Hydraulic characteristics of the lower part of Diyala River

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Abstract. A one-dimensional hydraulic model was conducted to simulate the flow in Diyala River. The research aims to study the flow capacity along Diyala River and especially concerning on reach of the river within Baqubah City during flood seasons by using HEC-RAS, 5.07 software. Moreover, specifying the hydraulic problems and then the necessary treatments to overcome them were suggested. A 190 km length of the reach of Diyala River was included in this study, starts from Diyala submerged weir to the confluence of Diyala-Tigris River south of Baghdad City. Good agreement resulted between the measured and the simulation results with a determination coefficient ($R^2$) value of 0.84 with Manning Coefficients in the steady-state flow of 0.028 and 0.045 for the main channel and for the over-banks of Diyala River, respectively. Moreover, the model results and the field surveying of the river showed that the flood capacity of the Diyala River within Baqubah City is cannot be exceeding 750 m$^3$/sec. Also, the flood-prone areas were identified, that they were located between Kharnabat to Um Al-Atahm, which requires training for the cross-sections and rising the embankments to increase the discharge capacity of the river for more than of 1000 m$^3$/sec.

Keywords: Baqubah City, Diyala River, Hydraulic Simulation, Flood.

1. Introduction
The use of one-dimensional hydraulic models in the simulation of the rivers flow has significant importance to specify the flow capacity and the hydraulic characteristics of the flow in these rivers. Moreover, it specifies the hydraulic problems, and then it will be easy to suggest the necessary treatments overcome.

Diyala River is the fifth tributary of the Tigris River, consisting of the confluence of the Sirwan and Tangro rivers in the Darbandikhan Lake in the Sulaymaniyah Governorate in northern Iraq. The river passes through Iran and Iraq and has a total length of 445 km. The river originates from the Zagros Mountains and flows into the Tigris River south of the Iraqi capital, Baghdad. The Diyala River stretches within Iraqi territory for a length of 350 km, and many dams have been built along the course of the Diyala River, including dams for storage purposes like Darbandikhan and Humreen Dams, and some dam building for irrigation purposes like Diyala weir.

Different studies were conducted to investigate the hydrologic and morphological behaviour of Diyala River. Wisam, et al. [1] carried out an analysis of water discharge frequency for Diyala river downstream of DerbendiKhan Dam. They have used some statistical models such are. The models were applied to annual water discharge for Diyala River. The water discharge magnitudes computed for many return periods. The models were Compared using different statistical measures such as standard error and root mean square error. The Chi-Square test also used to evaluate the goodness of fits for these models. According to this test and using the aforementioned measures, the Log-Normal
III distribution could be taken as the best for the water discharge series. This type of model is useful for designing the dam or spillway by computing the magnitude of water discharge flood versus different return periods.

GIS and image processing techniques were employed to identify the morphological features and analyzing the basin properties of Diyala River. Nadia et al.[2]. GIS hydrology tools used for watershed identification and analysis of the morphological features based on the Radar Topography Mission (SRTM) DEM data. Moreover, the study involved the geometric characteristic, where it defined the parameters of the sub-basins morphometric like; area, stream frequency, perimeter, width and length, stream orders, and drainage density. The results present to delineate five sub-basins with five stream orders, the drainage density of these the sub-basins. The number of streams in the first to the fifth-order were defined. The stream length reaches the maximum in the first-order, and it decreases with increasing the stream order. This result could be valuable for regional planners and overall policy-makers for agricultural/ water management strategies. Saddam et al.[3] Have studied the processes of water resource with decision-making for the Diyala River basin. The have involved impacts of climate change that require coherent climate datasets that may exhibit high spatial and temporal variability. These datasets are used in models with forcing data provided by statistical weather generators that mimic observed system behavior. The datasets must conserve historical correlations, or they will lead to wrong decisions about future climate change influences. And they evaluate the impact of the cross, spatial, and temporal correlations in climatic datasets on the climate change decision variables, as well as examine the contributions of variability in each sub-correlation on system performance outcomes. A predeveloped nonstationary bottom-up approach used to assess the operational rules of a multipurpose reservoir constructed on Diyala River basin in Iraq. The study utilizes different trajectories of statistical weather generator with different climate scenarios, by varying the accuracy of the cross, and the correlations of the temporal and spatial. The results demonstrated that the performance of the system is influenced significantly by the nature of the basin, and it revealed that the datasets is of paramount importance in hydrologic modelling and climate change impact assessment.

The low flow of the water in the Diyala River, in the most previous seasons after Diyala weir, led to a change in the morphology of the river, which affected the flow characteristics. Sediment eventually settles on the bottom river and cause narrowing for the River. Various types of materials of deposits have specifying characteristics, the quantity of these deposits depend on hydraulic factors such as the velocity of water, depth of water, and other properties of controls in determining the ability of the river to transport these deposits.

Asaad and Abed [4] studied the characteristics of the flow of Tigris rivers in the Baghdad city throughout the deficit period by using HEC-RAS Software. there is a large decrease in rates of the Tigris river water in Baghdad Region. This decline has affected about 12 schemes of freshwater on Tigris River-banks in Baghdad city due to the decline in river water flow levels by about 46%. The reach was involved from northern Baghdad city at the Al-Muthanna Bridge to the confluence of the Tigris River and the Diyala River southern Baghdad. Manning coefficient (n) established of 0.032 for the main river bed, and a 0.040 for the riverbanks with the RMSE of 0.076. The results showed that due to of low cost original, easy effectiveness and the possibility to inflate and deflate quickly and easily, the water supply scheme of inflatable weirs were considered a suitable solution to the essential rates of water for continuous operation. Daham and Abed [5] modelled 1D and 2D hydraulic simulations of unsteady flow in Al-Gharraf River to specify the hydraulic characteristics to define the locations that facing problems and suggesting the required treatments. The research is located between Kut and Hai Cities. HEC-RAS software was used to numerical simulation with flow rates between 100 to 350 m$^3$/s. The simulation results of the 2D model were more accurate than their corresponding 1D model, which gives minimum values of RMSE and R$^2$. AL-Zaidy and AL- Thamiry [6] simulated the flow at the Euphrates, Al Sabeel rivers and the Al Aţshan to study the real condition within Assamawa City by using HEC-RAS Software. After that, the simulation was implemented with conducting by modifying the cross-sections of Al Sabeel and the Euphrates rivers to increase capacity to 1200 and 1300 m$^3$/s, respectively. The results showed that the maximum discharge capacity under real conditions of Al Sabeel and Al Aţshan Rivers is 500 m$^3$/s and for Euphrates River is 750 m$^3$/s. Shayeaa and AL- Thamiry [7] modelled the hydraulic simulation Euphrates River within Anassiriyah City to
increase the discharge capacity during flood seasons. The results of current conditions showed that Euphrates River has a maximum discharge capacity of 300 m$^3$/s within Annassiriyah City. After re-simulation with applied improvements and removed Al Chibayish Weir hypothetically from the system of the river, the capacity can reach 1300 m$^3$/s. Azzubaidi and Abbas [8] carried out a numerical simulation to study the discharge capacity of the Tigris River between Amarah Barrages and Kut of 250 km in length. The results showed that the discharge capacity of the Tigris River between Amarah Barrages and Kut is 400 m$^3$/s in the current capacity for the main channel. They concluded that there are reduced by about half the discharge capacity during the period of 1988. And that is due to the reach has a large quantity of sediment during the period from 1988 to 2012. Prastica, et al [9] evaluated numerically by a flow simulation for the Bengawan Solo River in Bojonergero, Indonesia, flood potential of and it is effects on the town of Bojonergero by using the HEC-RAS software. The results obtained showed that the water levels along the river are more than the tail rivers. Rumansko et al [10] simulated the flow by using HEC-RAS software in the Sucevita River in northeastern Romania, to determine the effect of floods in the village of Marginea in eastern Karpathia on the community and houses. The results show that with the flood possibility of 1% will be affected by 17 buildings. While with the flood possibility of 5% will be severely impacted by 54 houses. Patel, et al [11] analysed the Ambica River that located east of Navasari town in India using a 1D steady-state flow modelling by HEC-RAS software. The obtained results showed that both the left and the right banks of the Ambica River be flooded, thus the Navasari City is endangered by floods. According to the analysis of these results, advisable the retaining wall is building parallel to the longitudinal section of the river at both banks that is to reduce the water levels during a flood to lowest levels.

The present research aims to simulate the hydraulic characteristics of the one-dimensional flow in Diyala River using HEC-RAS software, version 5.07, and specify the flow capacity along the lower part of the river especially within Baqubah City. Then suggest the required treatment T cross-sections training, or banks rising) for increasing the flow capacity of the river and to prevent the flood of the surrounding areas.

2. Description of Study Area

The reach of the study area has been located in the lower part of the Diyala River. This reach started from Diyala Submerged Weir to the north east of Baqubah City and extends to the confluence of Diyala-Tigris Rivers south of Baghdad City. The total length of the reach of the river is 190 km, as shown in Fig.1. The upstream boundary of the reach is started from the downstream of Diyala Submerged Weir, shown in Fig.2. In the past decades, the capacity of the River was able to pass a discharged up to 2500 m$^3$/s and the maximum water level at Al Jamahiriya Bridge inside Baqubah City was 44.8 m.a.m.s.l., at the flood of 1988. While in the recent year 2019, there was no ability to pass a flood discharge greater than 750 m$^3$/s in the Diyala River, and the maximum water level at the same location was 42.39 m.a.m.s.l. The study area is passing three cities they are Al khalass, Al Mugdadiyah, and Baqubah Cities. This study is focusing on Baqubah City due to a lot of meandering sections of the river through this city, as shown in Fig.3. Furthermore, Baqubah City is the center of the Diyala Governorate and having the highest density of population. Therefore, there is a need for studying the possibility of improving the flow capacity of the lower part of the lower Diyala River, especially in Baqubah City to ensure flood mitigation during flood seasons.
Figure 1. The lower part of the Diyala River, *Google earth*.

Figure 2. Diyala Submerged Weir.
Figure 3. Shows the location of the Baqubah City on the reach of the study area, by ArcGIS.

3. Basic Equations of HEC-RAS Software

The software HEC-RAS 5.0.7, introduced by the US Army Corp of Engineers which achieves the model of the hydraulic by according to several equations that necessary to obtain the water surface elevation, and velocity. Several basics equations are governing the unsteady state one-dimensional flow, these equations by Brunner and Gary [12] will be described below;

\[
\frac{\partial A}{\partial t} + \frac{\partial q}{\partial x} - Q_t = 0
\]

The equation of momentum as following;

\[
\frac{\partial q}{\partial t} + \frac{\partial qv}{\partial x} + gA \left( \frac{\partial z}{\partial x} + S_F \right) = 0
\]

The equations of “Saint-Venant” is obtaining by solving the previous equations that represent;

\[
\alpha V \frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + g \frac{\partial Y}{\partial x} = g(S_o - S_F)
\]

Where: Q = Total flowrate, \( m^3/s \). \( q = \) flowrate per unit length, \( m^2/s \). A =area, \( m^2 \). Y = stage, m. \( \alpha = \) Velocity coefficient, dimensionless. \( S_o = \) slope of the bed, dimensionless. \( S_I = \) slope of energy, dimensionless. g = gravity acceleration, \( m/s^2 \). \( v = \)Velocity, m/s. \( z = \)water surface elevation, m. t = time, sec.

4. INPUTS AND BOUNDARY CONDITIONS FOR ONE-DIMENSIONAL STEADY AND UNSTEADY FLOW MODELING

Much software can used to analyze the flow in river systems. In the present study, HEC RAS, 5.0.7, software used to conduct the hydraulic model for the flow in one-dimension to simulate the steady and unsteady state for the Diyala River. The essential input data required to develop the one-dimensional steady and unsteady flow model along the river that extends from the Diyala Submerged Weir to the confluence of Diyala-Tigris Rivers was gathered from numerous directorates affiliated with the
Ministry of Water Resources (MoWR), in addition to the field measurements were conducted. The model implemented using 209 cross-sections that carried out for Diyala River, 34 cross-sections for Tigris. The schematic diagram of the reach of the study area is as shown in Fig.4. The adopted boundary conditions for the steady-state were the discharge at the upstream of the reach of Diyala River and the upper flowrate of Tigris River, While the normal depth was selected as a downstream boundary condition, in Tigris River, 500 m downstream the confluence of the two rivers, south of Baghdad City. The flow hydrograph adopted as a stream boundary condition for the unsteady flow model, and stage hydrograph for downstream boundary conditions at the same mentioned locations. Different values of flowrates that ranged between 30-1200 m$^3$/s for Diyala River as different cases were supposed to study the hydraulic characteristics of the river. The period of the wave was taken as twenty-four hours for the unsteady flow modelling.

![Diagram of the reach of the studied area of Diyala River](image)

**Figure 4.** Schematic diagram of the studied reach of Diyala River.

5. **Results and analysis**

5.1. **Calibration and verification**

Fig.5 and Fig.6 present the calibration steady-state flow model in the main channel and over-banks of Diyala River. The calibration of the steady-state model was carried out to specify the appropriate value of the manning coefficient that reaches the minimum difference between the predicted and simulation results of water levels and discharges. The results showed that the optimum value of the manning coefficient is equal to the main channel of ($n_1=0.028$) and over-banks of ($n_2=0.045$) gave the best results with a minimum The Root Mean Square Error (RMSE) of 0.21 and 0.07, respectively. Fig.7 and Fig.8 present verification of steady-state flow model for the water level and discharges in Diyala River using the optimum values of manning coefficient. Moreover, the result showed that good agreement between the measured data and the simulation results with the determination coefficient ($R^2$) value equal to 0.84. Finally, data used in calibration was measured by the Ministry of Water Resources for the period from (23/01_31/03)/2019. As for data used in verification was measured in the period from (01/04 to 31/04)/2019.
Figure 5. Calibration of the manning coefficient in of the main channel (n1) of Diyala River.

Figure 6. Calibration of the manning coefficient in of overbanks (n2) of Diyala River.

Figure 7. Verification of steady-state flow model for water level in Diyala River.
5.2. Steady flow conditions

This part presents, several flowrates that were passed through the Diyala River. Fig.9 to Fig11 shows the water levels profile of full reach in the Diyala River with the low discharges of (30-300 m$^3$/s), the medium discharges of (600 - 750 m$^3$/s), and the Flood discharges of (750-1200 m$^3$/s), respectively. The low and medium discharges passed through the river without any operation problems, as well as it showed that the maximum discharge could pass through the river is 750 m$^3$/s. As for the flood discharges (1000-1200 m$^3$/s) are considering the most dangerous cases due to the river will be flooded in some regions along that needed to treat. Furthermore, that is back to exceeding the water level of the river more than the levels of the banks in this region, especially in Baqubah City. Eventually, Fig.12 shows the Water levels profile of Diyala River at Baqubah City with the discharges of (750,1000, and1200 m$^3$/s). This Flowrates passed through the Diyala River within Baqubah City to explained the zones of the critical banks. For example, in the area of Kharnabat north of Baqubah and the areas between al-Sharif and Al-Jumhuriya Bridges and the village of Shiva, located all in the center of the city, the left banks are unsafe for discharges exceeds 750 m$^3$/s. While, the area of Um A-Atahm, south of Baqubah, the right banks are considered unsafe if the discharges more than 900m$^3$/s.

Of all the above cases, it can be concluded that the discharge which does not result in flood on the right and left banks within Baqubah city is 750 m$^3$/s. Furthermore, for increasing the capacity discharge of more than 1200m$^3$/s, the regions that are required protection must be treated, for the purpose of passing the largest of the flood waves. Finally, there is more than methods to protect, for example, retaining wall, stoneware cladding, gabions, concrete mattresses, and modified (training) the cross-sections, and the selection of proper method is depending on the situation of the region, the length of the reach that needs protection, and basically according to cost.
Figure 9. Water levels profile of full reach in Diyala River with the low discharges.

Figure 10. Water levels profile of full reach in Diyala River with the medium discharges.
Figure 11. Water levels profile of full reach in Diyala River with the Flood discharges.

Figure 12. Shows water levels profile of Diyala River at Baqubah City with the discharges between (750-1200 m$^3$/s).
5.3. The Confluence of Tigris River and Diyala River Effects

The backwater curve is considering the main phenomenon hydraulic at the confluence of natural rivers. Therefore, in this part, the analysis focused on the impacts of discharges from the Diyala River to the Tigris River at the confluence. Then, the phenomenon has explained the effect on an increase in levels of water surface at the confluence of both rivers.

5.3.1. The Diyala River’s effect on the Tigris River

In this part, the effect of the Diyala River on the Tigris River was demonstrated. Firstly, the observations were recorded for the Tigris River in the Saray gauge in Baghdad in flood 1988. The formation of the backwater curve at the confluence was directly proportional to the flow of the Diyala River. The highest discharge of the Diyala River 2500 m$^3$/s was recorded at the back of the Hamrin Dam, and 1820 m$^3$/s in Tigris River on 3/29/1988. The water level became 34.12 m in the Saray gauge in Baghdad and it became 33.3 m on the backside of the Hamrin dam for the discharges of 650 m$^3$/s, and 1820 m$^3$/s in Tigris River, respectively. Table 1 shows the effect of the Diyala River on the water level of the Tigris River in the last flood of 2019 in the Saray gage at Baghdad. Although, there are measured the same flows of the Tigris River. However, the water levels were changed for the same discharges, and the reason is discharge into the Diyala River. Finally, it became any discharge into the Diyala River affects the water levels in the Tigris River at Baghdad city.

Table 1. Effect Diyala River on Tigris River in the year 2019.

| NO. | Wl. Tigris (m) | Q in Tigris (m$^3$/s) | Q in Diyala (m$^3$/s) |
|-----|----------------|----------------------|----------------------|
| 1   | 28.45          | 324                  | 540                  |
| 2   | 27.84          | 324                  | 450                  |
| 2   | 27.85          | 350                  | 177                  |
| 3   | 28.15          | 350                  | 320                  |
| 3   | 28.69          | 400                  | 320                  |
| 4   | 27.74          | 400                  | 150                  |
| 4   | 28.97          | 450                  | 324                  |
| 5   | 27.97          | 450                  | 96                   |
| 5   | 28.87          | 539                  | 273                  |
| 6   | 28.72          | 539                  | 250                  |
| 6   | 28.63          | 540                  | 250                  |
| 6   | 29.09          | 540                  | 332                  |

5.3.2. The backwater curve in the Diyala River

By using the numerical model of the HEC-RAS, the effect of the Tigris River on the Diyala River was demonstrated at the confluence of the two rivers. Fig.13 shows the backwater curve impact on Diyala River at confluence by HEC-RAS modelling with several scenarios. Scenarios were formed with three cases, the discharge of the Tigris River is more than, less than, or equivalent to the discharge of the Diyala River. After analysing the results of these scenarios, the formation of this backwater curve showed the cases of the discharge of the Diyala River more than or equivalent to the Tigris River. While it does not impact when the flow of the Tigris River is less than the Diyala River. Because of the absence of a measuring station in the Diyala River close to the confluence. The numerical results
of the model only were relied on, for analysing the results of the formation of the backwater curve and it not to compare with observed measuring water levels.

Figure 13. Backwater curve impact on Diyala River at confluence by HEC-RAS modelling.

5.4. Unsteady flow conditions

After carrying out and find the optimal values of manning roughness for the main channel and over banks of Diyala River and apply it to the model and simulate different flow duration time for the wave of 4hr, as shown in Fig.14 to Fig16. The results of one-dimensional unsteady flow modelling for the purpose of comparison with steady-state, expressed by the profile of the water levels and velocity as well as duration time of the wave for unsteady flow. The obtained results showed a good agreement between steady and unsteady flow for discharges less than of 550m$^3$/s.

Figure 14. Velocity comparison between steady and unsteady at Baqubah City.
Figure 15. Water level comparison between steady and unsteady at Baqubah City.

Figure 16. Duration time for wave arrival from Diyala weir until Baqubah City for unsteady flow.

6. Conclusions
Established on the analysis of the obtained results, the main conclusions are:

- The suitable manning coefficients of the steady-state were 0.028 and 0.045 for the main channel and for the over-banks of Diyala River, respectively that gave the best results with a minimum (RMSE). Moreover, the result showed that good agreement between the measured and the simulation results with a determination coefficient ($R^2$) value equal to 0.84.
- The currently maximum actual capacity of the reach of the study area of Diyala River within Baaguba City is equal to 720 m$^3$/s.
- The risk areas were located between AL-Shraif Bridge passing through Kharnabat and reaching Um Al-Atahm that required treatments to increasing the flowrate capacity to more than 1200 m$^3$/s, and for the purpose of passing the largest of the flood waves.
- The obtained results showed a good agreement between steady and unsteady flow for the discharges of less than 550 m$^3$/s.
• Any discharge of the Diyala River and due to its higher level will affects about the water levels in Tigris River at Baghdad City, while Diyala River influenced by the cases of the discharge in Tigris River that they more than or equal to discharges of the Diyala River.

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