Development and classification of flood hazard map using 2D hydraulic model

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Abstract A flood happens when water floods wet land. In Iraq, there have been floods several times in the Tigris River, but the flood in 2019 was one of the major events that have greatly affected Maysan city. This paper shows the study of Maysan's extreme flood with hydraulic models. HEC-RAS two dimensional has been utilized to model the action of the study area from the downstream of Kut Barrage to Al-Musandaq escape, at the Tigris River. The model includes descriptions of simulated temporal parameters such as water depth and flow velocity. HEC-RAS Validation of simulated flood outcomes was done by correlation coefficient (r) Equation Between simulated and observed data, where the coefficient of r for calibrating the Tigris River and the Al-Musandaq escape was 0.995 and 0.991 in an appropriate range, respectively. The validation results demonstrated that the HEC-RAS model performance is highly efficient and can be implemented for design and production by hydrologists or water resources engineers.

Keywords: HEC-RAS 2D, GIS, Flood Hazard.

1. Introduction
One of the events which occur naturally is river flooding, and it forms an integral part of the hydrological rainfall cycle, the flow of surface- and ground-water and water storage. Floods happen at the times when natural capabilities or man-made emptying systems are do not cope with the rainfall-generated volume of water flowing from the river basin[1,2]. When rainfall over wide river expanses is prolonged, and a network of ditches, streams, and tributaries and water flow feeds them, the water builds up to a level that overwhelms the normal channel, and the water floods over, entering the regions surrounding it. In the case of large rivers, flooding takes place over an appreciable period, post the rainfall, and lasts for a long interval until the large water volume drains out of the catchment [3]. Maysan, in Iraq, is one of the cities most affected by the floods, which affects cultivated land, infrastructure, and life. Repeated floods endanger human lives and property that require an appropriate flood risk management plan [4]. The flood prediction is not simple because the magnitude of flooding depends heavily on topography and changes over time. In spatial and temporal contexts, flood prediction is a very complex operation, whereas traditional methods of engineering take time [5]. A strategic and important approach of integrated floodland management is to use the hydraulic numerical model for flood analysis and flood plain management. [6,7]. The administration of flood hazard is a crucial step in the identification and mitigation of risk areas, existing hazards, and potential flood events [8]. To suggest flood management initiatives, it requires simple analysis of flooding
understanding. There are two methods of understanding, firstly flood observations in situ [9], but observations in situ are not always possible, so another approach is the observation of the flood by remote satellite sensing data [5,10] but it is still limited to the transient actions in flood events. It is therefore necessary to simulate floods with numerical models in order to map the flood hazards and to know how the flow events are temporary. Various researchers worldwide have carried out studies on river flood modeling with hydrodynamic model approaches to designing water and irrigation systems and flood hazards [11,12]. There are different numerical models such as HEC-RAS, built by the United States Engineering Army [13]. MIKE has been created by the DHI, Denmark and At Delft Hydraulics, Sobek developed. All these models can solve equations in 1D and 2D. For this analysis, the HEC-RAS model simulates flooding. This study aims to manage flood hazard at the Tigris river from downstream Al-Kut Barrage to Al-Musandaq escape.

2. Study Area and data

2.1. Study area

Tigris river for this study is located between the downstream of Kut Barrage to Al-Musandaq Escape downstream, Figure 1. the range is approximately 160 km. Kut barrage is the largest cross-regulator for the flow control of the Tigris River. The height of the river level is as high as 20 m on downstream of Kut Barrage. This height is eventually reduced to 9 m. The average longitudinal slope of the water surface is approximately 4 cm/km close to Al-Musandaq Escape. In the reach under our study, there is one flood escape to prevent flooding, particularly because of its gentle slope and its run across flat terrain. The Al-Musandaq Escape, its flood escape, is situated around 87 km downstream of the Kut Barrage, on the right of the reach. It was in 1934 when a fracture, known as the Al-Musandaq break, was first opened up on the right side of the River Tigris. This became the Al-Musandaq Escape with a drainage card which was 56 m³/s at that time. This was done to decrease the water pressure in the River Tigris and protect the agricultural land and civilian constructions from the flooding-related hazards before constructing the Al-Tharthar reservoir. This Escape is a 400 m long earth channel, which at its top width connects the River Tigris with the Uma Marsh [14]. During the 1974 flood, this Escape was opened up by the authorities to release 1800 m³/s of water to minimize the flood risk of the reach downstream [15].

![Figure 1. The River Tigris located between the Kut Barrage downstream and Al-Musandaq Escape (GIS software).](image-url)
2.2. Data

The geographical information for the Tigris River discharge are the most relevant data forms that provide a geographical overview of the region and flow data. Digital elevation model (DEM) was used for the geographic data from the Shuttle Radar-Topography Mission (SRTM) with a grid of 30 m cell size Figure.2. The research concentrated on an area between the coordinates of 32° 29' 00" N latitude, and 46° 25' 00" E longitude. The flow data was based on the Tigris River discharge data from the IMI station at Kut Barrage. The analysis simulated the inundations between April 01, 2019, and April 30, 2019. Figure.3 shows the flow discharge of the Tigris river.

![Figure 2. DEM model picture for the study area (global mapper).](image)

![Figure 3. The flow discharge of the Tigris river.](image)
3. METHDOLOGY

3.1. Simulation Numerical

Flooding event was simulated by HEC-RAS-v5.0.7. HEC-RAS-v5.0.7 can resolve either the 2D diffusive wave equation or the full 2D Saint Venant equation[16],

\[
\frac{\partial h}{\partial t} + \frac{\partial (ph)}{\partial x} + \frac{\partial (qh)}{\partial y} = 0
\]  

\[
\frac{\partial p}{\partial t} + \frac{\partial (ph)}{\partial x} + \frac{\partial (pq)}{\partial y} = -\frac{n^2 \rho g (p^2+q^2)^{1/2}}{h^2} - gh \frac{\partial h}{\partial x} + pf + \frac{\partial}{\partial x} (h \tau_{xx}) + \frac{\partial}{\partial y} (h \tau_{xy}) \]  

\[
\frac{\partial q}{\partial t} + \frac{\partial (pq)}{\partial x} + \frac{\partial (pq)}{\partial y} = -\frac{n^2 \rho g (p^2+q^2)^{1/2}}{h^2} - gh \frac{\partial h}{\partial y} + pf + \frac{\partial}{\partial x} (h \tau_{xy}) + \frac{\partial}{\partial x} (h \tau_{xy})
\]  

Where,

\( yy, xx \) and \( xy \) = The productive components of shear stress, \( f = \) the Coriolis \((1/s)\), \( h = \) the depth of water \((m)\), \( p \) and \( q \) = the \( x \) and \( y \) directions of the particular flow \((m^2/s)\), \( S = \) the Elevation of surface \((m)\), \( n = \) the Manning coefficient, \( \rho = \) the Density of water \((kg/m^3)\). When the diffusive wave is selected, the inertial terms (2) and (3) are ignored.

The two dimensions diffusive wave equation is used for the simulation of flood events in this study. A closed polygon defines the computing domain and within the polygon are generated computing cells. The computing cells may be arranged in a stufented or unstufened grid of three to eight-sided polygons. A stalled 100m grid by 100m rectangular cells were used in this study. The chosen equations are resolved by an implied algorithm of finite volume. The solution for final volumes approximates the mean integrated portion by reference volume and allows for a more general approach to unstructured meshes. The equations' solution is identical to the unstable flow solution HEC-RAS 1D. Before beginning calculations, hydraulic property tables are computed. The elevation-volume ratios are determined for each cell and, similarly to the intersection pre-processing in 1D, the elevation-hydraulic properties (weathered perimeter, area). The equations are then calculated by an iterative scheme of no more than 40 iterations. Two types of boundary conditions have been used in the current study: one flow hydrographic boundary and two normal depth boundaries. The flow hydrograph boundary condition was situated downstream of the Kut Barrage at the Tigris river, which represented the observed flow entering the Tigris river and the simulation domain. As well as the flow hydrograph, an energy slope should be defined, which is used for distributing discharge across the boundary cells; the distribution is determined by the stated slope and the hydraulic properties pre-proceeded for each cell. A route of 0.0004 m\(^{-1}\) has been used because of the conditions in the study field. all results of the HEC-RAS 2D model (the water surface height, velocity, and depth) displaying in the RAS mapper then export to gis. To reach the goal of this study, the procedures cited were performed, as revealed in Figure 4.

3.2. HEC-RAS Model Calibration

Manning's coefficient roughness of river simulation is the most sensitive parameter. By simulating these streams using the HEC-RAS model along with the study distance, the calibration of the Manning coefficient roughness value of the river should be tried. Calibration is a reverse mathematical problem as it seeks to assess the original and local parameters representing a function in a given measuring data set using specific variables. Historically, hydrodynamic models have been tuned manually. The method of calibration minimizes the objective function by adjusting the parameter sets; the river is seen and the flow ranges are taken into account. A correlation coefficient \((r)\) Equation (4)[17] between simulated and observed data is the most frequently used objective function.
\[ r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \] ........................ (4)

where, \( n \) = number of data points, \( x \) = observed flow, \( y \) = simulated flow.

3.3. Flood Depth Generation
The flood risk was created for the study area in flooded areas, based on the simulated flood depth. The classification of risks has been allocated according to the Ministry of Land and Transportation MLT of Japan shown in Table 1.[18].

| Flood Risk | Depths (m) | Risk    |
|------------|------------|---------|
| F1         | <0.5       | Very low|
| F2         | 0.5-1      | Low     |
| F3         | 1-2        | Medium  |
| F4         | 2-5        | High    |
| F5         | >5         | Extreme |

Five classifications of flood risks F1, F2, F3, F4, and F5 are graded according to flood depth. The F1 risk (under 0.5 m deep) is allowable as people can easily evacuate on their feet. The risk of F2 (depth 0.5-1 m) is very limited, and it is becoming difficult to evacuate adults and children in this area and animals are subject to threat. F3 (depth 1-2 m) is a medium zone where people may drown, but they are safe for 0.6 to 1 meter in their homes. F4 risk (2-5 meter deep) is a high-risk zone where all...
residents in this zone are not protected in their houses but can be as protected on their roofs as possible. F5 risk (depth greater than 5 meters) is a danger zone in which even on their roofs citizens are not protected.

4. Results and Discussion

4.1 HEC-RAS Calibration and Validation

Different Manning 'n' values were assumed for the main channel and its flood plain to examine and determine their impact on water surface height from previous studies. This range of values measured for the Tigris river (0.021-0.031) and the Al-Musandaq escape (0.02-0.028). The r test was used to compare flows simulated and observed. Figure 5 describes the comparison of simulated and observed fluxes for Manning n values. 'n' was 0.031 for Tigris and 0.028 for Al-Musandaq Escape. For calibration and validation, the r values are 0.995 and 0.991 in an appropriate range, respectively. A graphical comparison of the correlation between observed and simulated flow data is shown in the Figure 6 indicates that the model has shown very good correlation results.

![Figure 5. The comparison of simulated and observed flows for values of Manning's n: (a) Tigris river in comparison, (b) Al-Musandaq escape n comparison.](image)

![Figure 6. Statistical parameter of unsteady flow calibration: (a) the Tigris river, (b) Al-Musandaq Escape.](image)
4.2 Flood risk Map generate
The flood risk Map has been generated by considering the model's simulated extreme flood (maximum depth). The risk classification is based on Table 1 from the Japanese Ministry of Land and Transportation. Figure 7 displays this analysis on the flood risk map.

The depth is divided into five groups between F1 and F5. Many villages are affected on the southeastern side of the Tigris River at the entrance to the city of Maysan. These villages are in the F2 and F3 risk zone category.

![Figure 7](image-url)

5. Conclusion
The HEC-RAS model was calibrated using the correlation coefficient, it got the best result when used the Manning coefficient 0.031 for the Tigris River and 0.028 for the al-Musandaq Escape where the r values are 0.995 and 0.991 in an appropriate range, respectively. The depth of inundation increases the higher the inflow of the river. The villages located on the southeastern part of the Tigris River in F2 and F3 risk zone category are suggested for people to move to a higher direction than these areas, removes the middle islands from the river to disperse the flood wave and reduce its danger or The government is building a weir at the front of the al-Musandaq escape to control flooding and protect people and property from it.

6. References
[1] Getahun Y S and Gebre S L 2015 Flood hazard assessment and mapping of flood inundation area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS model *J. Civ. Environ. Eng.* 5(4) 1
[2] Feyissa T A and Tufa F G 2019 Floodplain modelling of Awetu River Sub-Basin, Jimma, Oromia, Ethiopia
[3] Samadi A, Sadrolashrafi S S and Kholghi M K 2019 Development and testing of a rainfall-runoff model for flood simulation in dry mountain catchments: A case study for the Dez River Basin *Phys. Chem. Earth, Parts A/B/C* 109 9–25
[4] Agrawal R and Regulwar D G 2016 Flood analysis of Dhudhana river in upper Godavari basin using HEC-RAS *Int J Eng Res* 1 188–91
[5] Ban H J, Kwon Y J, Shin H, Ryu H S and Hong S 2017 Flood monitoring using satellite-based
RGB composite imagery and refractive index retrieval in visible and near-infrared bands

Remote Sens. 9(4) 313

[6] Haq M, Akhtar M, Muhammad S, Paras S and Rahmatullah J 2012 Techniques of Remote Sensing and GIS for flood monitoring and damage assessment: A case study of Sindh province, Pakistan Egypt. J. Remote Sens. Sp. Sci. 15(2) 135–41

[7] Farooq M, Shafique M and Khattak M S 2019 Flood hazard assessment and mapping of River Swat using HEC-RAS 2D model and high-resolution 12-m TanDEM-X DEM (WorldDEM) Nat. Hazards 97(2) 477–92

[8] Sherwood K L M M C R and Brosnahan S M 2018 Baseline coastal oblique aerial photographs collected US Army corps of engineers field research facility, Duck, North Carolina

[9] Ranzi R et al. 2011 Critical review of non-structural measures for water-related risks KULTURisk

[10] Daham M H and Abed B S 2020 One and two-dimensional hydraulic simulation of a reach in Al-Gharraf River J. Eng. 26(7) 28–44

[11] Mohammadi S A, Nazariha M and Mehrdadi N 2014 Flood damage estimate (quantity), using HEC-FDA model. Case study: the Neka river Procedia Eng. 70 1173–82

[12] Nigusse A G and Adhanom O G 2019 Flood Hazard and Flood Risk Vulnerability Mapping Using Geo-Spatial and MCDA around Adigrat, Tigray Region, Northern Ethiopia Momona Ethiop. J. Sci. 11(1) 90–107

[13] Brunner G W 1995 HEC-RAS river analysis system. hydraulic reference manual. version 1.0. Hydrologic Engineering Center Davis CA

[14] Al-Rubaie A A K 2008 Ecological and morphological study of Iraqi Southern marshes Mesopotamian J. Mar. Sci. 23 (2)

[15] Azzubaidi R Z 2020 Current and modified flood discharge capacity of a reach of Tigris River between Kut and Amarah barrages J. Eng. 26(2) 129–143

[16] Quirogaa V M, Kurea S, Udoa K and Manoa A 2014 Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: application of the new HEC-RAS version 5 Ribagua 3(1) 25–33

[17] Akoglu H 2018 User’s guide to correlation coefficients Turkish J. Emerg. Med. 18(3) 91–3

[18] Surwase T, SrinivasaRao G, Manjusree P, Begum A, Nagamani V and JaiSankar G 2019 Flood inundation simulation of Mahanadi River, Odisha during September 2008 by using HEC-RAS 2D model in Proceedings of International Conference on Remote Sensing for Disaster Management 851–63