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Research Article

Identification of Manning's Coefficient Using HEC-RAS Model: Upstream Al-Amarah Barrage

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In understanding the hydraulic characteristics of river system flow, the hydraulic simulation models are essential tools. This study submits the results of the proposition of a hydraulic model in order to determine the roughness coefficient (Manning's coefficient n) of the Tigris River along 3.5 km within the Maysan Governorate, south of Iraq. HEC-RAS software was the simulation tool used in this study. The HEC-RAS model was adopted, calibrated, and validated in adopting two sets of observed water levels. Graphical and statistical approaches were used for model calibration and verification. Results from this investigation showed that a value of Manning's coefficient of 0.025 gave an acceptable agreement between observed and simulated values of water levels.

1. Introduction

In predicting flood, the mapping and estimation of flood volume and various hydrodynamic models are developed and applied to several rivers with the aid of computers and numerical techniques. In forecasting and warning of a flood, the river stage and discharge are considered as the variables. Among various hydraulic parameters, especially in hydraulic modelling, the roughness coefficient (or Manning's coefficient) is an important parameter. Knowing Manning's coefficient of roughness in open channels is of great importance in achieving any modelling that aims to study a variable of river variables such as flooding, sediment transport, and others.

The parameters from models practiced in the engineering of hydraulics may be grouped into two groups: physical parameters and empirical parameters. The physical parameters describe the physical properties of materials; usually, they are constants while the empirical parameters are established on mathematical models. Because of the complexities of hydraulic engineering, specific values for the empirical parameters, such as Manning's coefficient n, are often uncertain. As an empirical parameter, the roughness coefficient (Manning's n) includes the elements of roughness of channel surface, bed material, vegetation, channel alignment and irregularities, channel shape and size, stage and discharge, suspended sediment load and bed sediment loads, etc [1]. Several empirical formulas for the estimation of the value of n in practical problems have been proposed in the past [2].

Determination of "n" value presents an influential and creative task in the hydraulics of open channel flows. Due to changes in time and space in the value of the coefficient n, the determination of the coefficient n becomes a very complex problem. This change in n value depends on geometric, geomorphological, and hydraulic parameters of water current and river or channel beds [3].

A number of researchers suggested several methods for the determination of n. Ramesh et al. determined a single Manning's n value for the flow in open channel using optimization method; they took the boundary conditions as constraints [4]. Ali et al. investigated the roughness value of the Parit Karjo channel in Malaysia using Manning's equation. They found that the roughness value was between 0.04 and 0.48 [5]. Ding et al. presented a numerical method for estimating Manning's coefficient in modelling of flow in shallow waters [2]. Abdul Hameed investigated four formulas to estimate Manning's n (Manning, Bajorunas, Einstein, and Kennedy) at Falluja regulator on the Euphrates River in Iraq. Then, he was noticed that Einstein and

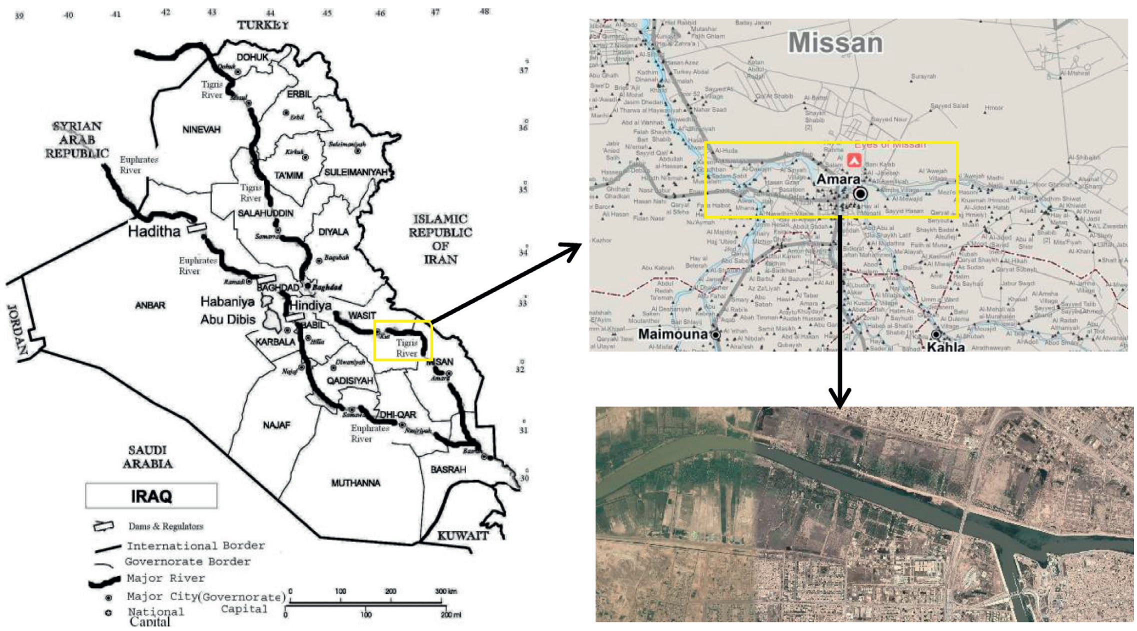


Figure 1: Location of study reach.

Bajorunas gave values closer to the exact than the others did [6]. Parhi used the HEC-RAS model to calibrate and validate the value of the roughness coefficient "n" for Mahanadi River in Odisha (India). He considered the floods for the years 2001 and 2003 in the calibration and verification [7]. Shamkhi and Attab also employed the HEC-RAS model to investigate and estimate the value of "n" downstream of Kut Barrage in Wasit, Iraq [8].

The target of this study is to calibrate and estimate the value of Manning's roughness coefficient (n) in areach of Tigris River; upstream of Amarh Barrage; because there is no previous information about Manning's n in this reach of Tigris River; in addition to importance of the barrage in regulating discharges to Basrah province. The importance of knowing the value of Manning's coefficient in the study reach becomes clear when you know that the study reach suffers from sedimentation bars due to the low water speed in the river due to the low discharges in this reach in most times of the year. This leads to a decrease in the depth and a continuous change in the section of the river. However, the study reach may be exposed to floods coming from Iran for a short period of the year, which may cause flooding in the city. Therefore, it is necessary to know Manning's coefficient in order to conduct more studies to analyse the risk of flooding, as well as to know the amount and locations of sediment deposition.

2. Model Description

The United States Army Corps of Engineers developed the Hydrologic Engineering Centre's (HEC) River Analysis System (RAS) model. The HEC-RAS model version 4.1 allows operating the hydraulics calculations of one dimensional steady and unsteady river flow. It is regularly used to calculate water surface profiles and energy grade lines in 1D, steady state, and gradually varied flow analysis.

The model used empirical Manning's equation, in the form of equation (1), to supply the relationship between the river discharge, hydraulic resistance, river geometry, and the friction energy loss. In the case of changing in channel geometry, energy losses were assessed using coefficients of contraction or expansion multiplied by the change in velocity head. Head loss between two sections will be computed from equation (2), while the water surface will be calculated from the energy equation, equation (3) [1].

In this study, HEC-RAS has been used to accomplish one dimensional, steady, and hydraulic calculation for a reach of Tigris River at the upstream of Al-Amarah Barrage to simulate the flow and to distinguish the suitable value of Manning's roughness coefficient (n):

$$Q = KS_f^{1/2}, \tag{1}$$

$$h_e = LS_f + C\left(\frac{\alpha_1 v_1^2}{2g} + \frac{\alpha_2 v_2^2}{2g}\right), \tag{2}$$

$$H = Z + y + \frac{\alpha v^2}{2g}, \tag{3}$$

where Q = flow rate; K = conveyance of the channel; S_f = energy slope; g = acceleration due to gravity; h_e = energy head loss; C = expansion or contraction coefficient; α_1 and α_2 = velocity weighting coefficients; v_1 and v_2 = average velocities; H = water surface level above a specified datum; Z = bed elevation; y = depth of flow; α = kinetic energy correlation coefficient; and v = average velocity.

3. Reach of Study

The reach of study is a segment of the Tigris River 3.5 km in length, located in the center of Amarah city, Maysan

Figure 2: Locations of sections over study reach.

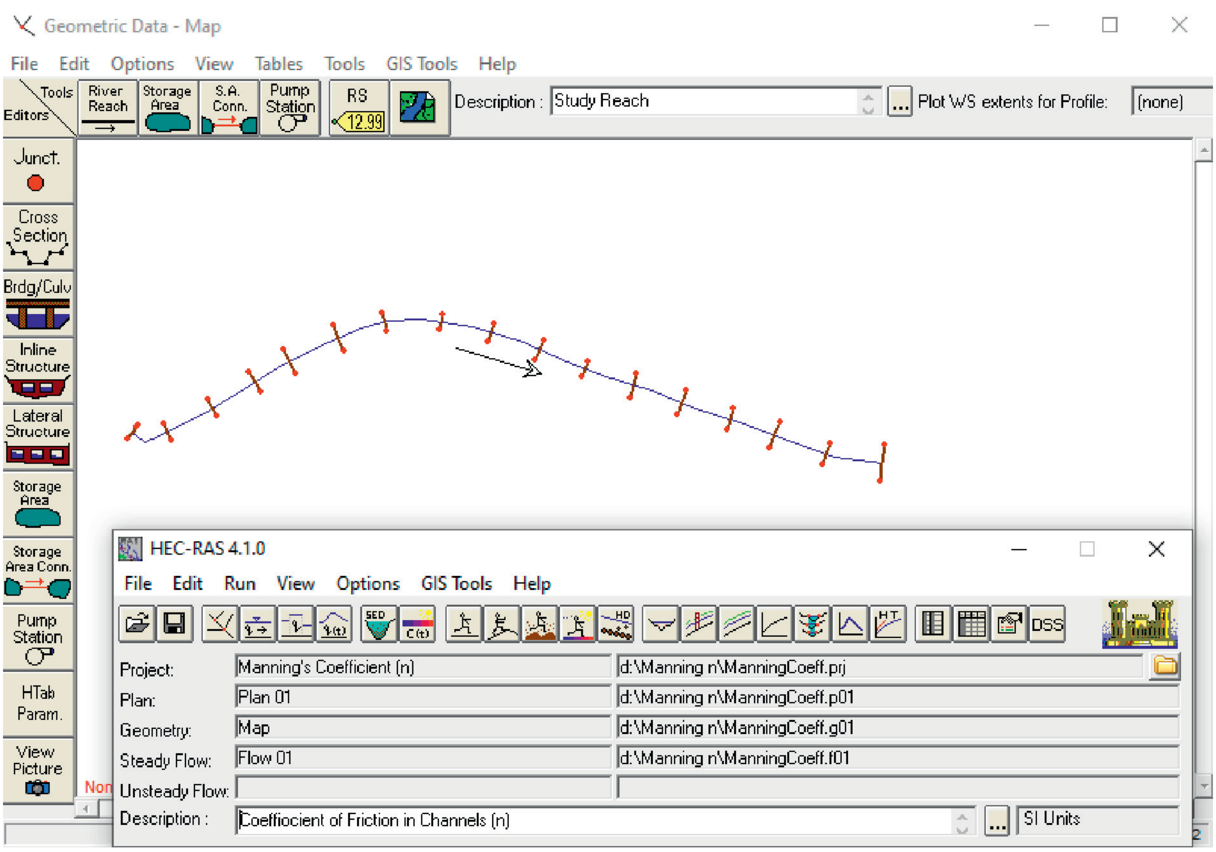
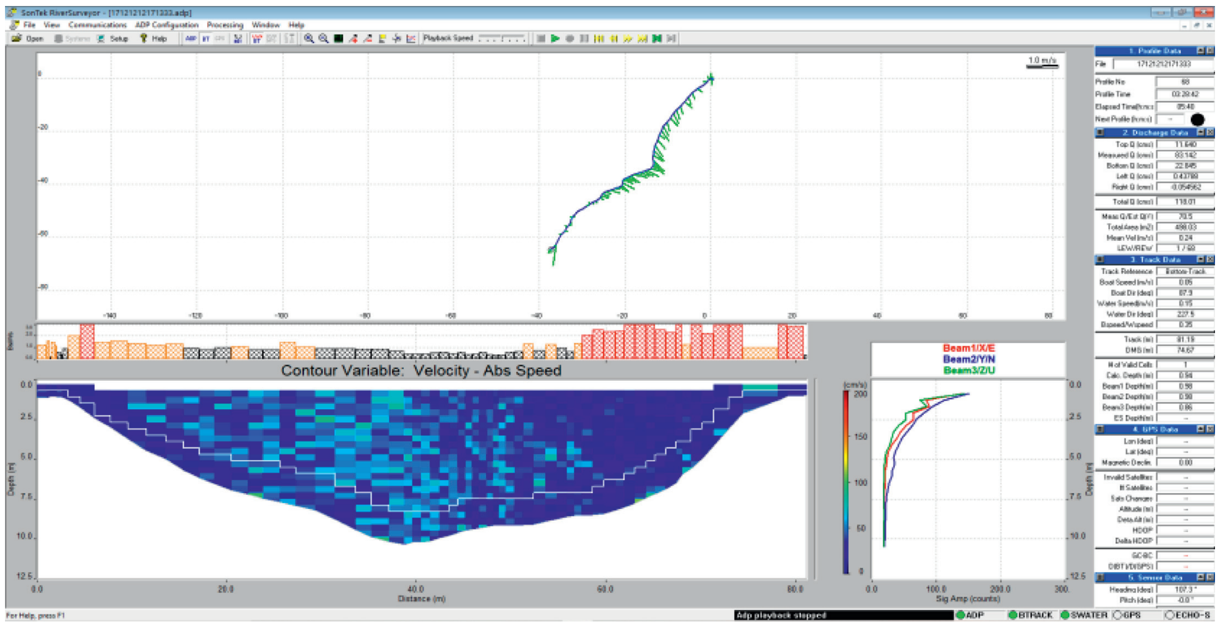


Figure 3: Study reach in the HEC-RAS model.

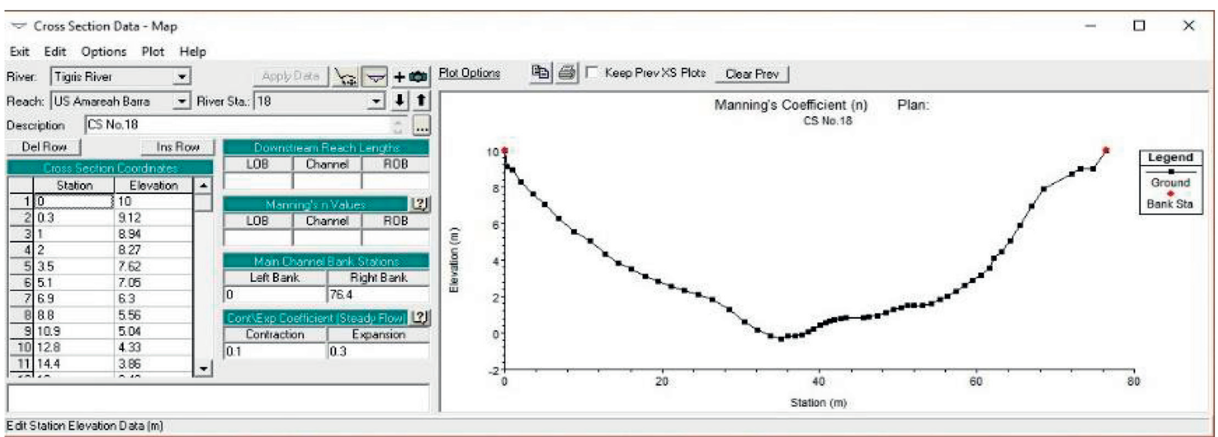
province, Iraq. This reach is upstream Al-Amarah barrage. It is located between latitudes 31.865°N and 31.850°N and longitudes 47.115°E and 47.155°E. Figure 1 shows the location of the reach of the study.

4. Methods

4.1. Geometric and Hydrologic Data. The geometry of the river reach, boundary conditions upstream and downstream



(a)



(b)

Figure 4: A sample of cross sections. (a) Cross section No. 18 from the ADCP. (b) Same cross section in the HEC-RAS.

are necessary parameters for implementing a simulation of flow using HEC-RAS. Special thanks to Khassaf and Hassan [9] who collected the data used in this paper and for the permission to use these data. They used the ADCP (acoustic Doppler current profiler) technology, SonTek river tracker surveyor (mounted on a boat), in determining area of cross sections, water velocity, and river discharge. They used Van Veen's grab in collecting samples from the riverbed. The total number of cross sections observed over the reach was eighteen cross sections as shown in Figure 2, a cross section every 200 to 250 m intervals extending over an entire length of 3.5 km of the river.

4.2. Development of HEC-RAS Model. The main parameters for the HEC-RAS hydraulic model are geometric and flow data. The geometric data have been developed by drafting the river schematically with the direction of flow. This was done with the aid of the button of river reach in the HEC-RAS main menu (window); the method was explained in detail in the software manual [1]. Figure 3 shows the schematic diagram of the geometry of the Tigris River study reach. Then, cross section data including cross section coordinate, down reach length, Manning's n values, main channel, and contraction or expansion coefficients were entered via the cross section data editor button on the same window.

Cross section coordinates were defined by entering the river station and elevation points from left to right bank in sequence along the river. Eighteen cross sections were allocated over the river reach. Figure 4 represents a sample cross section. After the geometric data are entered and saved, data of discharge were defined for the calculation process and finalizing the model creation.

4.3. Calibration and Validation of HEC-RAS Model. Calibration is a comparison between a known measurement (measured water levels) and the measurement using the model

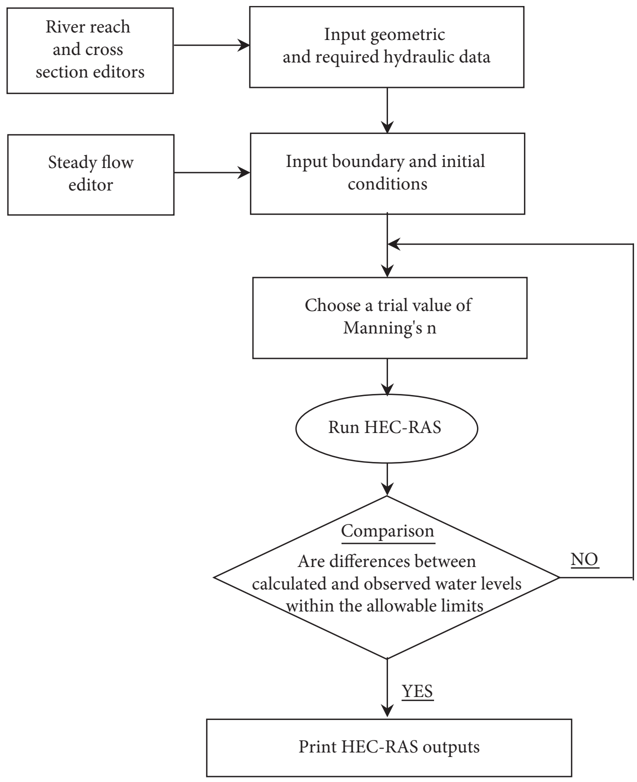


Figure 5: Calibration flowchart.

(simulated levels); it checks the accuracy of the model. The HEC-RAS model for the Tigris River was calibrated for predicting water levels and hence determining a single value of Manning's coefficient n. In order to check the ability of the calibrated model in predicting the water levels for different river flows, the model should be validated (verified) using measurement data other than the one used in calibrating the model.

The data published by Hassan are divided into two groups of data; for calibration, the water level values for the 18 cross sections corresponding to the 50 m^3/s flow rate were used, while for the validation, the water levels in section 18 for 36 flow rates were used.

4.3.1. Model Calibration. In the calibration, Manning's coefficient "n" was altered continually until the variations between observed and simulated water levels were within the acceptable limits. The procedure followed in the calibration is given in the flowchart in Figure 5. The calibration procedure gave the correct value of Manning's coefficient of the river reach.

This model calibration was done using an observed flow of 50.0 m^3/s at the upstream of the river reach at cross section No. 1. This flow rate (50.0 m^3/s) represents the discharge released from Kut barrage upstream of the study reach; this flow considered a low flow in the Tigris River and is the available flow in most parts of the year. The calibration was performed by comparing the results of the water level in each cross section obtained by the model with the observed levels.

From the literature reviewed previously [6, 8], the initial value of n was elected to be in the range 0.020 to 0.035 with an increment of 0.005. The flow in this reach of Tigris occurs only in main channel; no flow occurs in banks; therefore, the calibration of the HEC-RAS model was achieved using single values of n applied to the main channel of the river beginning from 0.020. By starting with an initial value, the n value was altered until the differences between observed and simulation water levels became small as far as possible. So, the outcomes of the HEC-RAS model for distinct values of n were compared with the observed water surface profile, tabulated in Table 1 and represented in Figure 6.

It is obvious from Figure 6 that the best choice for Manning's n value is 0.025 because it gives a good matching between observed and simulated water surface profile.

To provide an additional accuracy measurement, the root mean square deviation (RMSD) was tested between observed and simulated water surface elevations. The root mean square deviation is commonly used as a measure of the differences between predicted and observed values, as presented in the following equation:

$$\text{RMSD} = \sqrt{\frac{\sum_{i=1}^{N}\left(Y_{i\text{sim}} - Y_{i\text{obs}}\right)^2}{N}}, \quad (4)$$

where N = the number of data (total number of cross sections); i = the identification number of cross section; $Y_{i\text{sim}}$ = water level for cross section No. i (simulated); and $Y_{i\text{obs}}$ = water level for cross section No. i (observed). Values of RMSD are tabulated in Table 2; it is also clear that the best

Table 1: Observed and calculated WL for different Manning's n.

CS No.	WL (observed)	Water level (calculated)			
		$n = 0.02$	$n = 0.025$	$n = 0.03$	$n = 0.035$
1	10	9.74	10.03	10.33	10.71
2	9.98	9.69	10.03	10.18	10.62
3	9.96	9.65	10.03	10.15	10.6
4	9.94	9.61	10.01	10.17	10.55
5	9.94	9.64	10.01	10.15	10.48
6	9.9	9.57	9.97	10.13	10.47
7	9.88	9.55	9.95	10.11	10.5
8	9.86	9.53	9.93	10.09	10.5
9	9.85	9.53	9.88	10.08	10.49
10	9.84	9.51	9.91	10.11	10.42
11	9.82	9.53	9.89	10.05	10.46
12	9.82	9.49	9.89	10.05	10.46
13	9.8	9.47	9.87	10.03	10.44
14	9.79	9.48	9.86	9.94	10.43
15	9.76	9.43	9.83	9.99	10.4
16	9.75	9.42	9.82	9.98	10.33
17	9.75	9.42	9.82	9.98	10.33
18	9.74	9.41	9.79	9.97	10.25

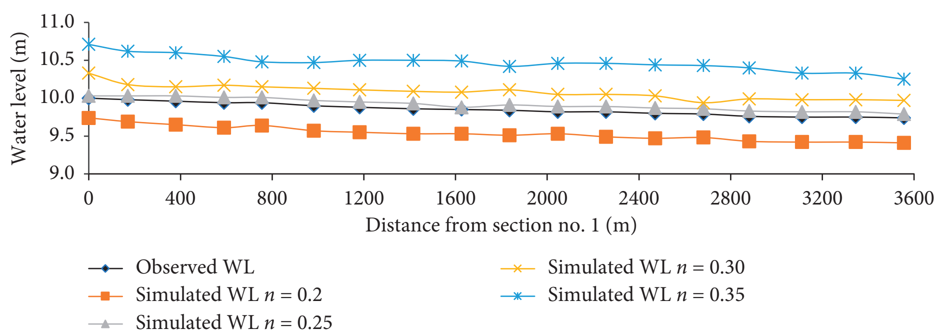


Figure 6: Observed and simulated water surface profile.

Table 2: RMSD values for Manning's n.

Manning's roughness coefficient	0.020	0.025	0.030	0.035
RMSD	0.318	0.065	0.231	0.616

Table 3: Validation of model.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Q	50	47	45	42	40	39	38	37	35	33	64	80
WL (Ob.)	10	9.86	9.77	9.63	9.53	9.48	9.43	9.14	9.31	9.17	10.6	11.2
WL (Sim.)	10.12	9.74	9.69	9.45	9.11	9.66	9.19	9.51	9.22	9	10.56	11
No.	13	14	15	16	17	18	19	20	21	22	23	24
Q	85	76	78	67	63	72	52	56	59	63	66	68
WL (Ob.)	11.41	11.2	11.15	10.72	10.56	10.92	10.09	10.26	10.39	10.56	10.78	10.8
WL (Sim.)	11.06	11	11.39	10.38	10.19	11.21	9.51	10.39	10.35	11.06	10.64	10.6
No.	25	26	27	28	29	30	31	32	33	34	35	36
Q	72	136	76	57	48	83	80	83	85	61	67	69
WL (Ob.)	10.92	13.1	11.17	10.31	9.91	11.34	11.23	11.34	11.62	10.48	10.6	10.8
WL (Sim.)	10.87	13.8	11.02	10.27	9.87	11.28	11.05	11.28	11.36	10.57	10.68	10.2

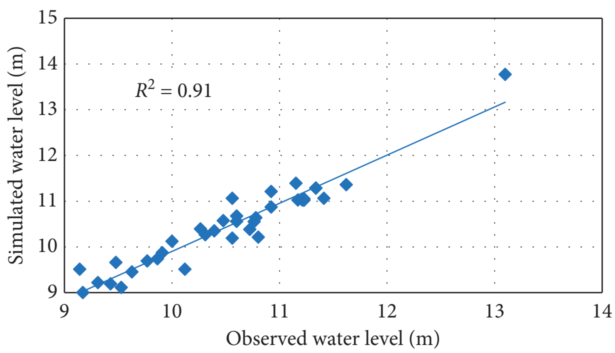


Figure 7: Observed versus simulated water surface level.

Manning roughness coefficient value for the study reach is 0.025.

4.3.2. Model Validation. There are 36 measurements available for the verification of the model; Hassan did these 36 observations in section No. 18. Validation was performed in order to check the suitability of a single value for the coefficient of 0.025 with several values of flow rates. The comparison between observed and predicted values of water level for these flow rates is shown in Table 3 and Figure 7. Depending on the value of the coefficient of determination (R^2), 0.91, the elected Manning's n (0.025) gives an acceptable matching between observed and predicted water levels [10].

For high flow rates, the model shows high errors; this can be enhanced by collecting more flow observations including multiple levels of flow (low, medium, and high) in the calibration of the model. Also, we may do a value refinement, maybe in the range 0.022 to 0.028.

5. Conclusions

HEC-RAS software can be used for hydraulic modelling. Therefore, it can be used effectively in modelling and simulating water surface profiles. A hydraulic model was performed using HEC-RAS on the Tigris River within a reach of 3.5 km in Al-Amarah city, Maysan province, in order to identify the value of n coefficient. The roughness coefficient (n) equals 0.025 which gives an acceptable matching between observed and predicted water levels. The model can be further improved by using GIS with HEC-RAS to produce an accurate channel geometry and hence an accurate flow simulation. In addition, flood risk can be analysed using HEC-RAS 2.0 using the result as a determined value of Manning's coefficient.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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