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WATER QUALITY MODELLING AND MANAGEMENT OF DIYALA RIVER AND ITS IMPACT ON TIGRIS RIVER

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Abstract

A numerical water quality model (HEC-RAS) was developed to simulate the carbonaceous biochemical oxygen demand (CBOD) and the dissolved oxygen (DO), within a selected reach extended about 25 km in Diyala River and 22 km in Tigris River. The model has been calibrated and validated using sets of data collected from previous studies during the wet and dry seasons. The results revealed that the simulated CBOD and DO were in agreement with the measured values. Moreover, the results showed that Diyala River was polluted in the region located downstream of Al-Rustimiya wastewater treatment plants (WWTPs) with values of CBOD ranged from 18 to 25 mg/L and DO varied from 1 to 3.1 mg/L for the wet and dry seasons. While for Tigris River, the CBOD values decreased from 17 to18.1 mg/L during the dry season and from 3 to 5 mg/L during the wet season. It was found that the Diyala River affects the water quality of Tigris River by increasing the value of CBOD by 6 to 66 % in Tigris River after the confluence with Diyala River. Furthermore, different scenarios were examined to propose proper options for water quality management in the river. HEC-RAS model can be used as an effective tool to manage the water quality in the river.

Keywords: CBOD, Diyala River, DO, HEC-RAS, Tigris river, Water quality.

1. Introduction

River and stream water quality monitoring and assessment are very important in order to attain an overall integrated water resource management of developing countries since the river is consumed in multiple uses like domestic use, agriculture, industry, recreation, and providing energy. Most rivers are the main sources of water supply, irrigation, and industrial uses in different parts around the world. River water quality is constantly changing and is affected by several factors such as anthropogenic input, weather, geology, etc. [1]. The monitoring process of rivers requires time, effort, and costs. An additional cost is also required when levels of water quality are not met.

Water quality modeling would solve this problem and can be useful tools to simulate pollutant transport in surface water, which can contribute to reducing the cost of labors and materials needed in the Lab for water quality analyses [2]. On the other hand, river systems are very complex, and the development process of river water quality model needs extensive data in order to achieve the simulation process. However, the evolution of computer technologies helped in solving many complicated problems in the field of water management [3, 4]. Numerous water quality models (WQMs) have been developed to predict the water quality in the rivers during the last decades such as SIMCAT, QUAL series, HEC-RAS v.5, WQRRS, MONERIS, WASP, MIKE-11, AQUATOX [5-12].

The selection of the water quality model (WQM) represents another challenge, in which each WQM has its conceptualization, processes, advantages, and limitations. Chinyama et al. [13] have proposed a simple procedure for the selection of WQMs based on criteria such as critical parameters that need to be simulated, data availability, model use, and availability of the model (public domain) and supports (like manuals). Other studies published in the literature have reviewed some popular WQMs based on a set of criteria [2, 7, 14, 15]. Their main conclusions were that every WQM can serve a range of functionalities and WQM selection relies on time, cost, and a specific application.

In Iraq, river water quality is suffered from deterioration due to the mismanagement of water resources [16]. The process of monitoring water quality in Iraq is uncontrolled due to the unstable situation in the country, in addition to the lack of financial resources [17]. Therefore, river water quality modeling in developing countries, including Iraq, is of prime importance. The current study examined the modeling of the water quality of the Diyala River and its effect on the Tigris River. Diyala River is characterized by low DO and high BOD concentration in the lower reach of the river due to several point discharges of wastewater. Furthermore, there is no existing plan to maintain the quality of the river [18, 19]. Few studies have been reported on the water quality of the Diyala river in the literature [20-22].

Ismail and Muntasir [19] have used the computational fluid dynamics (CFD) technique to solve a two-dimensional advection-dispersion equation to predict the pollutant concentration at the confluence of the Diyala river with the Tigris River. However, they concluded that some errors in the simulation results, especially for the simulation of non-conservative pollutants. Dawood and Rasheed [20] have studied the dispersion of pollutants in the Diyala River using the one-dimensional finite-difference technique. They concluded that the results of the applied model were acceptable. However, they consider only conservative pollutants such as total dissolved solids (TDS), chloride (Cl^-), and Sulphate (SO_4^{2-}).

Al-Hussaini et al. [21] have used different indices such as WQI, metal index (MI), and pollution index, PI to evaluate the water quality of Diyala River within Baghdad city during the period extended from 1999 to 2015 using collected data from previous studies. They found that the water quality of Diyala River was good in 1999 and 2008, and then, it became poor for the years from 2009 to 2015, due to the impact of the reduction of the efficiency of Al-Rustimiya's plants for wastewater treatment. Al-Rubaie and Al-Musawi [22] evaluated the impact of Diyala River on the water quality of Tigris River using GIS technique. The length of the selected reach of Diyala River was 25 km. While the selected length of Tigris River was 22 km. fourteen water quality parameters were estimated for the period between November 2017 and April 2018. The results showed that the most polluted station was downstream of Al-Rustimiya's old plant on Diyala River. Furthermore, they found that the water quality in Tigris river has deteriorated downstream of the confluence with Diyala River.

In the present paper, the HEC-RAS (version 5) model was selected to simulate the water quality of the Diyala and Tigris rivers. The selection of WQM was based on the framework proposed by Chinyama et al. [13]. HEC-RAS is a public domain software that simulates the hydraulics of water flow through natural rivers and other channels. The previous versions of HEC-RAS were incapable to simulate the water quality. In February 2016, HEC-RAS supports water quality modeling by simulating constituents such as algae, DO, CBOD, dissolved PO_4^{2-}, dissolved organic phosphorus, dissolved NH_4-NO_3, Dissolved NO_2, Dissolved NO_3, and dissolved organic nitrogen. The main aims of the present study are to simulate the CBOD and DO for a selected reach of the Diyala and Tigris rivers using HEC-RAS model during dry and wet seasons, to explore the effectiveness of the selected model in simulating water quality, and to examine the impact of Diyala River as a point source of pollution on the water quality in Tigris River and propose strategies to manage the water quality in the river.

2. Materials and Methods

2.1. Study area

Diyala River is considered an important tributary of Tigris River (Fig. 1). It covers a total distance of 445 km, including 386 km inside Iraqi territory. It is the most significant source of water in Diyala city. The length of the selected reach of Diyala River was 25 km, begins about 13 km upstream of Al-Rustimiya's third expansion wastewater treatment plant (WWTP), and ends at the confluence with Tigris River. Diyala River was divided into three stations, station no.1 located at (Nissan 9 station) about 13 km upstream of Al-Rustimiya's third expansion WWTP. Station No.2 located downstream of Al-Rustimiya's third expansion WWTP, and station No.3 is located downstream of Al-Rustimiya's old plant (Fig. 2). The length of the selected reach of Tigris River was 22 km, starting at 7 km upstream of the river confluence with Diyala River and ends with a distance of 15 km downstream of the confluence. Tigris reach was divided into 2 stations: station No.1 located at Al-Zaafraniya water project (before the confluence with Diyala River), and station No.2 located at Salman Pak pump station in Al-Madain (after the confluence with Diyala River). Figure 2 shows the scheme of the selected stations along the rivers.

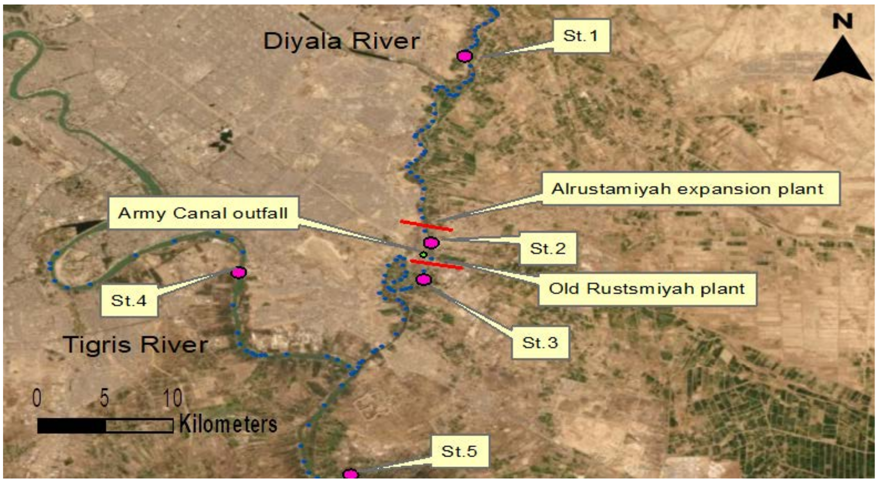


Fig. 1. The layout of the study reach.

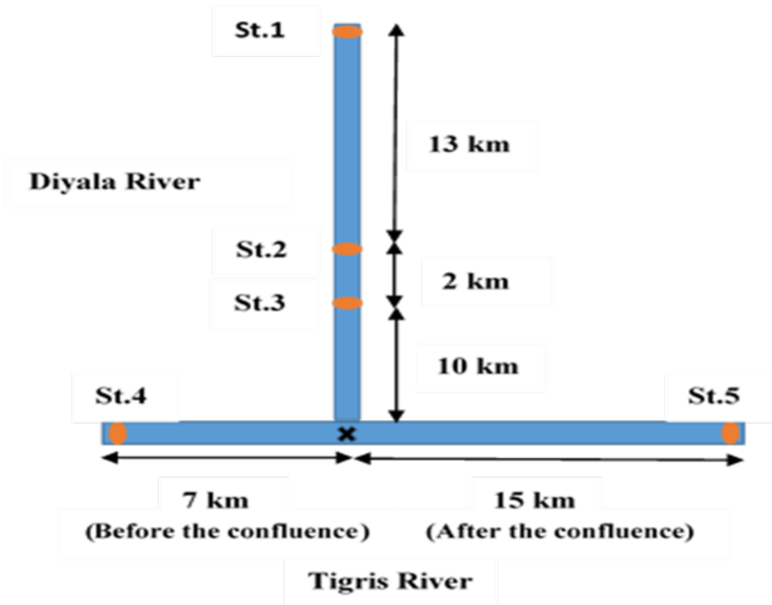


Fig. 2. The scheme of the selected stations along the rivers.

2.2. Model selection

HEC-RAS model has been developed by the United States Army Corps of Engineers. It is widely applied in the flood management [24-27], calculating the hydraulic characteristics of rivers [28, 29], coupled with GIS to produce inundation maps [30] or coupled with another water quality model to reach a specific goal [31]. According to our knowledge, HEC-RAS did not be applied in the field of water quality simulation and management.

Applications of three-dimensional models are not necessarily the most useful models [32], let alone they required extensive data set for the calibration and verification processes, and this might result in very complex models. On the other hand, some WQMs can include parameters that have never been previously reported in the literature, which lead to unreliable simulation results [31]. Therefore, one-dimensional or two-dimensional WQM could be an option, especially there are many successful examples have been reported in the literature [8, 33-36]. In the present study, and after reviewing different WQMs developed in the literature, HEC-RAS was chosen based on the framework proposed by Chinyama et al. [13]. The model is applied as a one-dimensional steady-state. It solves the dispersion equations using the numerical method (explicit method). The following equation is the advection-dispersion equation in one direction [37]

$$\frac{\partial}{\partial t}(V\Phi) = -\frac{\partial}{\partial t}\,(Q\Phi)\Delta x + \frac{\partial}{\partial x}\,(\Gamma A\frac{\partial \Phi}{\partial x})\Delta x\ \pm S \quad (1)$$

where, V= The cell volume (m^3), Φ= concentration of CBOD and DO (kg/m^3), Q = Flowrate (m^3/s), Γ= dispersion coefficient (m_2/s), A= Area (m^2), S = discharge of Nutrient (Sources or sinks) (kg/s).

The equation of water temperature (Heat) transport in source and sinks terms (HEC-RAS 2016) is

$$\text{Heat}\,\frac{source}{sink} = \frac{q\ net \times As}{\rho w \times cpw \times V} \quad (2)$$

where, $q\ net$ = the net heat flux located in the air-water interface (W/ m^2), ρw = water density (kg /m^3), cpw = Specific heat of water (J/kg°C), As = surface area of cell (m^2), V = The cell volume (m^3). For complete documentation on this model, refer to HEC-RAS [37].

2.3. Model implementation and input

The selected scheme of the rivers for this study extends about 13 km upstream of Al-Rustimiya's third expansion WWTP and ends about 15 km downstream of the confluence between Diyala River and Tigris River. A total number of 35 cross-sections were distributed along the Tigris River with a distance between 600 to 650 m, while in Diyala River the total number of cross-sections was 35 distributed with distance interval equal to 700 m.

The model requires hydraulic data, information about the geometry of the rivers, and water quality data to develop a water quality model. The water quality file consists of three components: temperature, Nutrient parameters (algae, DO, CBOD, dissolved PO_4^{2-}, dissolved organic phosphorus, dissolved NH_4-NO_3, dissolved NO_2, dissolved NO_3, and dissolved organic nitrogen), and meteorological dataset (air temperature, atmospheric pressure, humidity, wind speed, solar radiation, and cloudiness). In this paper, DO and CBOD were included in the model, and other parameters were assumed to be negligible. This is because the discharges of domestic wastewater have been identified as the major source of pollution in the river [19, 23]. Moreover, DO is very essential for all higher aquatic life, and low values of DO in rivers can unbalanced ecosystems with fish mortality, odours, and other aesthetic problems [14].

The water quality model was developed by submitting the required data into the water quality file, this model created to predict the values of CBOD and DO, therefore the boundary conditions for upstream of Diyala River (station no.1) and both upstream and downstream of Tigris River (station no. 4 and station no. 5) was the time series of CBOD and DO concentration values. The water quality data used in this study was provided by Al-Rubaie and Al-Musawi [22] and Mustafa et al. [23].

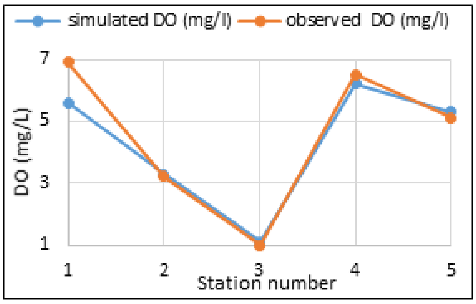
The meteorological datasets were obtained from the Iraqi meteorological organization and seismology. The geometric and hydraulic data such as information of coordinates and the cross-sections have been obtained from a technical report for the General Authority for Surveying of the Ministry of Water Resources, Iraq, "Data on the cross-sections and coordinates of Tigris River and Diyala River (2008-2019)". The value of Manning roughness coefficient for Tigris River was applied as 0.032 for the main river bed and 0.040 for the floodplain [38]. Whereas Manning roughness for Diyala River the manning roughness value was 0.027 [23]. Model parameters including rate constants for physical and chemical reactions between simulated constituents were obtained from various technical reports [19, 23, 37, 39]. HEC-RAS acknowledged the range values suggested in the QUAL2E model for the simulated constituent's rate constants and parameters. Table 1 shows the model parameters that have been considered in this study.

Table 1. Model parameters used in the present study.

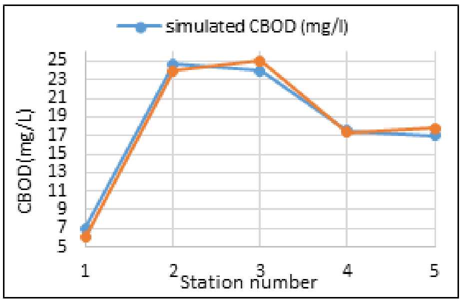
Parameter	Unit	QUAL2E Suggested Range	Default Value	Temperature Correction coefficient	Calibrated value
CBOD					
Deoxygenation rate (k_1)	1/day	0.02-3.4	0.02	1.047	0.02
Settling rate (k_3)	1/day	-0.36 - 0.36	0	1.024	0
DO					
Reaeration rate (k_2)	1/day	0-100	0	1.024	0

2.4. Model calibration and validation

The one-dimensional WQM was calibrated using the collected data from previous studies at the selected stations [22, 23]. Different sets of data were tested during different environmental conditions and the measured values of CBOD and DO in November 2017 were compared to the simulated values of both CBOD and DO during the same period. The root mean square error (RMSE) value was 0.7 mg/L and the determination coefficient (R^2) value was 0.94 for CBOD. While the RMSE and R^2 were 0.6 mg/L and 0.97 respectively for DO. Figure 3 shows the calibration results for the DO and CBOD in November 2017. The validation results of WQM was conducted by simulating the model data collected in April 2018 without changing the model rates and parameters and then comparing the results with measured values. The RMSE value was 0.8 mg/L and the R^2 value was 0.97 for CBOD, and for DO, the RMSE and R^2 were 0.55 mg/L and 0.98 respectively. Figure 4 shows the validation results for the DO and CBOD in April 2018.

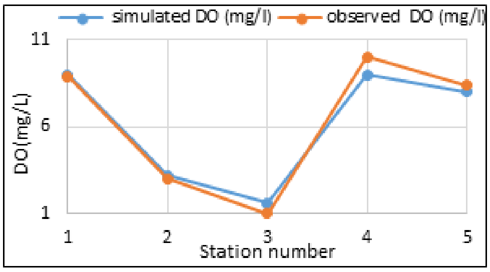


(a) DO concentration

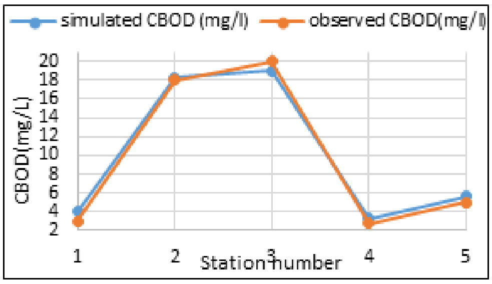


(b) CBOD concentration

Fig. 3. The calibration process of water quality model for the river reach in November 2017.



(a) DO



(b) CBOD

Fig. 4. The validation process of the water quality model for the river reach in April 2018

3. Results and Discussions

The water quality model was simulated during the dry and wet seasons and the obtained results were compared with standard values of water quality to indicate the polluted regions in both rivers. Actual values of flowrate were taken in the rivers for both scenarios, and the first scenario was simulating the water quality model for the dry season (19 m^3/s for Diyala River and 398 m^3/s for Tigris River). While the second scenario was simulating the model during the wet season (50 m^3/s for Diyala River and 677 m^3/s for Tigris River). The measured values of flow rate were established by the Ministry of Water Resources, Iraq according to the report "Data on the flowrate) and hydraulic information of Tigris River and Diyala River (2017-2018)". Figures 5 to 8 demonstrate the results of both scenarios' cases.

From Fig. 5, the results showed the values of CBOD in upstream of Diyala River (station no.1) were ranged from 4 to 7 mg/L during the wet and dry season which considered within the permissible limits to protect the aquatic health in the river according to typical scale conducted by environmental protection agency [40]. The value of CBOD increased suddenly at distance 13 km from upstream of Diyala River during the both seasons (at the station no.2, downstream of Al-Rustimiya third expansion WWTP) with values ranged between 18 to 24 mg/L. It continued to increase at distance equal to 15 km from upstream of the river for both seasons (at station no.3, downstream of Al-Rustimiya's old WWTP) with values ranged from 19.7 to 25 mg/L. This sudden increase in values of CBOD refers to the impact of domestic treated wastewater effluent from WWTPs on the water quality of the Diyala River which threatens aquatic life in this region for all seasons.

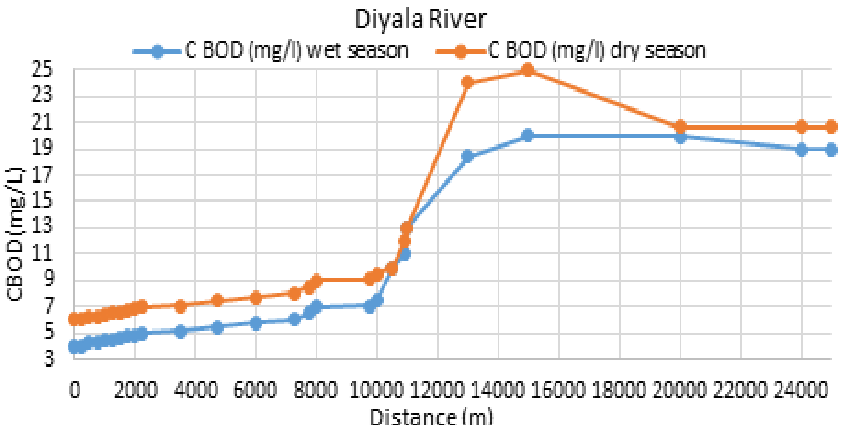


Fig. 5. CBOD values during the wet and dry season in Diyala River.

From Fig. 6, it can be seen that the CBOD concentration in Tigris River during the wet season ranged from 3 mg/L (station 4) to 5 mg/L (station 5) which is considered within the acceptable limits according to EPA. While, the CBOD values of Tigris River during the dry season ranged from 17 mg/L (station 4) to 18.1 mg/L (station 5), which is not within the acceptable limits for CBOD. For both seasons there is an increase in CBOD values after a distance 7 km from upstream of Tigris River, due to the confluence with Diyala River that affects the water quality of Tigris River by making it poor after the confluence.

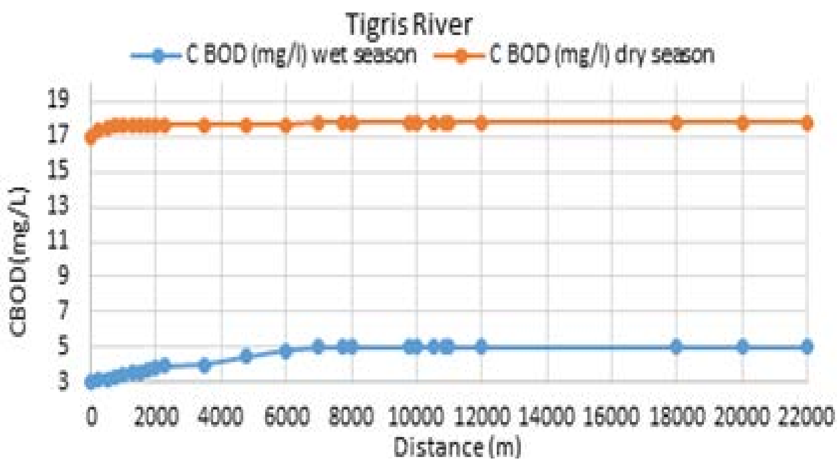


Fig. 6. The CBOD values during the wet and dry season in Tigris river.

Figure 7 shows the values of DO in Diyala River at station no.1 were ranged from 7 to 9 mg/L during the wet and dry season which is considered within the permissible limits (equal or more than 4 mg/L). The values of DO for station no. 2 (downstream of Al-Rustimiya's third expansion WWTP) ranged between 3 to 3.1 mg/L during the wet and dry season. Whereas, the DO values at station no. 3 (downstream of Al-Rustimiya's old WWTP) ranged from 1 to 1.3 mg/L during both seasons. The region in Diyala River that extended from downstream of Al-Rustimiya's WWTP till the confluence with Tigris is considered polluted since both CBOD and DO levels were not within the acceptable limits (DO equal or more than 4 mg/L) according to USEPA [41] and CBOD above 10 mg/L according to [42]. Figure 8 reveals that the DO values during the wet season in Tigris River, which ranged from 9.7 mg/L (at station no. 4) to 8.6 mg/L (at station no. 5). While during the dry season, it ranged from 6.1 mg/L (at station no.4) to 5 mg/L (at station no. 5). Generally, there is no problem in Tigris River concerning the DO values.

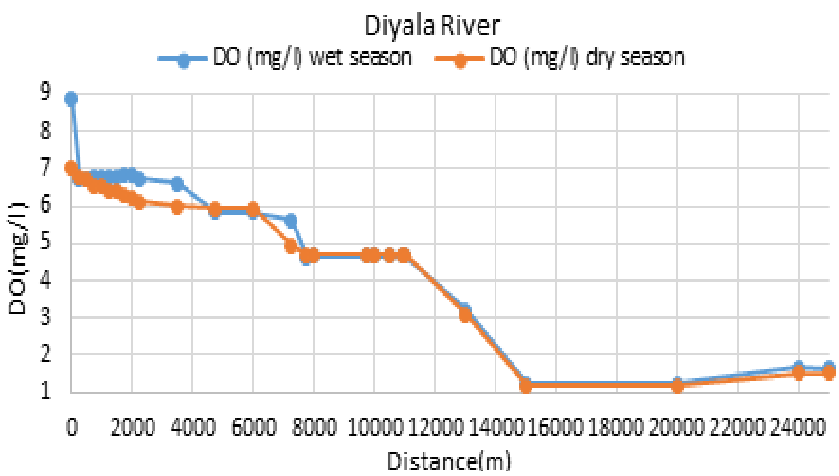


Fig. 7. The DO values during the wet and dry season in Diyala River.

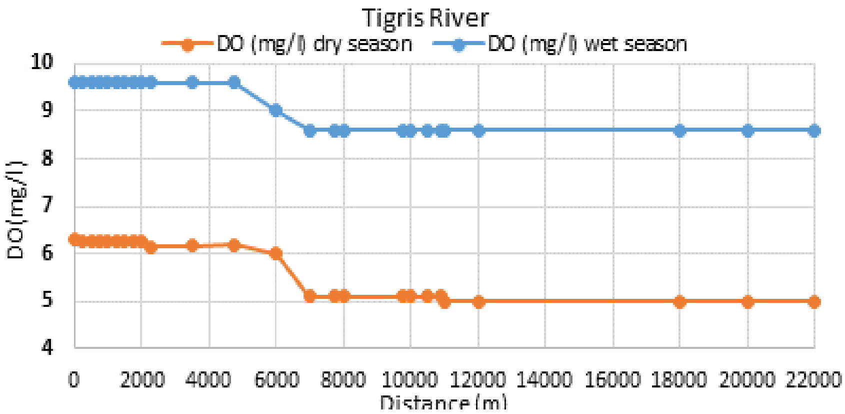


Fig. 8. The DO values during the wet and dry season in Tigris river.

The results of CBOD and DO were relatively compatible with the study of Mustafa et al. [23]. In this study, the mean values of DO and CBOD in January 2014 (validation result) were about 5 mg/L and 14 mg/L, respectively, and no fluctuation in the value of DO and CBOD along the Diyala River. Whereas in the present study, the values of DO and CBOD in the wet season was ranged from 9 to around 1 mg/L and from 4 to 19 mg/L. Mustafa et al. [23] have used the QUAL2K model to simulate the DO and BOD in the Diyala River using data in 2014. This may indicate that the BOD load was relatively increased during the recent year especially, there is no adequate treatment from WWTPs that discharge their wastewater into the Diyala River and this may support the argument about the deterioration of river quality [43, 44].

On the other hand, Ismail and Muntasir [19] have stated that the BOD concentration downstream of the confluence point between Diyala and Tigris river is about 5.5 mg/L in February 2017 (wet season). The results of the present study are completely compatible with Ismail and Muntasir (2018), in which the value of CBOD downstream of the confluence point is equal to 5 mg/L (Fig. 6).

Water quality management options

Three scenarios were examined in order to preserve the water quality in Diyala River and to keep DO concentrations within the standard value to protect aquatic life in the river. Each scenario includes three sub-scenarios and was performed by compensating the value of CBOD in the point discharge as 10, 20, and 30 mg/L. The first scenario was implemented by fixing the flow rate in Diyala River as 10 m^3/s. The second and third scenarios were performed by fixing the flow rate in Diyala River as 30 and 50 m^3/s, respectively. Figure 9 shows the three different scenarios that have been examined in order to control the water quality of Diyala River.

According to Fig. 9(a), it is clear that when the flowrate equal to 10 m^3/s and the values of CBOD are 30, 20, or 10. The DO concentration along the river becomes less than 4 mg/L after a distance of almost 13 km downstream of the river mouth and DO reach the lowest value of about 1.5 mg/L after a distance of 15 km till the confluence point with Tigris river. The same was noticed when the flowrate in the Diyala River equal to 20 m^3/s, Fig. 9(b). Furthermore, Fig. 9(c) revealed that the concentration of DO could be preserved (more than 4 mg/L along the river) when the flow rate in the Diyala River equal to 50, and the value of CBOD does not increase by 10 mg/L at all point discharges. Therefore, authorities should take an action to implement a strategy by increasing water releases and control the effluent of Al-Rustimiya WWTPs. This study may be extended by proposing other solutions such as build weirs to increase the DO level in the river. This needs to be investigated by simulation. Moreover, the present version of HEC-RAS model was effective in simulating the water quality of Diyala and Tigris rivers, since the model is capable of representing the water quality in rivers.

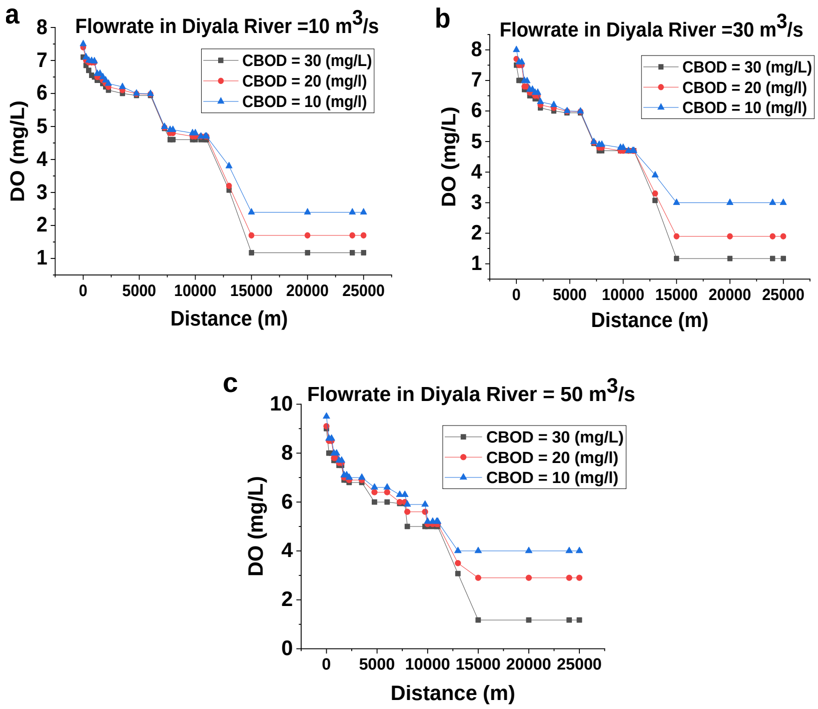


Fig. 9. DO values in Diyala River for the three scenarios examined, (a) Flowrate = 10 m^3/s, (b) Flowrate = 30 m^3/s, (c) Flowrate = 50 m^3/s.

4. Conclusions

The most polluted region in the rivers was at station no. 2 and station no. 3, located at a distance of 13 km and 15 km from upstream of Diyala River, respectively, and the values of CBOD ranged between 18 to 25 mg/L during wet and dry seasons. Moreover, the values of DO for the same stations varied from 1 to 3.1 mg/L during both seasons since these stations are located downstream of Al-Rustimiya's WWTPs which affect the water quality in Diyala River. The CBOD values in Tigris Rivers decrease from 17 to 18.1 mg/L during the dry season and from 3 to 5 mg/L during the wet season, because the flowrate is amplified in the rivers due to an increase in precipitation that makes the river flow fast and reduces the concentration of pollution due to dilution process. The CBOD values in Tigris Rivers during all seasons increased after the confluence with Diyala River by a value varied from 6 to 66 %, which means the Diyala River has a destructive effect on the water quality of Tigris River. DO concentration could be maintained as more than 4 mg/L along

Diyala River when the flow rate in the Diyala River equal to 50 m^3/s, and the value of CBOD does not increase by 10 mg/L at all point effluents. HEC-RAS model can be used as a tool for water quality management and decision-making.

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