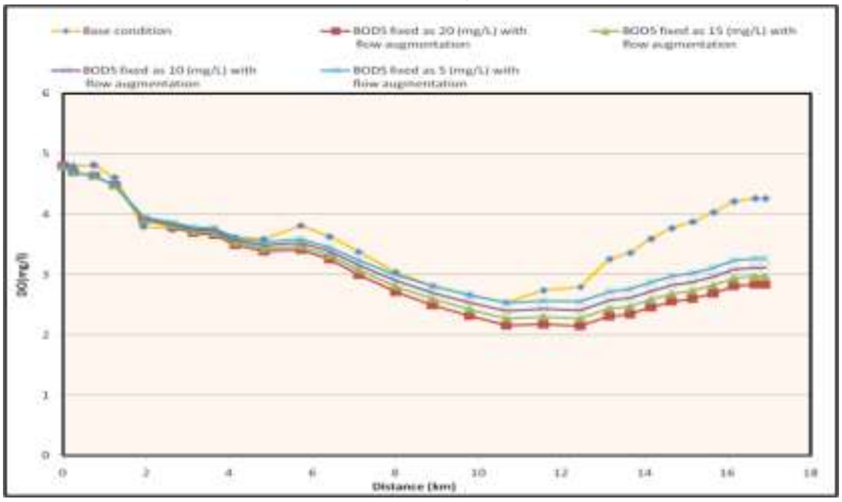

Figure 8. DO concentrations along the lower reach of Diyala River with different BOD5 concentrations for point sources and head water flow augmentation.

3- Local oxygenation : weir placement at critical locations with different heights to move DO concentration at or above 4 mg/l.

Local oxygenation is successful in raising DO levels [30] .In the QUAL2K model ,the amount of DO entering the stream due to local oxygenation is calculated by an empirical equation relating DO deficit above and below weir to the geometrical properties of weir, weir type, quality of water and water temperature.

From the third scenario (case1: weir placement at different positions with 1m height) result as shown in Figure (9), it can be seen that the local oxygenation is effective in raising the DO levels. The DO concentrations are increased at downstream of weir at all locations ,but none of the DO profiles completely meets the minimum DO requirement.

From the third scenario (case2) result as shown in Figure (10), it can be seen that the DO profiles with 15 mg/L BOD5 limit for point sources and weir at critical position (6.67km) with 0.6 and 0.8 m height meets the minimum DO concentrations of 4.0 mg/L at all locations except for distance between (8.89-12.45) km in which DO concentration is (3.62-3.96) mg/L. The DO profile with 15 mg/L BOD5 limit for point sources and weir at critical positions (6.67km) with 1m height are almost within limits at all locations.

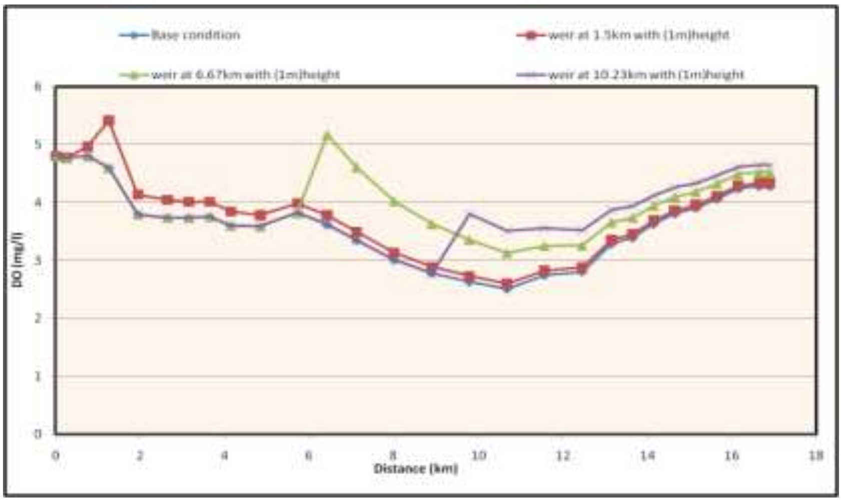

Figure 9. DO concentrations along the lower reach of Diyala River with (1m) height of weir that constructed at different location downstream of headwater.

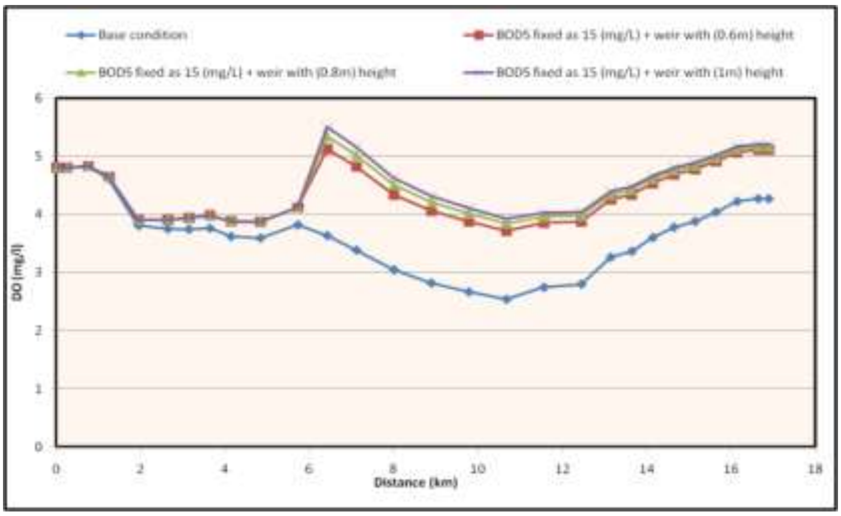

Figure 10. DO concentrations along the lower reach of Diyala River with BOD5 fixed as 15 (mg/L) for point sources and different heights of weir that constructed at (6.67km) downstream of headwater.

4. Conclusion

The conclusions of this study are summarized below:

1. Based on the simulation results, it was concluded that the pollutants concentrations of Diyala River were increased due to effluents discharge from Army Canal and Rustimiyah wastewater treatment plants. Then the pollutants level is slightly decreases after (10.68km) downstream of headwater due to no contaminated source at this distance and self-purification of the river.
2. The concentration levels of DO and BOD5 in the study reach exceed the allowable limits. Thus, the river water is not suitable for preserving the ecological health of the river.
3. The most polluted zone in the study region was starting at upstream of old Diyala bridge which about 8.45 km downstream of headwater and extending 4.5 km distance along the bridge.
4. From the scenarios results we can concluded that the pollution loads modification (value BOD5 for point sources decreases) and local oxygenation(weir placement at any position with any height) are effective in raising DO levels for Diyala River while flow augmentation(the value of river flow increases) does not give significant results in which the level of DO decrease. The combination of wastewater modification and local oxygenation(BOD5 of the discharged effluent from point sources should not exceed 15 mg/L and weir construction at critical positions 6.67km from the beginning of the study region with 1m height) is necessary to ensure minimum DO concentrations.

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