Tikrit Journal of Engineering Sciences (2023) 30 (1): 112-118
DOI: http://doi.org/10.25130/tjes.30.1.11

IRAQI
Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

College of Engineering

TJES
Tikrit Journal of Engineering Sciences

Flood Risk Analysis: The Case of Tigris River (Tikrit /Iraq)

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Keywords:

Flood risk; Flood Management; 2-D HEC-RAS Model; Tigris River

ARTICLE INFO

Article history:

Received	06 Feb.	2023
Accepted	18 Mar.	2023
Available online	02 Apr.	2023

Citation: Mohammed-Ali WS, Khairallah RS. Flood Risk Analysis: The Case of Tigris River (Tikrit /Iraq). Tikrit Journal of Engineering Sciences 2023; 30(1): 112-118.
http://doi.org/10.25130/tjes.30.1.11

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Abstract: The study of flood risks has a fundamental role in ensuring the safety of cities near rivers and drawing up plans to protect them during future floods. This study aims to manage potential flood risks, and Tikrit city was used as a case study. The daily discharge of the Tigris River in the study area was provided by the Iraqi Ministry of Water Resources from 2019 to 2022. The HEC-RAS software was utilized to build a 2-D flood model to simulate potential flood scenarios. First, the model was calibrated by adjusting the value of Manning's coefficient (n), and it was found that $n = 0.031$ reflects the nature of the region because the *Nash-Sutcliff Error* (*NSE*) was 0.93. Then, the efficiency of the 2-D flood model was verified by comparing the model's results with the study area's satellite images, and the results showed a great match. Following that, the 2-D model was used under different flooding scenarios. The results showed that the size of areas exposed to flooding increased with the discharges passing through the Tigris River. For instance, increasing the discharge to 800m^3/s increased the flooded areas by 13.7%, while increasing the discharge to 1500 m^3/s increased the flooded areas by 90.7 % compared to the river's normal flow. Also, the results showed that the eastern regions of the riverbanks are more vulnerable to flooding than the western side because the ground levels are low on the eastern side compared to the western part of the riverbanks.

تحليل مخاطر الفيضانات: حالة نهر دجلة (تكريت/العراق)

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الخلاصة

ان دراسة مخاطر الفيضانات لها دور اساسي في ضمان سلامة المدن القريبة على الانهار وكذلك رسم خطط لحمايتها اثناء الفيضانات المستقبلية. تهدف هذه الدراسة الى رسم صورة واضحة لغرض ادارة مخاطر الفيضانات المحتملة وتم استخدام مدينة تكريت كحالة دراسة. تم توفير بيانات عن التصاريف في منطقة الدراسة من قبل وزارة الموارد المائية للفترة من عام 2019 ولغاية 2022. تم استخدام برنامج HEC-RASلعمل موديل فيضان ثنائي البعد لغرض محاكاة سيناريوهات محتملة للفيضانات. اولا، تم معايرة الموديل من خلال تعديل قيمة معامل الخشونة (معاملماننك n) وتبين ان معامل ماننك $n = 0.031$هو الذي يعكس طبيعة المنطقة اذ كانت نتيجة معامل الخطأ 0.93 بعد ذلك، تم التحقق من كفاءة الموديل الرياضي ثنائي البعد من خلال مطابقة نتائج البرنامج مع الصور الجوية للمنطقة واظهرت النتائج تطابقاً كبيراً. تم استخدام الموديل في سيناريوهات فيضان مختلفة وبينت النتائج ان مساحة المناطق المعرضة للفيضان تزداد مع ازدياد كمية التصاريف المارة في نهر دجلة اذ ان زيادة التصريف الى 800 مترمكعب /ثانية سيؤدي الى زيادة في المناطق المغمورة بمقدار 13.7% اما زيادة التصريف الى 1500 متر مكعب /ثانية سيؤدي الى زيادة المناطق المغمورة بنسبة 90.7% مقارنة بالمناطق المغمورة اثناء الجريان الطبيعي للنهر. كذلك فأن النتائج اوضحت ان المناطق الشرقية من ضفاف نهر دجلة في مدينة تكريت معرضة للفيضان أكثر من الجانب الغربي وذلك لكون مناسيب الارض منخفضة في الجانب الشرقي مقارنة مع الجزء الغربي من ضفاف النهر.

الكلمات الدالة: مخاطر الفيضان، ادارة الفيضانات، موديل HEC-RAS ثاني البعد، نهر دجلة.

1.INTRODUCTION

A flood is a disaster situation that may happen due to both natural and human activities. In addition to the damage to properties, floods substantially impact the living situations of people affected by floods, as floods create economic disruption or halting, as well as population emigration [1]. Some floods result from the rapid melting of ice in the spring or rare cases such as the collapse of a dam. However, much flooding is the result of the overflowing of river banks. Flooding in rivers results in numerous financial and personal losses. Flooding happens when a river's water level increases and exceeds its overall storage capacity, pushing the extra water over the banks and drowning low-lying areas. Another factor that may influence the incidence of floods is the development of economic and social activities and changes in land use in flood-prone areas, as these actions modify floodplains' response to flood risk [2, 3]. Many agricultural regions, particularly those near river banks and at risk of flooding, are being used as residential areas as a result of the rapid increase in the population [4]. One of the most significant challenges in water resources engineering is the management of flood disasters and the predictions of unexpected changes in the water level of rivers, especially in the residential areas close to the riverbanks of the rivers. Over the last decades, the issue of floods and their control has become critical due to their continuing occurrence. Federal Emergency Management Agency (FEMA) claims that flooding is the second most frequent natural disaster after fires in the United States [5]. Floods constitute a risk that extends from being localized to a single area of the planet to being prevalent everywhere [6, 7, 8]. There have been several alternative approaches created to reduce the impact of flooding through a process called flood mitigation; some mitigation strategies necessitate the installation of structures to regulate the flow of water in its canal, while others aim to reduce the rate of water flow on the earth [9, 10]. However, these solutions increase the problem because producing these materials harms the environment besides its high cost and logistic work [11, 12]. In addition, several studies stated that a structural strategy alone would not be enough to prevent repeated flood hazards [11]. Flood risk mapping is thus an essential non-structural approach [13]. However, if proper flood risk management measures and knowledge about flood-prone locations are accessible ahead of time, the associated hazards can be reduced [14]. Such events cannot be prevented; however, it becomes possible, with advances in technology, to identify areas prone to flooding, potential flood depths, and the extent and can eventually be used to create a flood risk map and can be used to aid decision-making in the event of an emergency. With the development of technology and the huge computer revolution, flood management has become possible. Understanding the dynamic behavior of floods, their causes, and their impacts can be done with the help of numerical modeling approaches. The sort of model and simulation equations and how accurate a model is employed affect [15]. Many studies were conducted to forecast the water surface elevation downstream of rivers during flood events. Indeed, most of these prediction studies were accomplished using very complex models, making them hard to handle by engineers. Physical modeling was used to predict flood events, such as regression models [16, 17] and hydrodynamic modeling [18]. The data collection method has been costly and time-consuming. Still, a physical model for a flood modeling study would be unusual, with many simulation computer programs practically available for every hydraulic modeling work. The flow depth was simulated using a MIKE 11 model to study India's delta region of the Mahanadi River basin. The results of this model gave a master plan that helped predict and manage flood risk in the region to save the life of people in the study area from the flood risk [19]. Also, one of the most complex flow regimes is the Rideau River in Canada, which was simulated using a 1-D MIKE 11 model. The hydrodynamic model MIKE 11 performance was examined with ten years of flow data to establish a 1-D prediction flood model that helped manage flood risk in this study area [20]. Furthermore, the HEC-RAS and HEC-HMS models were used to study the flood risk of the Al-Khazir River in Iraq. This study employed the data from rainfall return periods of 2, 5, 10, 20, 50, and 100 years to inspect the impact of rain on the villages near the river. The results of this study gave a guide to protect people from floods [21]. As a result, more efforts were made toward using the HEC-RAS model in flood risk. Consequently, another study was held to inspect the impact of Manning's coefficient upstream of Al-Amarah Barrage in the South of Iraq to understand the hydraulic characteristics of the Tigris River in this area. The results of this study showed the accuracy of using the HEC-RAS model to mimic the flow behavior [22]. The flow characteristics, for sure, influence the water surface elevation inside streams or rivers, which would act in such a way to affect the riverbank's flood. However, the 2-D flood modeling has yet been covered much in previous research investigations, which helps to understand how a systematic or formal inquiry should carry out the flow pattern to discover and examine the impact on the riverbank's flood. Thus, as a case study, this research aims to use a 2-D HEC-RAS model to simulate flood scenarios' potential impact on the Tigris River riverbank near Tikrit City in Iraq.

2.THE HYDRODYNAMIC MODEL

Hydrological Engineering Center- River Analysis System, HEC-RAS, is a software model established by the Hydrological Engineering Center/U.S. Army Corps of Engineers as a River Analysis System. HEC-RAS has a graphical user interface that can help for interactive use in generating the results report and inserting the input data easily. The HEC-RAS software can model various hydraulic events, including steady/unsteady flow, riverbank stability, and water quality analysis. From the hydrodynamic side, the HEC-RAS model can handle both One-Dimensional (1D), Two-Dimensional (2D) types of flow besides mixed 1D/2D unsteady flow routing. The Two-Dimensional flow modeling can be accomplished by including a simulated flood area component in the hydrodynamic flow model. Numerically, the HEC-RAS software solves the Saint-Venant and the Diffusive Wave equations consecutively by a four-point implicit box differential equation for the 2D flood simulation [23]. Besides the HEC-RAS user manual, several respected publications described the derivation of this solution methodology [6, 7, 12]. The required data for running a flood model in the HEC-RAS software are the Geometric data, Flow Data, and Boundary conditions. Once users set these data together, a plan file will be created to show the simulation results. For the 2-D flood simulation, the geometric file will contain the digital elevation model with the elevation information and data of the study area. The geometric file will also include the cross-sections of rivers or streams passing through the subject study area and the distances between these cross-sections that can be either established from the site survey or the DEM file itself. Furthermore, the Geometric file should have information about Manning's roughness of the cross-sections in the study area. The Flow file should include the flow hydrograph of the river information for the Unsteady flow simulation or the amount of flow for one event during the steady flow modeling. Regarding the Boundary Condition file, the flow type in the upstream and downstream of the study area should be set. For example, the depth of flow elevation, normal depth status, and known flow hydrograph can be used for downstream conditions. However, the upstream boundary condition can be set to be either the depth of the flow hydrograph or the flow discharge hydrograph. Fig.1 shows the flowchart of creating and establishing the results from a 2D hydrodynamic model in HEC-RAS.

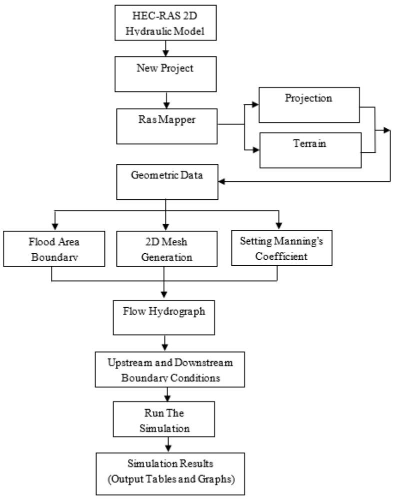

Fig.1 Flowchart of Preparing a 2D Hydraulic Model in HEC-RAS.

3.STUDY AREA AND DATA DESCRIPTION

The Tigris River crosses the border of Iraq at the northern of Zakho city and extends to southern Iraq in the city of Basra with about 1415 km, after which it meets the Euphrates River, forming Shatt al-Arab. During its pathway through Iraq, the Tigris River is a main source of water supply to many cities, and the city of Tikrit is one of these cities. The city of Tikrit is located at a distance of 160 km north of the capital of Iraq, Baghdad, as shown in Fig.2. A topographical map with high resolution is used herein for the study area provided by the U.S. Geological Survey (USGS) [24]. In addition, the Digital Elevation Model (DEM) of the topographical map, shown in Fig.3, was utilized in the hydrodynamic model later, which helped to make complete plans about the nature of the study area. Also, the daily discharge values of the Tigris River for the study area were provided by the Iraqi Ministry of Water Resources and previous studies for the duration of 2019 -2022 [25]. Fig.4 shows a sample of classical or usual discharge of the Tigris River measured at Tikrit city from November 2020 to September 2021[25].

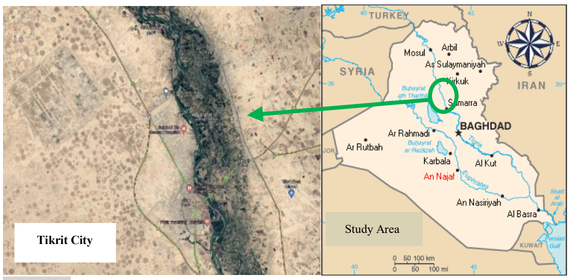

Fig.2 Iraq Map and Location of the Tikrit City.

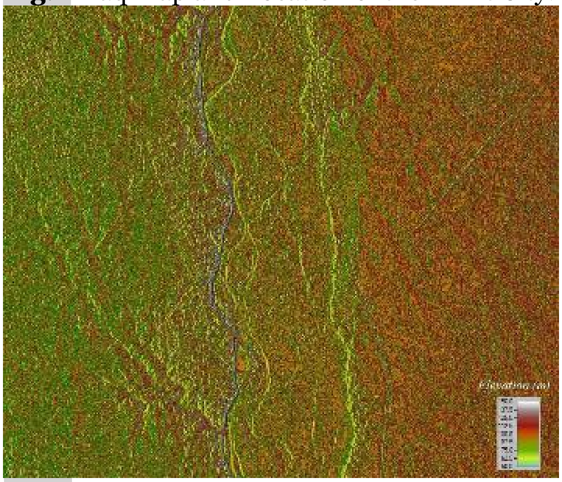

Fig.3 The Digital Elevation Model of the Study Area.

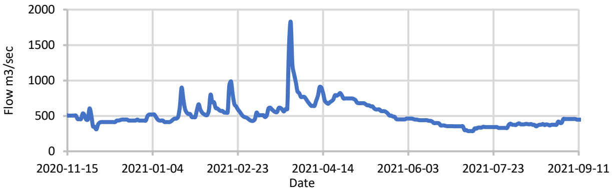

Fig.4 Flow Hydrograph of the Study Area (November 2020-September 2021).

4.THE CALIBRATION AND VALIDATION OF THE FLOOD MODEL

The calibration of flood models is a crucial prosses due to the high impact of this process on the final results of the simulation. Manning's coefficient (*n*) is the term that should be adjusted to reflect the topography of the study area inside the model itself. Visiting the site should allow the opportunity for best fitting to this matter. Fig.5 represents pictures of the Tigris River reaching through the study area. The riverbanks are covered with vegetation in some zones and mixed gravel in other portions. The flow data between February 2019 and November 2020 and from October 2021 to July 2022 was used to calibrate Manning's coefficient. These flow hydrographs represent around 70% of the available flow data of the study area in this work. The range (0.026 – 0.035) was set for Manning's coefficient along the river and floodplain of the study area. The flow hydrograph of the river from (November 2020 to September 2021), representing 30% of flow data, has been utilized in the model to validate Manning's coefficient. Then check with the model results. In addition, the Nash-Sutcliff Error methodology (*NSE*) was used herein to evaluate the model's performance [26]. As a result, Manning's coefficient value equals (0.031) shows the best matches real flow-depth data, as shown in Table 1. Then, *NSE* was used to evaluate the used Manning's coefficient value (*n* = 0.031) and to validate the 2-D flow simulation performance for the flood event during (May 2019). Fig.6 illustrates the matching of the water covering the study area from the HEC-RAS model and the satellite image provided by World Imagery Wayback [27]. Also, it shows the matching of the boundary of the water distribution in the study area for the flow event.

Table1 The Calculated Value of *NSE* Corresponding to Manning's Coefficient (*N*).

n	*NSE*
0.026	0.84
0.027	0.86
0.028	0.90
0.029	0.90
0.030	0.91
0.031	0.93
0.032	0.87
0.033	0.88
0.034	0.86
0.035	0.84

Fig.5 The Vegetation-density of the Riverbanks in the Study Area.

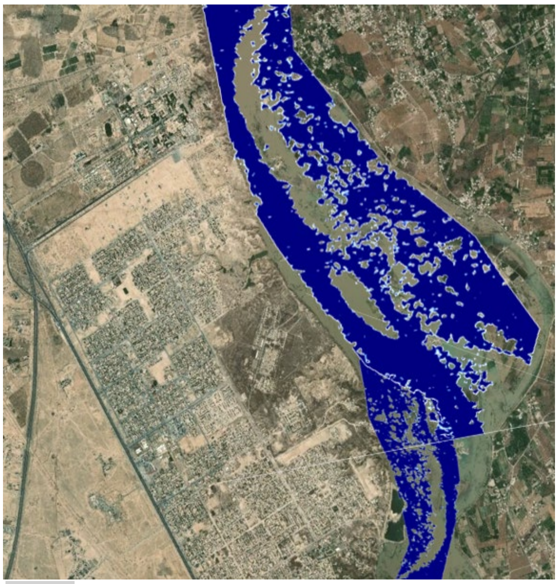

Fig.6 HEC-RAS Model Results in May 2019 in the Study Area.

5. RESULTS OF FLOOD SCENARIOS BY 2-D HEC-RAS MODEL

The risk of flood is a vital concern for both people and governments. Thus, having a flooding map for areas near rivers is crucial to avoid losing people's lives and reduce property damage during flood events. In this part, the flood scenarios were established by using the validated 2-D flood model. These scenarios assumed that the study area would be subjected to different flows and inspect the flood boundary line for each flow event. Table 2 lists the assumed flow events used at the study area's upstream boundary. These flow events were utilized in this study based on the historical data of the average flow range in the study area. Thus, this average flow was extended by 20%, 80%, and 125% to inspect the impact of this increase on the riverbank floodplain.

Table 2 The Flow Event Scenarios.

Scenario No.	Flow (m^3/sec)
1	400
2	800
3	1000
4	1500
5	2000

The variation in discharge impacts in the Tigris River along the riverbanks of Tikrit city were specified by developing 2-D flood maps for the study area. The 2-D flood map of each flow event mentioned in Table 2 is presented in Figs. (7-11). Furthermore, cross-section A-A represents the water surface elevation during the different flow events passing through the study area, as shown in Fig.12.

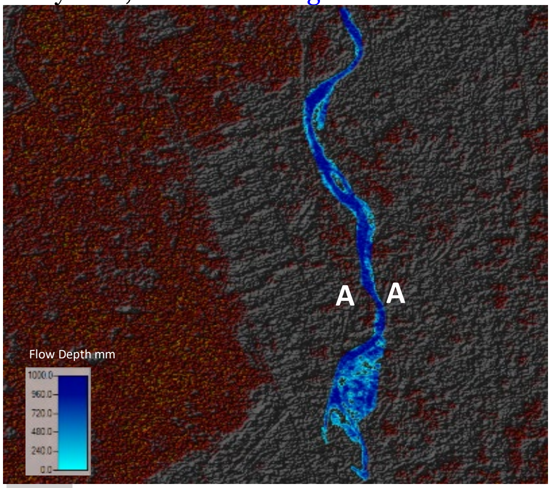

Fig.7 The Flood Map for Scenario No.1 Flow = 400m^3/sec.

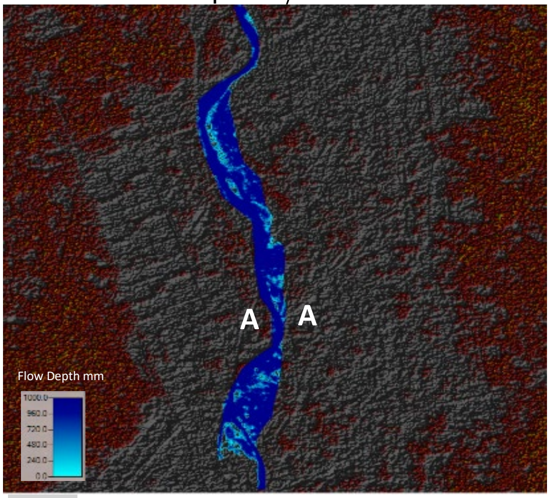

Fig.8 The Flood Map for Scenario No.2 Flow = 800m^3/sec.

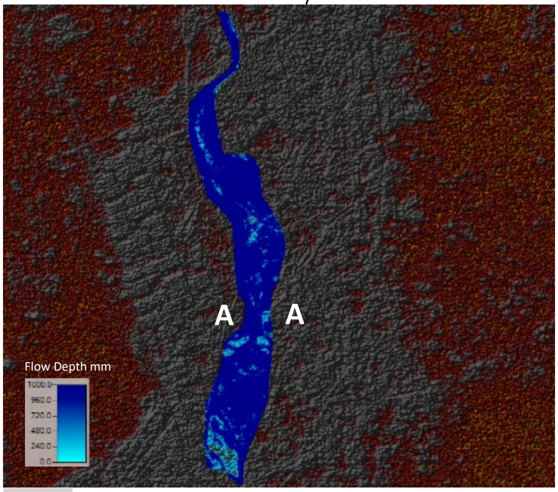

Fig.9 The Flood Map for Scenario No.3 Flow = 1000m^3/sec.

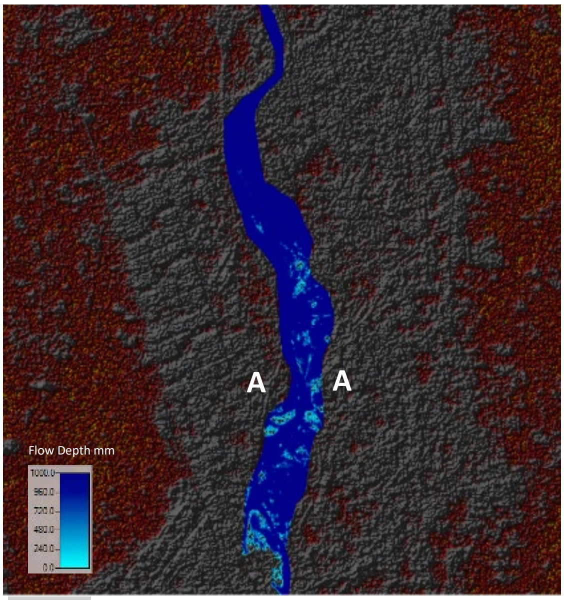

Fig.10 The Flood Map for Scenario No.4 Flow = 1500m3/sec.

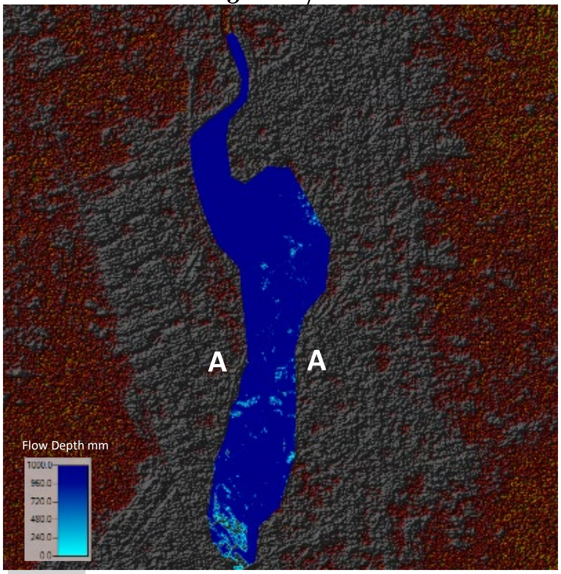

Fig.11 The Flood Map for Scenario No.5 Flow = 2000m3/sec.

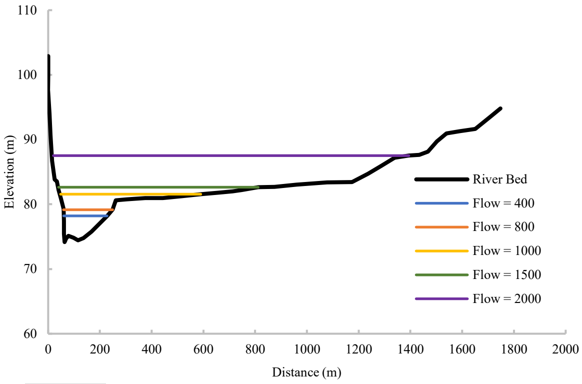

Fig.12 Cross-section A-A During the Different Flow Events.

During all flood scenarios, it is very easy to perceive that the size of flooded areas increased with the amount of discharge passing through the river. This increase was much visible in the eastern portion of the riverbanks because the ground levels are low compared to the western riverbank, which was dominated by the high elevation in most parts. In order to estimate the percentage of the increase in the submerged areas that resulted from the difference during each simulated flood event, the discharge value of 400 m^3/sec was adopted as a reference for the normal discharge in the river. The increase ratio in the flooded area is listed in Table 3.

Table 3 The Percentage of Flooded Areas Above the Normal Flow.

Flow Scenario (m^3/sec)	Flooded Area Percentage %
800	13.7
1000	39.8
1500	90.7
2000	117.5

6. CONCLUSIONS

A 2-D flood model was established to address the issue of flood risk. The riverbanks of Tikrit city were examined as a case study. The developed model was built using the Hydrological Engineering Center- River Analysis System, HEC-RAS, to quantify the potentially flooded area subjected to different flow events along the study area. The 2-D model was first calibrated and then validated with measured data from the field. Then, the validated model was applied with different flow scenarios to measure the size of the flooded area. The results showed that most of the eastern portion of the riverbanks would be subjected to flood risk compared to the western portion of the study area due to the low ground level at the east riverbank. These flooded areas would be increased when the discharge of the river increased. Besides the potential benefit of this study to enhance people's safety and decrease the risk of flood, it could be considered as one move of a deeper investigation of another river's reach. Further investigations can be handled to combine this finding with estimating the flood wave travel and arrival time to the area, especially with areas close to dams that may become subject to collapse.

REFERENCES

[1] Kovacs Y, Doussin N, Gaussens M, Pacoud CL, Afd O. **Flood Risk and Cities in Developing Countries**. *Technical Reports* 2017; **35**:1-104.

[2] Ramirez JA, Rajasekar U, Patel DP, Coulthard TJ, Keiler M. **Flood Modeling Can Make a Difference: Disaster Risk-Reduction and Resilience-Building In Urban Areas**. *Hydrology And Earth System Sciences Discussions* 2016:1-21.

[3] Mihu-Pintilie A, Cîmpianu CI, Stoleriu CC, Pérez MN, Paveluc LE. **Using High-Density Lidar Data and 2D Streamflow Hydraulic Modeling to Improve Urban Flood Hazard Maps: A HEC-RAS Multi-Scenario Approach**. *Water* 2019;**11**(9):1832.

[4] Elsheikh A, Albo–Hassan AS, Al–Zayadi SK, Alamedy SG, Alzamili HH. **Using the Integration of GIS and RS in the Initial Selection of the Site for the Construction of the New Al Diwaniyah City and its Alternatives in Iraq**. *Journal of Physics: Conference Series*: IOP Publishing 2021. pp. 012042.

[5] Federal Emergency Management Agency. **Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings: Government Printing Office**; 2003.

[6] Mohammed-Ali W, Mendoza C, Holmes RR. **Riverbank Stability Assessment During Hydro-Peak Flow Events: The Lower Osage River Case (Missouri, USA)**. *International Journal of River Basin Management* 2021; **19**(3):335-343.

[7] Mohammed-Ali W, Mendoza C, Holmes Jr RR. **Influence of Hydropower Outflow Characteristics on Riverbank Stability: Case of The Lower Osage River (Missouri, USA)**. *Hydrological Sciences Journal* 2020; **65**(10):1784-1793.

[8] Mohapatra P, Singh R. **Flood management in India**. Flood Problem and Management in South Asia: *Springer*; 2003. pp. 131-143.

[9] Green CH, Parker DJ, Tunstall SM. Assessment of Flood Control and Management Options. *WCD Thematic reviews*. *World Commission on Dams Secretariat, South Africa*. 2000.

[10] Mohammed-Ali WS. **The Effect of Middle Sheet Pile on the Uplift Pressure under Hydraulic Structures**. *European Journal of Scientific Research* 2011; **65**(3):350-359.

[11] Masood M, Takeuchi K. **Assessment of Flood Hazard, Vulnerability and Risk of Mid-Eastern Dhaka Using DEM and 1D Hydrodynamic Model**. *Natural Hazards* 2012; **61**(2):757-770.

[12] Mohammed-Ali WS. *Minimizing the detrimental effects of hydro-peaking on riverbank instability: The lower Osage River case*. Missouri University of Science and Technology; 2020.

[13] Grimaldi S, Petroselli A, Arcangeletti E, Nardi F. **Flood Mapping in Ungauged Basins Using Fully Continuous Hydrologic–Hydraulic Modeling**. *Journal of Hydrology* 2013; **487**:39-47.

[14] Patel DP, Ramirez JA, Srivastava PK, Bray M, Han D. **Assessment of Flood Inundation Mapping of Surat City by Coupled 1D/2D Hydrodynamic Modeling: A Case Application of the New HEC-RAS 5**. *Natural Hazards* 2017; **89**(1):93-130.

[15] Mohammed-Ali WS, Khairallah RS. **Review for Some Applications of Riverbanks Flood Models**. *IOP Conference Series: Earth and Environmental Science* 2022; **1120**(1):012039.

[16] Mediero L, Kjeldsen TR. **Regional Flood Hydrology in a Semi-Arid Catchment Using a GLS Regression Model**. *Journal of Hydrology* 2014; **514**:158-171.

[17] Al-Juhaishi EHK. *Novel approaches for constructing persistent Delaunay triangulations by applying different equations and different methods*. Missouri University of Science and Technology; 2020.

[18] Gallien T, Sanders B, Flick R. **Urban Coastal Flood Prediction: Integrating Wave Overtopping, Flood Defenses and Drainage**. *Coastal Engineering* 2014; **91**:18-28.

[19] Patro S, Chatterjee C, Mohanty S, Singh R, Raghuwanshi NS. **Flood Inundation Modeling Using MIKE FLOOD and Remote Sensing Data**. *Journal of the Indian Society of Remote Sensing* 2009; **37**(1):107-118.

[20] Ahmed F. **A Hydrodynamic Model for the Lower Rideau River**. *Natural Hazards* 2010; **55**(1):85-94.

[21] AL-Hussein AAM, Khan S, Ncibi K, Hamdi N, Hamed Y. **Flood Analysis Using HEC-RAS and HEC-HMS: A Case Study of Khazir River (Middle East-Northern Iraq).** *Water* 2022; **14**(22):3779.

[22] Abbas SA, Al-Aboodi AH, Ibrahim HT. **Identification of Manning's Coefficient Using HEC-RAS Model: Upstream Al-Amarah Barrage**. *Journal of Engineering* 2020:1-7.

[23] USACE. HEC-RAS River Analysis System, Version 5.0, Hydrologic Engineering Center User Manual. Hydrologic Engineering Center Davis CA; 2015.

[24] USGS. Global DEM Data Sources – Digital Elevation Models. GISGeography; USA.2020.

[25] Sabeeh NN, Alabdraba WMS. **The Hydrodynamic Model using HEC-RAS: The Case of Tigris River Downstream of Samarra Barrage (Iraq).** *IOP Conference Series: Earth and Environmental Science* 2022; **1120**(1):012017.

[26] Nash JE, Sutcliffe JV. **River Flow Forecasting Through Conceptual Models Part I—A Discussion of Principles**. *Journal of Hydrology* 1970;**10**(3):282-290.

[27] ARCGIS. World Imagery Wayback. 2019.