Simulation of Sediment Transport in the Upper Reach of Al-Gharraf River

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Abstract. For the past few years, the sediment began to accumulate in Al-Gharraf River which reduces the flow capacity of the River. In the present research, a numerical model was developed using Hec-Ras software, version 5.0.4. to simulate the flow and sediment transport in the upper reach of the river. The hydrological and cross-section data measured by the Ministry of Water Resources, for the reach located between Kut and Hai cities and having a length of 58200 m, was used to perform calibration and verification of the model. Moreover, field sampling of suspended and bed loads was gathered for five months starting from 7/2/2019, and laboratory tests of samples were conducted to be used as input data in the model. Actual flowrates for the year 2018 were used to predict the sediment accumulation in the river, and the results show that the accumulated deposition was ranged between 2.5 cm to 1m, while the erosion depth ranged between -4cm to -2cm. Furthermore, the estimated amounts of sediment discharges were ranged between 70 and 1308 Tones/day. Then four scenarios of flowrates ranged between 100-300 m$^3$/s were used to analyze the possible sedimentation problems and to propose the treatment needed to preserve the morphology of the river. The results show that the invert changes of bed depth were ranged between -2 to 9 cm, and the sediment discharge ranged between, 33 to 970 Tones/day. A lining of specified sub-reaches using the concrete or by the grouted riprap was proposed to avoid sedimentation or erosion respectively.

Keywords: Al-Gharraf river, sediment transport modeling. Hec-Ras 5.0.4.

1. Introduction
The sediment accumulation in Al-Gharraf River became one of the important problems that concern the Ministry of Water resources due to its significant influence on the River abilities of convenience and the benefits of it. There were no previous studies concerning the sedimentation in the upper reach of Al-Gharraf River. Kayyun and Dagher [1] formulated a model using Hec-Ras software to simulate the sediment transport within the Tigris River located between Al-Muthana Bridge and ends at the Sarai Baghdad gauging station located in the center of Baghdad City, the model simulated from 2012 to 2017. The results indicated that erosion was found in the upstream and the downstream of the River reach with a depth equal -0.51m, And the deposition located in the center of the stream with depth equals 0.39 m. Safi et al. [2] simulated a quasi-unsteady analysis model to simulate the sedimentation and erosion in Kunar River which located in Afghanistan. The results showed that Kunar River erosion occurs in upstream of the reach with maximum erosion depth about -2.449 m and sedimentation happens in downstream of reach with maximum deposition depth about 1.495 m.

Khassaf and Abbass [3] studied and estimated the transporting amount of sediment using Hec-Ras software, in upstream of Al-Yaa’o regulator, located on Euphrates River within Al-Qadissya City. The conducted maximum amount of total sediment load from the model was (248419) Tons/year. Mohammed et al. [4] studied sediment transport capacity in Euphrates river at Al-Abbasia reach using
Hec-Ras model, the result of simulating the model for one year shows that the average sediment discharge was 50 Tones/day. Mustafa et al. [5] constructed an HEC-RAS model to study the sediment transport for a specified reach in the Euphrates River, the study reach located between Haditha dam and Heet station which located in Heet city. The results of the simulated model for one year showed that the total sediment discharge was 237.38 Tons/day. (Dysarz et al. [6] created a model using Hec-Ras to study the deposit accumulation during 10 years in Ner River located in Poland, the result showed the average depth of deposition accumulation was 0.5 m.

There are several solutions to treat the deposition in the streams like statistical methods, or numerical modeling for the sediment analysis, either way, the sediment samples must be gathered to identify the bed type and measure the concentration of sediment in the River. AL-Gharraf River is the largest tributaries of Tigris River there for it’s the main resource of water for the cities lies in the middle and south of Iraq. The selected reach for this study extends from Kut city, downstream of Kut Barrage and it ends near Hai city with reach length equal to 58200 m. The reach of the River includes important structures like Gharraf Head Regulators and Hai Regulator and also includes few subdivisions. In this study, only subdivisions that have a flowrate value greater than 1 m$^3$/s were selected, which are Janabyat Al Hai, Gamela, and Um al Tubaikh, Fig.1. This research aims to create a numerical model to simulate the sediment transport in the upper reach of Al-Gharraf River and find out the suitable treatment for sedimentation problems in that reach.

![Satellite image of the upper part of Al-Gharraf River, Google earth](image)

2. Basic Equations Concern Sediment Modeling

There are basic equations concerning sediment transport in the Rivers. Firstly, the sediment continuity equation, from [7]:

$$\frac{\partial QS}{\partial X} = (1-\lambda P) b \frac{\partial \eta}{\partial T}$$  \hspace{1cm} (1)

Where; $b =$ channel thickness in m, $\eta =$ channel altitude in m, $\lambda P =$ porosity, $QS =$ sediment discharge in Tones/day. The Following equation was chosen in sediment transport function called the Laursen-Copeland transport function equation, from [7]:
\[ C_M = 0.01\gamma \left( \frac{d_D}{D} \right)^{1.167} \left( \frac{\tau}{\tau_c} - 1 \right) f \left( \frac{d_D}{\omega} \right) \]  

(2)

Where: \( \gamma \) = the water-specific weight in kg/m\(^3\), \( d_D \) = mean diameter of sediment in mm, \( D \) = Effective depth for the flow in m, \( \tau \) = the shear tension of channel in pa bottom, \( \tau_c \) = Critical shear stress of channel bed in pa, \( \omega \) = fall velocity of deposit in m/s, \( u^* \) = Shear velocity m/s, and, \( C_M \) = concentration of Deposit flowrate Tones/day.

3. Inputs and Boundary Conditions

In this study, the Hec-Ras, version 5.0.4, the software was used to simulate the sediment transport in Al-Gharraf River. This software was adapted in the United State in, February 2016, by the US Corp of Engineers to analyze the schemes of the Rivers.

3.1. One-dimensional steady flow modeling

The one dimensional model in the steady-state must be created first and calibrated before simulating the sediment transport model. A schematic of the River was entered and extends from the upstream of the Gharraf Head Regulator, at station 58200m and it ends near Hai city at station 100m that having a total number of 24 stations through an interval space ranges from 100 to 1000m between each cross-section. All the survey data were measured by MOWR [8]. Even though the hydrological data for the mainstream, outlets, and Regulators were from MOWR [8,9]. The boundary condition for the upstream was the discharges and for the downstream, the normal depth was selected with an energy slope value of 8 cm/km. While for the gate openings, actual data were taken for both Regulators that equal to 260 cm for Al-Gharraf Head Regulator and 210 cm for Hai Regulator.

3.2. Inputs of Morphological model

Hec-Ras present Quasi unsteady flow method to analyze sediment transport in the Rivers. The selection of the hydraulic model must be appropriate and the model should be calibrated using various manning roughness coefficient values. Several required data that quasi unsteady flow needed, such as the flowrates, the entered flowrates in this research were actual measured values of the Al-Gharraf River by the Ministry of Water Resources, MOWR. These data were considered as the upstream boundary condition, located at the station No.58200 m, which represents the flow time series. While The selected boundary condition for Hydraulic structures was Gate Time Series, Both of The Regulators gates openings data were taken from actual operation, for Head Regulator it ranged between 0.60 m to fully opened, and for Hai Regulator it ranged between 1m to fully opened. The adopted boundary condition at the last station of the study, station No. 100, was the Stage time series, which were the measured values also conducted by MOWR. The selected boundary conditions for subdivisions are the Normal depths, as well as the selected value of the energy slope was 8 cm/km. The mean of the measured temperature values during sediment sampling was 20°C, which was considered as input data into the quasi-unsteady window.

3.3. Sediment Transport modeling

The sediment transport Model was conducted by entering data into the following files: file of geometry, file of quasi unsteady flow, and the file of sedimentation information. The sediment data file contains the transport functions, these functions are sensitive and must be chosen carefully. In this study the bed type of the River bed was silty clay, Therefor, Laursen-Copeland was the selected function to characterize the sediment transport in Al-Gharraf River. The selected boundary condition for the upstream of the study was the rating curve which calculates the sediment flowrate and it requires the discharge of the water, the sediment load, and the grain size distribution for the upstream. Moreover, the sediment file requires the grain size distribution data for each cross-section, these inputs are the result of analyzing the bed material samples in the laboratory. A total number of six-bed gradation templates were inputted into the specified sections were the bed material samples gathered, and nine samples of suspended load were gathered, including three sets of suspended sediment samples at the upper reach of Al-Gharraf River which governed by the present study at cross-section No.1, at station
58200, to be as inputs of concentration of sediment discharge. Figure 2 illustrates the grain size distribution for the upstream of the study reach.

4. Results and Analysis

In the following articles, the calibration and the verification of the flow and sediment transport models will be illustrated. Moreover, the results of the real and assumed flow conditions will be analyzed.

4.1. Calibration and Verification of the steady flow model

The calibration process was conducted to know whether the model simulation accurate or not, several manning roughness values were tested to determine the optimal manning roughness coefficient value for the steady-state of Al-Gharraf River. The calibration process occurs by comparing the observed values measured by MOWR at Al-Hai Regulator with simulated values of the model. The measured discharge value ranged between 160-180 m$^3$/s with a discharge interval of 5 m$^3$/s, and water surface elevation (WSE) ranged between 12.04 to 12.7 m, Table 1. The tested values of manning roughness were ranged between 0.024-0.028, and the simulation time was one day. Figure 3 shows the optimal manning roughness value for steady-state was 0.026 with Root Mean square, RMSE value 0.0914, and the coefficient of determination value equal to 0.995. While the verification process was conducted by using the measurement data for the year 2018, using 0.026 the optimal value of manning roughness for the steady-state. The coefficient of determination value, $R^2$ was 0.99, Fig.4.

| Month    | $Q$ (m$^3$/s) | WSE (m) |
|----------|---------------|---------|
| June     | 160           | 12.04   |
| July     | 165           | 12.1    |
| August   | 170           | 12.2    |
| September| 175           | 12.5    |
| October  | 180           | 12.7    |

Table 1. The observed data of Hai Regulator for the year 2017.

**Figure 2.** Particle distribution curve for bed material at the upstream reach of the river.
Figure 3. Calibration of the steady-state flow model for the year 2017.

Figure 4. Verification of steady-state flow model for the year 2018.

4.2. Calibration and Verification of the Sediment transport model
The Calibration of the sediment model is a significant process to check the model validation to simulate the actual condition of Al-Gharraf River and solve the sedimentation problem. In the present study, the model was calibrated using observation measurements of the cross-section conducted by the MOWR [8] and the measurements conducted by [10]. Eight sections were selected where the significant deposition and erosion occur, to calibrate the sediment transport model, four of them were illustrated in Fig.5. In the calibration of the simulation model, the comparison will be presented for the four years periods extended from 2012 to 2016 for selected sections to show the influence of sediment accumulation or erosion occurs in those cross-sections with the measured cross-sections by Arrar [10] using a maximum accumulation depth during the simulation time equal to 48 cm, these results achieve high values of R² which ranges from 0.99 to 0.975. The obtained value of RMSE was 0.0353. While the verification process was conducted by performing for two different cross-sections where significant Sedimentation and erosion also occur. The value of the R² value was ranged between 0.996 to 0.998 and RMSE value equal to 0.01, which was obtained when comparing the simulation results with the measured data in the other two sections, Fig.6. That indicates good agreements between these results,
as well as the good ability of the simulation model to estimate the transport of the sediments in the reach of the river.

Figure 5. The calibration process of the sediment transport model in selected cross-sections.

4.3. Result of sediment simulation
The sediment transport model was simulated for one year using all the necessary flow data that measured during 2018, to visualize the River sections and to conduct the invert change depth and the sediment discharge values. Invert change is the difference between the initial bed level and the predicted bed from the model simulation, where, all the negative signs in figures and tables mean erosion while the positive signs mean sedimentation. The results of simulating the model for one year showed that the maximum sediment accumulation occurs upstream of Gharraf Head Regulator. At station 58200 m, cross-section No. 1, with depth equal to 1 m for the year 2018, and the sediment discharge of it was 1308 Tones/day, while the minimum sediment accumulation depth was near Hai city, at station 100, cross-section No.
24, with depth equal to 2.5 cm and sediment discharge 70 Tones/day. The maximum erosion occurs in station 17300, cross-section No. 14, with erosion depth equal to -4 cm. Fig.7.

![Figure 7](image_url)

**Figure 7.** Accumulative changes of invert bed depth along the reach of River for the year 2018.

Another simulation of the sediment transport model was conducted at different assumed values of discharge within the capacity of Al-Gharraf River; 90-100, 190-200, 290-300 m³/s for one month, to handle the sedimentation problem in Al-Gharraf River. The results show that the value of invert change depth was ranged from – 2 to 9 cm, which means the maximum value of sedimentation depth, was 9 cm and the maximum erosion depth was -2 cm, and the sediment discharge ranged between 32 and 527 tones/day when 90-100 m³/s was released Fig. 8. For the case of discharge equals 190-200 m³/s, the invert change depth ranged from -2 cm to 9 cm also, and the sediment discharge ranged from 77 to 970 Tones/day Fig. 9. While the values of invert change and the sediment discharge in the cases of Q equals 290-300 m³/s were -2 to 1 cm and 91 to 350 Tones/day respectively, Fig.10.

![Figure 8](image_url)

**Figure 8.** Accumulative changes of invert bed depth along the reach of River when Q=90-100 m³/s.
Figure 9. Accumulative changes of invert bed depth along the reach of River when Q=190-200 m³/s.

Figure 10. Accumulative changes of invert bed depth along the reach of River when Q=290-300 m³/s.

4.4. Suggested treatments for Sedimentation problems

The Simulation during the period of field sampling extended from 7/2/2019 to 7/7/2019 using the values of the discharges that measured during that period are ranged between 250-210 m³/s. The simulation results show the cross-sections in which the maximum deposition occurs was at RS 58200, RS 57300, RS 56800, and RS 600. And the maximum erosion occurs at RS 13000, and RS 5000, Fig.11. The values of accumulative sediment depths were ranged between 0.15 and 0.37 m, and the scouring depth values were ranged between -0.02 and -0.04 m. To minimize the sediment accumulation, the Manning Roughness coefficient (n) value must be reduced for a distance preceding the sections that sediment accumulated in. That will maximize the velocity and reduce the deposition of sediment. While in the erosion sub reaches the Manning Roughness value must be increased to reduce the velocity values which results in minimizing the scour in these sub reaches.

The actual value of Manning (n) used in the present study was 0.026. Several values of manning roughness coefficients were tested and the results obtained indicate that the suitable Manning (n) values that minimize the deposition and erosion of sediment are 0.015 and 0.028 respectively. The concrete lining with n equals 0.015 was proposed to reduce the roughness of River with a percent of 42%. While the Grouted Ripraps was proposed for the lining the erosion sub reaches with n equals 0.028 that
increases the roughness of River with a percent of 8%. The obtained results from the simulation model point out that the deposit depths when the proposed lining used were reduced from 0.15 - 0.37m to 0.012-0.21 m. The resulted erosion depths were reduced from -4cm to 2 mm when the proposed lining was used.

![Figure 11](image-url)  
**Figure 11.** Accumulative changes of invert bed depth for the period (7/2/2019 to 7/7/2019).

| Station | Invert change before treatment (m) | Invert change after treatment (m) | Percent of change |
|---------|-----------------------------------|----------------------------------|-------------------|
| 58200   | 0.377                             | 0.21                             | 44%               |
| 57300   | 0.283                             | 0.101                            | 64%               |
| 56800   | 0.156                             | 0.06                             | 62%               |
| 13000   | -0.039                            | 2.34E-03                         | 94%               |
| 5000    | -0.038                            | 1.45E-03                         | 96%               |
| 600     | 0.151                             | 0.012                            | 92%               |

### 5. Conclusions

The following conclusions were extracted from the results obtained from the simulation and sedimentation model:

- The developed numerical model was well simulated the flow and the hydraulics of sediment transport in the reach of the study due to good agreement between the simulated and measured results of water surface elevation and the morphology of the river.
- The suitable manning roughness coefficient that produces a good simulation of Al-Gharraf River for the steady-state was 0.026.
- To minimize the sediment accumulating occurs at specified sites along the reach of the river, lining with concrete for these sites will reduce the accumulation of sediment, and the results show that the invert changes of the governing bed dropped by a range between 44-92%.
- To minimize the scouring occurs at some site along the reach of the river, lining with grouted riprap was proposed to reduce the erosion of the bed and banks by 92-96%.
- The simulation results of the sediment transport model show that when the flowrate value ranged between 290-300 m$^3$/s, a minimum accumulation of sediment resulted in the river, and the estimated amount of sediment transported in the reach was ranged between 91 and 350 Tones/day. So, it may be considered as the optimum flowrate passes through the river.
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