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2D-HEC-RAS Modeling of Flood Wave Propagation in a Semi-Arid Area Due to Dam Overtopping Failure

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Abstract

Dam overtopping failure and the resulting floods are hazardous events that highly impact the inundated areas and are less predictable. The simulation of the dam breach failure and the flood wave propagation is necessary for assessing flood hazards to provide precautions. In the present study, a two-dimensional HEC-RAS model was used to simulate the flood wave resulting from the hypothetical failure of Al-Udhaim Dam on Al-Udhaim River, Iraq, and the propagation of the resulting dam-break wave along 100 km downstream the dam site for the overtopping scenario. The main objective is to analyze the propagation of the flood wave so that the failure risk on dam downstream areas can be assessed and emergency plans may be provided. The methodology consisted of two sub-models: the first is the dam breach failure model for deriving the breach hydrograph, and the second is the hydrodynamic model for propagating the flood wave downstream of the dam. The breach hydrograph is used as an upstream boundary condition to derive the flood impact in the downstream reach of Al- Udhaim River. The flood inundation maps were visualized in RAS-Mapper in terms of water surface elevation, water depth, flow velocity, and flood arrival time. The maximum recorded values were: 105 m (a.m.s.l.), 18 m, 5.5 m/s, and, respectively. The flow velocity decreased from upstream to downstream of the terrain, which means less risk of erosion in the far reaches downstream of the study area. The inundation maps indicated that the water depth and flow velocity were categorized as Catastrophic limits on the terrain's area. The results offer a way to predict flood extent and showed that the impact of a potential dam break at Al-Udhiam Dam will be serious, therefore, suitable management is needed to overcome this risk. Moreover, the maps produced by this study are useful for developing plans for sustainable flood management.

Keywords: Breach Hydrograph; Overtopping; Hypothetical Failure; Al-Udhaim Dam; 2D HEC-RAS Model.

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1. Introduction

Dams provide tremendous benefits to society; however, the risk of their possible failure is the most devastating of disasters. Dam failures can be caused by, overtopping of a dam due to inappropriate design of the spillway and insufficient capacity of the reservoir for large inflows, piping due to the removal of fines along a path between the upstream and downstream faces by seepage forces, settlements which are caused by slope slides on the upstream or downstream faces of the dam, and liquefaction due to earthquakes and dam foundation failure. International

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Commission on Large dams stated that about one-third of dam failures is caused by overtopping. In contrast, the second third is caused by piping, and the remaining third of the failures are due to other factors (settlements or liquefaction) [1]. For emergency plans, dam failure studies and flood inundation mapping are vital to specify the dam break flood's characteristics and the extent of the endangered area. Numerous models or software have been used for analyzing the dam failures and flood wave extent downstream of dam by flood inundation mapping. Of the most widely used model is the Hydrologic Engineering Centre's - River Analysis System (HEC-RAS) model developed by the Hydrologic Engineering Centre of the U.S. Army Corps of Engineers in 1981. In the recently launched version (release 5.0.7), the HEC-RAS model has been enriched with novel modules. It has been designed for different computations of steady and unsteady flow depending on one- and two-dimensions modeling of open channels' water surface profile. In one-dimensional models, unsteady flow computations are performed by 1D Saint Venant Equations at the channel cross-sections. While in the 2D HEC-RAS model, the flood inundation map is investigated on a 2D flow area (over the river channel and the floodplain) by constructing a computational Finite Element mesh that solves the 2D Sallow Water Equations (Saint Venant Equations) or 2D Diffusion Wave Equations [2].

As the 2D HEC-RAS model can simulate complex flow conditions, many studies and researchers have used it with different case studies. For example, Quirogaa and others in 2016 [3] applied HEC-RAS v.5 model to simulate February 2014 flood event in the Bolivian Amazonia to determine the water depth, flow velocity, and temporal variation of the flood. The study showed that the flood depth allows identifying areas exposed to different hazardous levels. A 2D HEC-RAS modeling approach was adopted for a study carried out by Joshi and Shahapure [4] to the dam break flood routing simulation under the overtopping failure for Ujjani Dam to determine flood-re susceptible areas the downstream side of the dam considering Pandharpur City as a study area. The authors stated that most earth-fill dam failure cases are due to overtopping failure. Also, Kumar et al. [5] utilized the 2D HEC-RAS v.5.0.7 model and Global Flood Monitoring System (GFMS) tools to develop a methodology for delineation of flood extent and identification of various food risk zones in Prayagraj, India, at the confluence of Ganga and Yamuna Rivers. While Sattar et al. [6] evaluated the possible hazard of the South Lhonak Lake located in the state of Sikkim, India, using hydrodynamic modeling approaches. From the results, they found that the worst scenario of glacial lake outburst flood GLOF is revealed during an overtopping failure of the dam. A considerable reduction in the flow energy because of the interaction of the flood wave with a major topographic obstruction located 15.6 km downstream of the lake minimized the impact of the South Lhonak GLOF. Albu et al. [7] used the 2D HEC-RAS model to assess the spatial risk following the theoretical breaching of Sulita Dam on Sitna River, Romania, including backwater flooding, hydro-morphometric parameter calculations (flow rates, flood times, depths, and velocity), and affected buildings and damaged land use categories. To confirm the suitability of the 2D HEC-RAS model for dam-break flood studies in steep alpine valleys, a study performed by Pilotti et al. [8] for comparing the discharge hydrographs of the 2D HEC-RAS model with those measured in a historical physical model built under Froude's similarity to analyze the consequences of the hypothetical collapse of the Cancano I Dam (northern Italy) and the propagation of the resulting flood wave along a reach of 15 km downstream of Alpine Valley. The experimental hydrographs and the measured extent of the flooded areas are well reproduced by numerical simulations in their study.

Ríha et al. [9] studied the breaching of a cascade of three relatively small embankment dams in the Čižina River catchment in the Moravian–Silesian Region of the Czech Republic. The analysis was carried out using various methods such as empirical formulae, analogy, and hydraulic modeling. They aimed to demonstrate the effect of the distance between dams on dam-break flood attenuation, and from the results it was found that the attenuation volume of small reservoirs is small when compared to the flood volume, meaning that the attenuation of the peak discharge usually varies between 5–10%. Sarchani et al. [10] investigated a post-flood after a severe rainfall event in a small ungauged basin located in northwest Crete, the flow hydrograph, and two high-resolution digital elevation models (DEMs) were used in the 1D/2D HEC-RAS model to determine the flooded area extent. They concluded that the combined 1D/2D HEC-RAS model provided better results for the floodplain extent at the peak outflow, maximum flood depths, and wave velocities. Furthermore, modeling with a DEM at 2 m spatial resolution showed more precise water depth output and inundated floodplains. Another study by Shahrim and Ros [11] used the HEC-RAS model to generate a breach hydrograph and inundation map resulting from a dam break under piping and overtopping failure. The researchers stated that a 2-D HEC-RAS model can generate the inundation map of dam failure in a wider area, so that flood hazard risk can be estimated, and the provision of an emergency action plan can be decided. Psomiadis et al. [12] analyzed the consequences of a possible failure at Bramianos dam on southern Crete Island in the downstream area using HEC-RAS software. Two datasets of the same area were used: a digital elevation model (DEM) taken from very high-resolution orthophoto images (OPH) of the National Cadastre and Mapping Agency SA and a detailed digital surface model (DSM) extracted from aerial images taken by an unmanned aerial vehicle (UAV). The analysis results showed that a dam break at Bramianos dam will be serious, and appropriate management measures are required to reduce the risk. The comparison of DSM and DEM cases showed that the DSM accurately simulated the surface relief which in turn produces more realistic analysis results.

As shown from these mentioned studies, using the 2D HEC-RAS model gives an acceptable analysis of dam break failure and propagation of flood waves downstream the dam. So, this model is used in the present study to predict and visualize the disastrous results of a hypothetical dam failure considering Al-Udhaim Dam North-East Baghdad, Iraq as a study case under available hydrological data for the overtopping failure scenario through computing main flood characteristics, such as the breach parameters, flood water surface elevation, flood depth, flood velocity, and the arrival time of the flood wave at flood susceptible area. One of the assumptions of this study is that the vertical water velocities will be negligible compared to the horizontal velocities because the water will not propagate in the vertical direction.

The main objectives of this study are the following:- 1- analysis of the impact of a hypothetical failure of the Al-Udhaim Dam in overtopping case, and 2- analysis of the propagation of flood wave resulting from dam-break failure along a reach of about 100 km downstream Al-Udhaim Dam and 3- assess the failure risk on the semi aired downstream dam area to help the preparation of emergency action plans. To achieve these objectives several difficulties and challenges, have been faced by the authors. The scarcity of studies on Al-Udhaim Dam's failure was one of the difficulties that hindered making a comparison of the results. Furthermore, the implementation of this study with the presence of the COVID-19 pandemic had a significant impact on the process of data collecting and site visits.

2. Study Area

The study focuses on an area within the semi-arid zone of Iraq that includes Al-Udhaim Dam which is located in Diyala Governorate approximately 135 km north of Baghdad, and a settlement area downstream of the dam across Al-Udhaim River to its estuary in Tigris River at an average distance of approximately 100 km, as shown in Figure 1. Al-Udhaim Dam is a zoned earth-fill dam constructed during the year (1999) for water supply, irrigation, and flood control purposes. The dam reservoir lies entirely within the borders of Iraq, in the north-eastern part, between the latitudes (34° 33′ 46″ N) and the longitude (44° 31′ 01″ E), Figure 2. The dam is 3800m long and 76.5m in height with a crest of 146.5 m (a.m.s.l); Other information about design levels is shown in Figure 3.

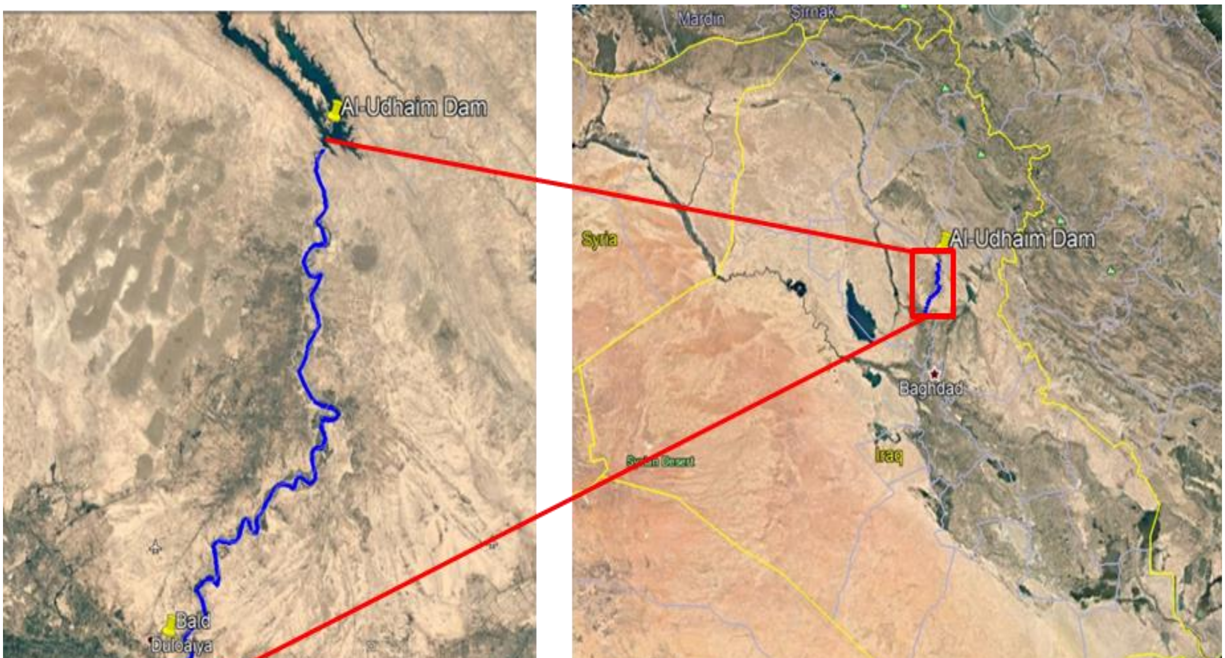


Figure 1. Location of the study area.

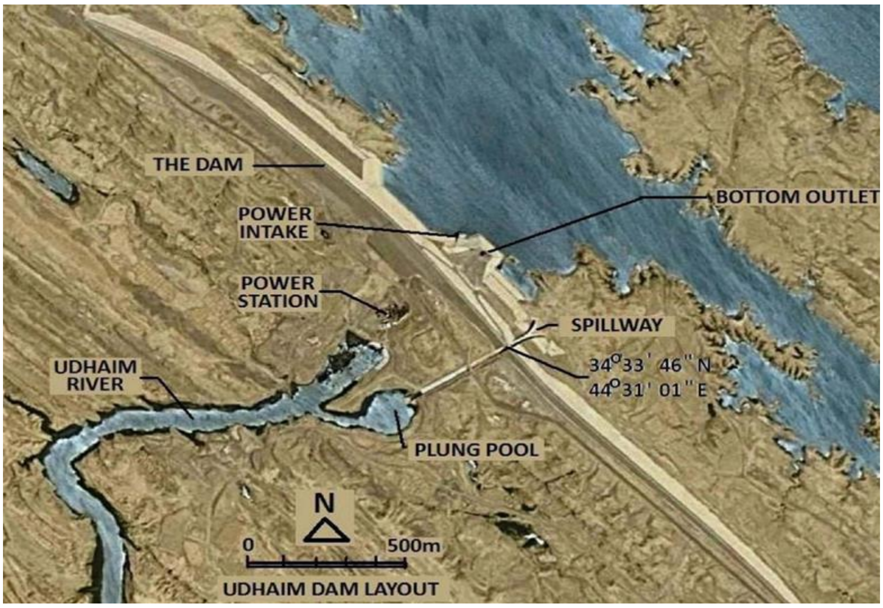


Figure 2. Al-Udhaim Dam layout

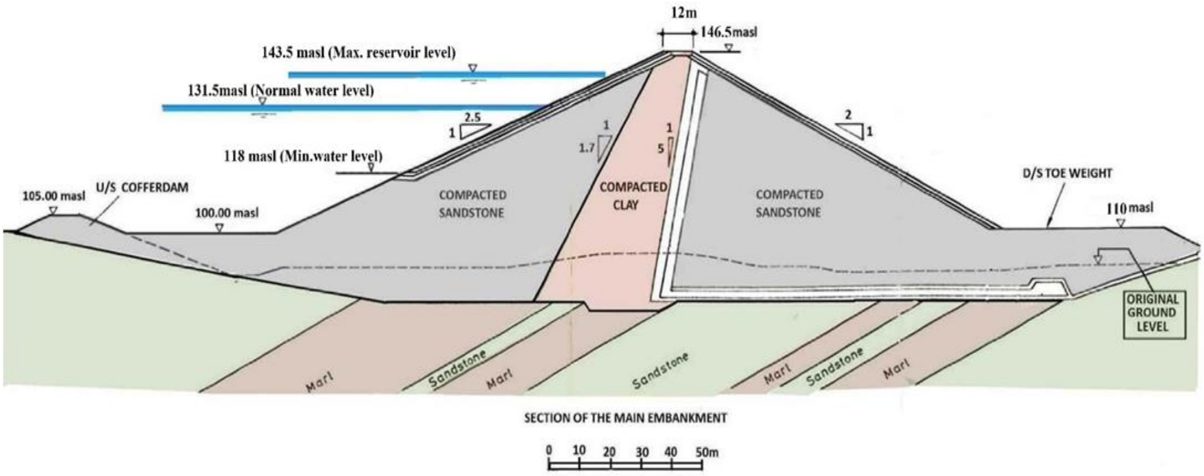


Figure 3. Typical cross-section of Al-Udhaim Dam [13]

3. Research Methodology

The process of estimating the dam breach failure using the HEC-RAS 2D model requires the collection of the dam characteristics, such as the type of the dam, its length, height, and reservoir volume. Furthermore, data required to rout the dam break failure are data for creating the map of the Digital Elevation Model (DEM) for the area downstream the dam, roughness coefficient, and initial and boundary conditions. After collecting these data, two sub-models were implemented using 2D HEC-RAS (v. 5.0.7) model: dam breach failure sub-model and hydrodynamic sub-model. The dam breach failure model is employed to estimate the breach parameters and derives the dam break hydrograph. Simultaneously, the hydrodynamic model performs the propagation of the flood wave downstream of the dam. The flood hydrograph is calculated by the first model and is used as the upstream boundary for the second model for estimating the distribution of water surface elevation, water depth, and water velocity at the inundated areas. The methodological approach through a schematic drawing is shown in Figure 4.

3.1. Digital Terrain Model

The geographic data was based on the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) with a grid cell size of 30 m, as shown in Figure 5. Digital Elevations Model (DEM) was then converted to Triangulated Irregular Network (TIN) map in the GIS environment. The geometric information of terrain can be converted to a grid system in the HEC-RAS model.

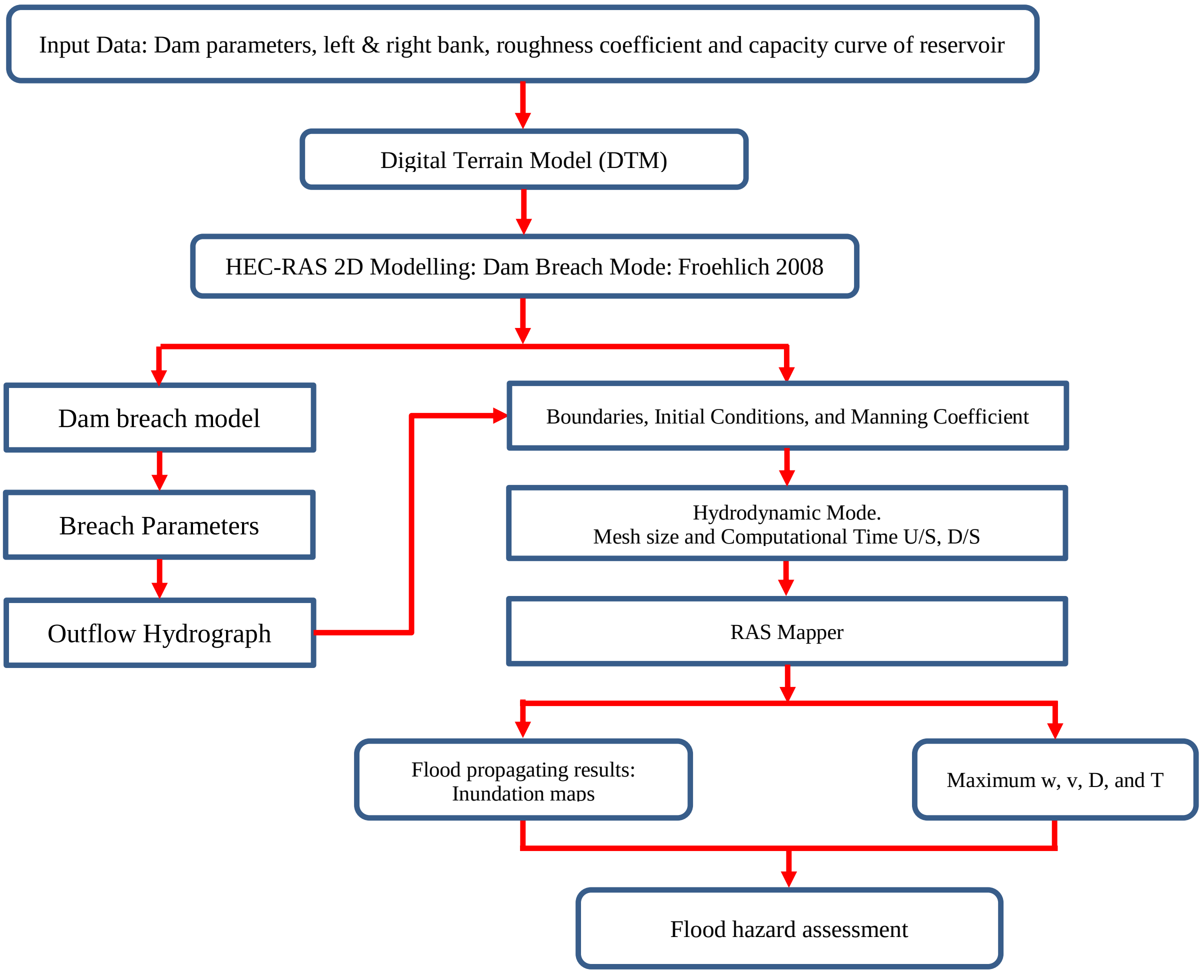


Figure 4. Schematic representation of the methodology

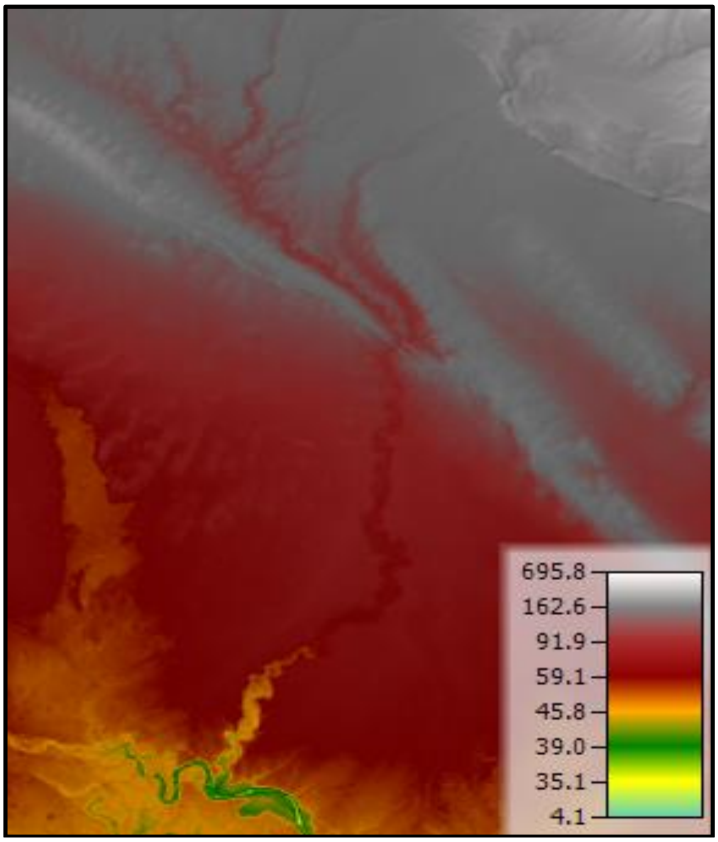


Figure 5. Digital Terrain Model (DTM) of Al-Udhaim Dam

3.2. Dam Breach Modeling

In the dam breach modeling, an overtopping model was used in the dam break tool of the 2D HEC-RAS model to simulate the Al-Udhaim Dam break through implementing two steps:

I. Breach Parameters Estimation

Estimation of the breach parameters is based on the regression analysis of the breach parameters and the dam characteristics. The dam breach is usually illustrated as a trapezoidal shape, so the geometric parameters include the breach depth, top width, bottom width, and side slope. Several empirical equations are utilized for several variables associated with dam break. 2D HEC-RAS model includes the application of different methods for estimating average width, side slope, and formation time of the dam breach (MacDonald et al, 1984; Froehlich, 1995; Froehlich, 2008; Von Thun & Gillette 1990; and Xu & Zhang 2009) [14-17]. Statistics showed that the most suitable method for estimating breach parameters for earth-fill dams was the Froehlich (2008) approach. For example, the study of Basheer et al. [18] applied different methods to estimate Mosul Dam, Iraq's breach parameters. The results showed that the most suitable method was the Froehlich approach. As the Mosul Dam reflects Al-Udhaim Dam's characteristics, therefore, the dam breach mechanism of Froehlich (2008) was found more appropriate in the present study. Average breach width and the breach formation time expressed by Froehlich (2008) are of the following:

$$B_{avg} = 0.27\, K_O V_w^{0.32} H_b^{0.04} \tag{1}$$

$$t_f = 0.0176(V_w/gH_b^2)^{0.5} \tag{2}$$

where $Bavg$ is the average breach width (m), K_O is the failure mode factor (1.3 for overtopping failure), V_w is the volume of the reservoir above the bottom level of the breach (m^3), H_b is the breach height which is the vertical distance from the dam crest to the breach invert (m), t_f is the breach formation time (in hours.), and g is an acceleration of gravity (m/sec^2). Froehlich recommends a breach side slope of (1:1) (H: V) for overtopping failure.

The hypothetical breach analysis of Al-Udhaim Dam is carried out for the worst condition considering the water surface elevation at the time of failure at which, the crest level is at 146.5m. The elevation-storage curve was introduced to define the characteristics of the storage area of Al-Udhaim Dam as in Figure 6 [19]. Calculated parameters of the dam breach using breach sub-mode of the 2D HEC-RAS model with different dam breach mechanisms are listed in Table 1. As shown in Table 1, the breach bottom width and formation time for Al- Udhaim Dam using Froehlich's (2008) equation is 314m and 5.95hr, respectively. The breach location was assumed to be at the dam centerline, Figure 7. Furthermore, the presumed progression plot is shown in Figure 8.

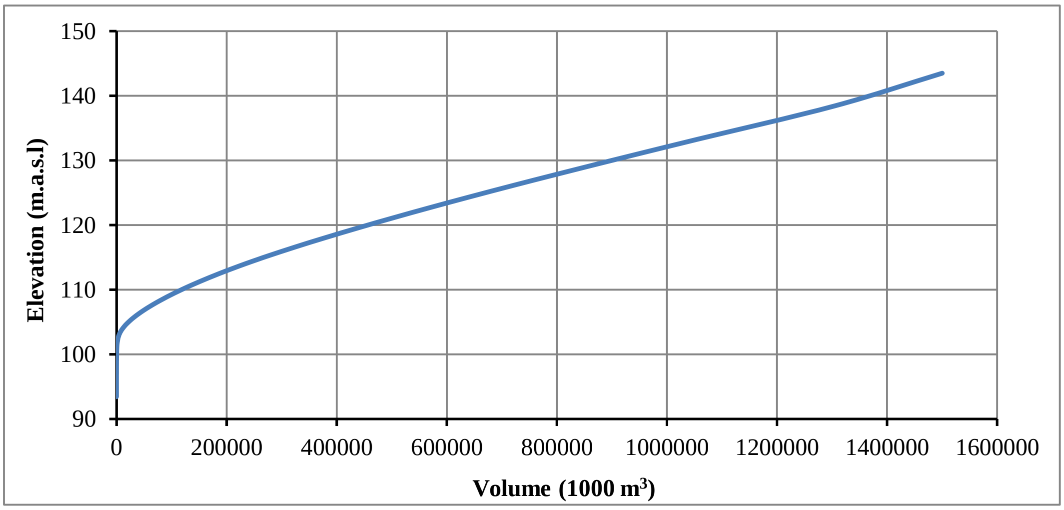


Figure 6. Volume –Elevation curve of Al-Udhaim Dam reservoir

Table 1. Calculated breach parameters for different mechanisms by 2D HEC-RAS model

Method	Breach bottom width (m)	Side slope (H: V)	Breach development time (hr.)
MacDonald et al, (1984)	1326	0.5:1	4.73
Froehlich (1995)	381	1.4:1	7.28
Froehlich (2008)	314*	1:1*	5.95*
Von Thun &Gillette (1990)	119	0.5:1	0.91
Xu & Zhang (2009)	289	0.75:1	10.21

Note: * The selected values for the hypothetical failure of Al-Udhaim Dam.

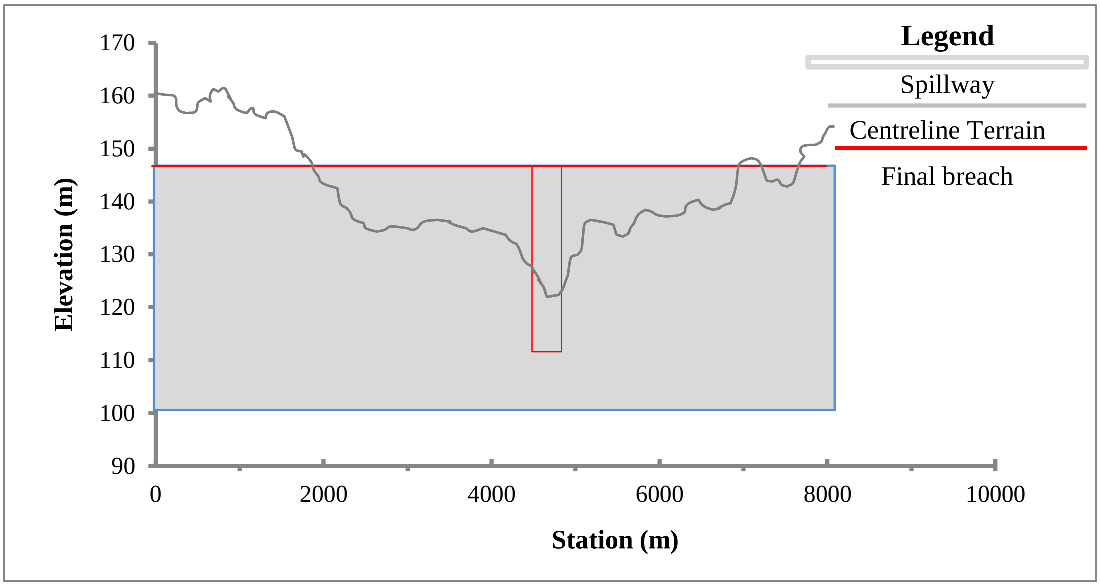


Figure 7. Dam breach geometry plot

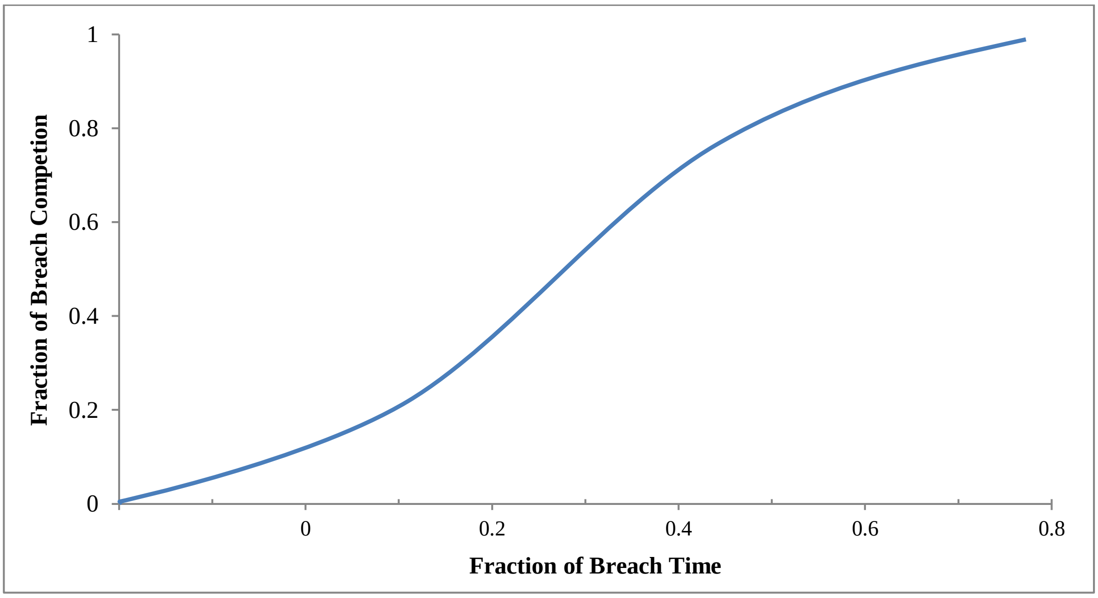


Figure 8. Breach progression curve

II. Breach Flood Hydrograph

The breach flood hydrograph was created using the dam breach option within the 2D HEC-RAS model. The outflow hydrograph due to the breaching failure can be derived using the weir equation as [20]:

$$Q(t) = CW(t)\,H \tag{3}$$

C is the breach weir dimensional coefficient, W(t) is the breach's width for each time increment, and H(t) is the hydraulic head over the breach crest. Simulation of Al-Udhaim Dam breach hydrograph using a value of 2.6 for the weir discharge coefficient, C, and the calculated breach parameters yielded the hydrograph shown in Figure 9. This hydrograph is used as input data to the second sub-model within the 2D HEC-RAS model, considering it as the upstream boundary condition.

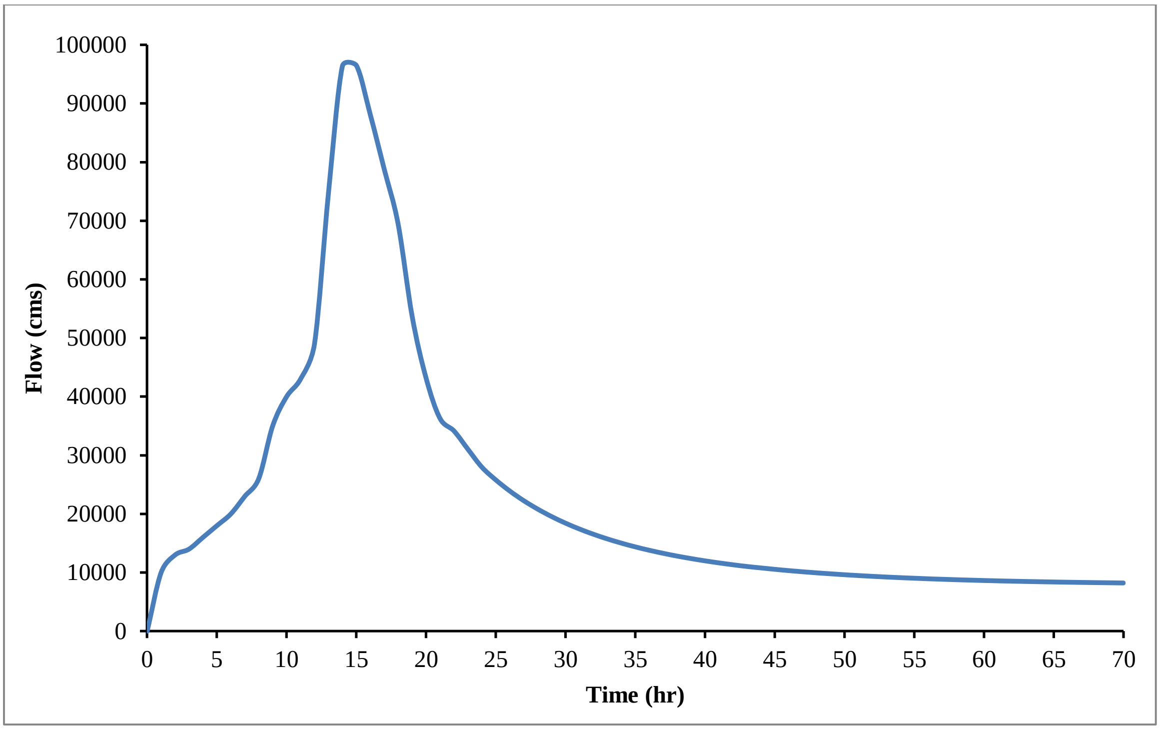


Figure 9. Dam breach hydrograph

3.3. Hydrodynamic Modeling

The flood propagation model has been performed by 2D HEC-RAS model using the fully dynamic Shallow Water Equations (SWEs), also called Saint-Venant Equations (the continuity, (Equation 4) and momentum Equations 5 and 6 as follows [2]:

$$\frac{\partial H}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}+q=0 \tag{4}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial H}{\partial x}+v_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-C_f u+f_v \tag{5}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial H}{\partial x}+v_t\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-C_f v+f_u \tag{6}$$

where: H is the water surface elevation, (L).h is the water depth, (L) u and v are the velocity components in the x and y direction, respectively, (LT^{-1}). q is a source/sink flux term per unit length (L^2T^{-1}) g is the acceleration of gravity (LT^{-2}), v_t is the horizontal eddy viscosity coefficient, C_f is the bottom friction coefficient, and f is the Coriolis parameter.

In the analyses with the HEC-RAS model, the mesh size of the 2D flow area can be selected according to the model stability. The mesh size of 100 m grids for flood inundation is generally said to be sufficient considering the relatively flat and wide floodplains [21]. However, this grid size requires more detailed geometric information of the connection line representing the dam body and the flood susceptible area. The flow area mesh of this study was generated with a grid system of (100×100) m cells using break lines and extra cells near the dam site yielding 61542 cells, as shown in Figure 10. On the other hand, the computational interval time step is estimated according to the Courant–Friedrichs–Lewy condition as:

$$C=\frac{c\Delta t}{\Delta x}=\frac{\sqrt{gh\Delta t}}{\Delta x}\leq 1 \tag{7}$$

where C is the Courant number, c is the celerity ($m.s^{-1}$), Δt is the time step (s) and Δx is the grid cell size (m). According to Brunner (2016) [21], it is appropriate to select the computational time step for dam-break studies between 1 and 60 seconds. For this case study, the computational time step has been taken as 30 seconds to satisfy the Courant condition for the analyses.

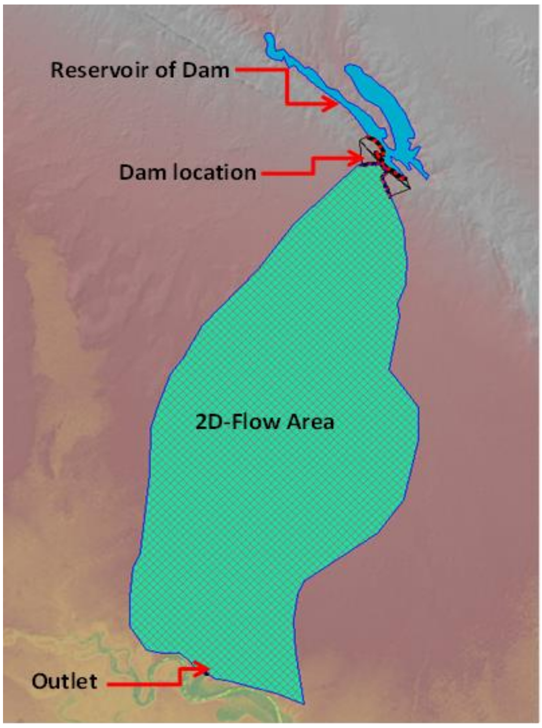


Figure 10. Model mesh

The primary input used for executing hydrodynamics modeling includes terrain data, Figure 5, boundary and initial conditions, and Manning's roughness coefficient (n). For the boundary conditions, the dam breach flood hydrograph, Figure 9 was applied as an upstream boundary condition. In contrast, a uniform flow regime is used for the downstream boundary condition with a friction slope value of (0.006). Furthermore, the water level corresponding to full reservoir capacity (143.5 m.a.s.l) was set as an initial condition in the reservoir. While the initial water level in the computation domain downstream of the dam is specified at terrain elevation. Three values of Manning's roughness coefficient (n) have been taken for each type of land cover according to Gibson [22] as 0.028, 0.03, and 0.035, for the: mean channel, forest, and village areas, respectively.

3.4. Assessment of the Flood Hazard

Flood water depth and flow velocity are the most vital factors affecting floods modeling. Pintilie, et al. [23] performed a classification of the flood hazard based on these parameters, as shown in Table 2. This criterion was considered in the present study for the flood hazard assessment.

Table 2. Classification of the flood hazard

Hazard level	Flood depth, (m)	Flow velocity, (m/s)
Low	Up to 1	Up to 0.01
Medium	1-3	0.01-0.05
High	3-5	0.05-0.1
Crisis	5-7	0.1-1
Catastrophic	More than 7	More than 1

4. Results and Discussion

RAS-Mapper in 2D HEC-RAS model was used to take profile lines for constructing relations of the maximum values of the: water surface elevation, flow velocity, water depth and flood arrival time at every point on the terrain. These relations were defined along the study region, which covers approximately 100 km from the dam body. Profile lines of the distribution of the water surface elevation, flow velocity and water depth for the study are shown in Figures 11, 12 and 13, respectively. Flood velocity considers an important result of the 2D HEC-RAS modeling process. According to Figure 12, the 1–3 m/s velocity class has the highest frequency except some values exceeding this range in different sites especially near the dam site and some are less than this range. Moreover, the water flow velocity values decreased from upstream to downstream of the terrain, which means that there will be less risk of erosion in the far reaches downstream of the study area. Regarding the maximum flood depth map, Figure 13, the maximum values were exceeded 5 m for the most sites and for the last 20km of the study reach the maximum depth values exceeded 15 m. Regarding the water arrival time, it was found that is increases the further away from the dam body.

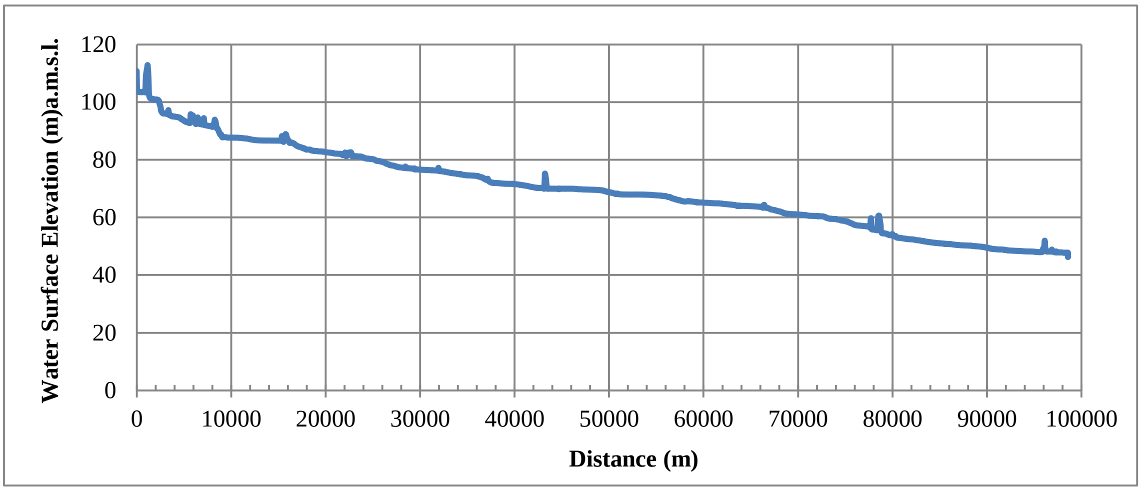


Figure 11. Maximum water surface elevation values for the study reach

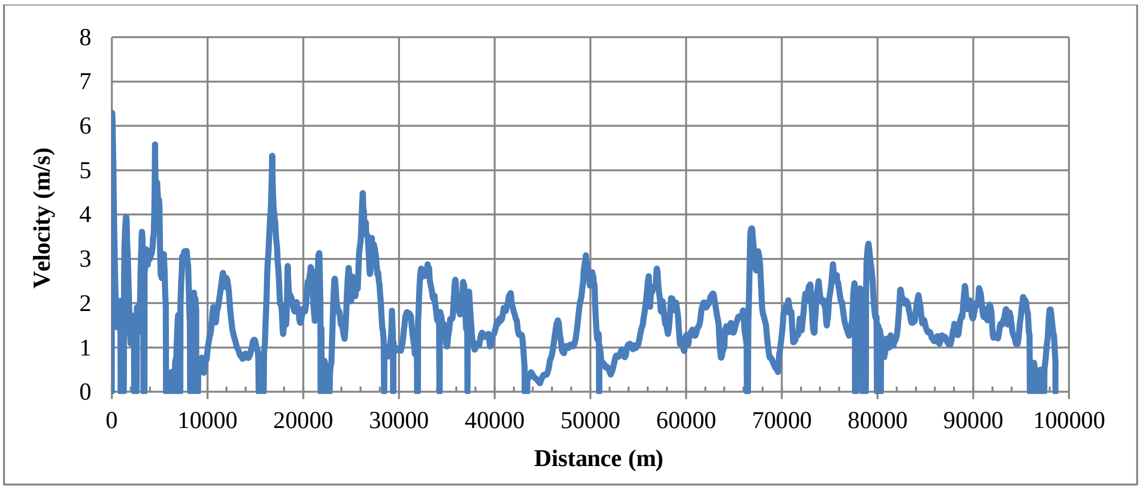


Figure 12. Maximum water velocity values for the study reach

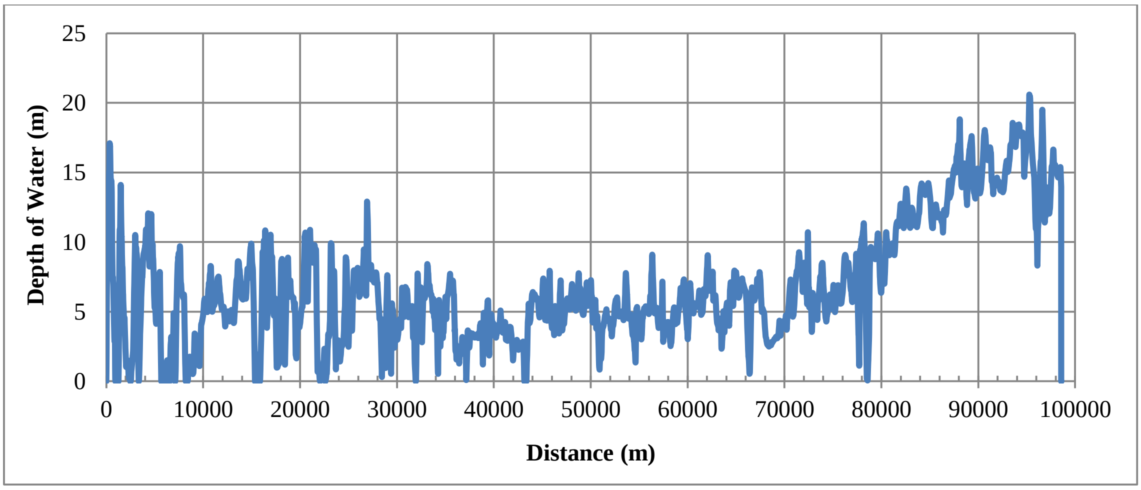
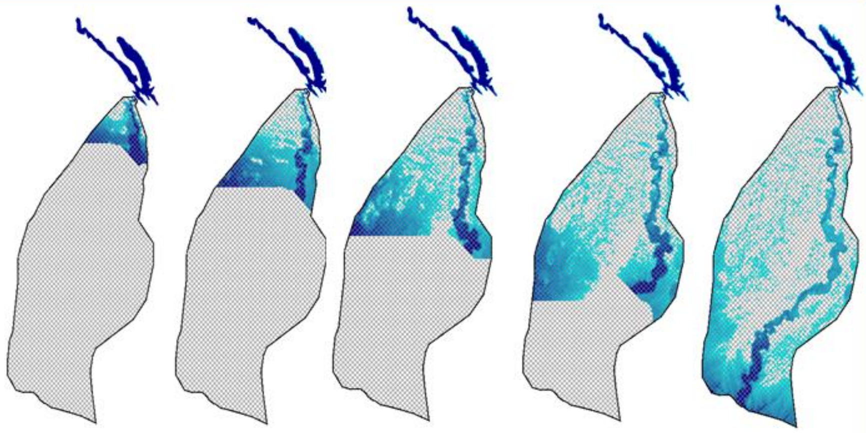


Figure 13. Maximum water flow depth values for the study reach

The flood extent along Al-Udhaim River after 5.5, 11, 17.5, 25, and 32.5 hrs. from the beginning of the simulation is depicted in Figure 14. Moreover, the simulated results of the study area at the end of the simulation time (32.5 hours from the beginning of the modeling) via RAS Mapper are shown in Figures 15 to 18. Figure 15 demonstrates the spread of the water surface elevation over the flooded areas. Figure 16 indicates the variance of the flow velocities of the floodwater, which shows that the highest range of the flood wave velocities was near the dam site and decreases to the lower range (> 1m/sec) in the other areas (about 80 km after the dam body). In Figure 17, the distribution of the flood depth propagation trend over the floodplains is displayed. Otherwise, the flood wave's travel time from the dam site to the end of the study reach was emphasized by generating the flood propagation time map with a total modeling duration equal to 32.5 hours, Figure 18. According to the Figures, the maximum values of these variables were found to be: 105m (a.m.s.l.), 5.5 m/s, and 18 m, respectively, at approximately 1000 m away from the dam body.

The flood propagating parameters are considered the most important results of flood modeling in which the severity of the flood can be classified. The study area was classified as being under Catastrophic hazardous according to a classification of (Mihu-Pintilie, et al., (2019)), since the values of the means of the maximum values of the velocity of water and flood depth were observed to be more than 1m/sec and 5 m, respectively.



Arrival Time (hrs)	5.5	11	17.5	25	32.5
Distance from dam(km)	20	40	60	80	100

Figure 14. Flood propagation through the study area

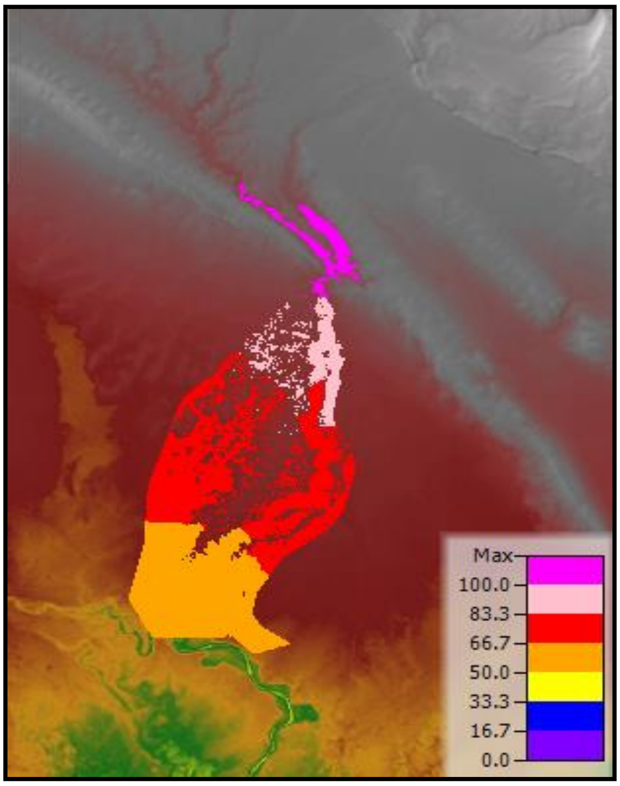


Figure 15. Distribution of water surface elevation

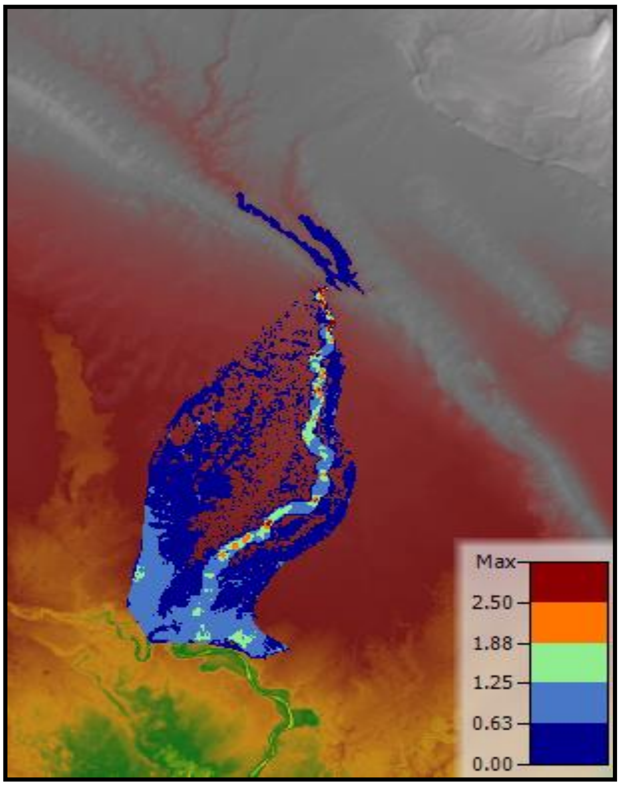


Figure 16. Distribution of water velocity

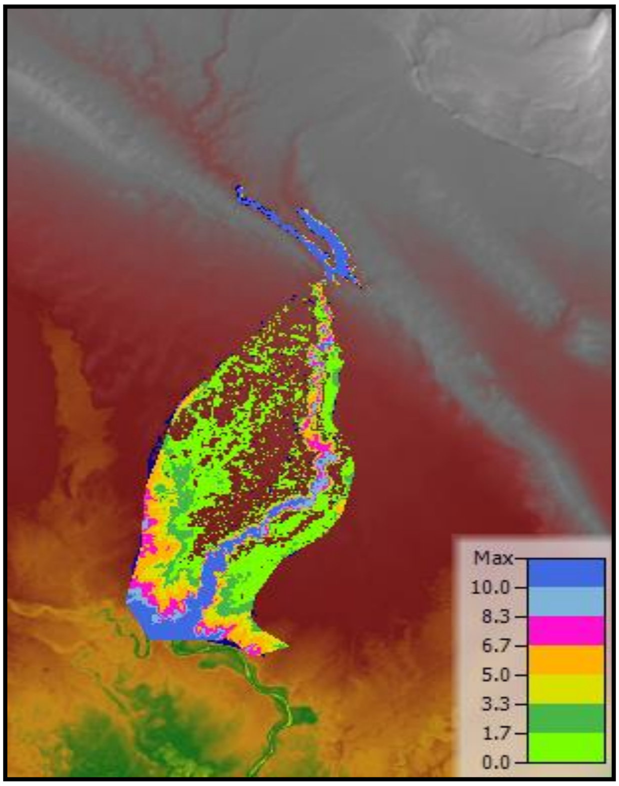


Figure 17. Distribution of the maximum depth

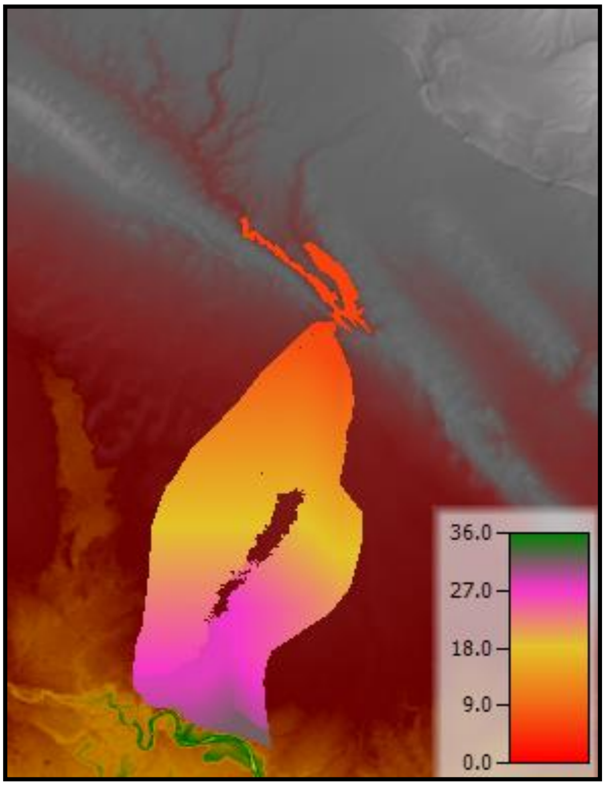


Figure 18. Distribution of flood arrival time

5. Conclusion

The hypothetical dam-break modeling results for the overtopping failure mode using the 2D HEC-RAS model were viewed from the output maps that were visualized on the DTM in terms of water surface elevation, flow velocity, depth of water, and flood arrival time. According to the modeling results, these parameters were observed to be decreasing from upstream to downstream of the flow area. The inundated maps indicated that the water depth and flow velocity were categorized as catastrophic hazardous limits on the terrain's area. This confirms that the flood hazard classification may be based on these three parameters altogether. Thus, the flood wave may cause severe damage to the study area, and a severe problem could occur when dam failure occurs. Accordingly, a vulnerability evaluation of the downstream areas of Al-Udhaim Dam to floods problem at dam failure time is essential. Therefore, this study will benefit future flood management in the study area by providing flood inundation maps. Additionally, the study will help identify the protection work and emergency plan during a flood to save human life and property, assess the area's damage after the flood and define the flood zone downstream and upstream of the study area. Moreover, the results provide a way to predict flood extent and show that the impact of a potential dam break at Al-Udhiam Dam is serious, and suitable management should be taken to reduce the risk.

6. Nomenclature

HEC-RAS	Hydrologic Engineering Center's, River Analysis System.	SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevations Model	DTM	Digital Terrain Model
B_{avg}	Average width of final trapezoidal breach	H_b	Maximum height of the final trapezoidal breach
K_o	Failure mode factor	t_f	Breach formation time
V_w	Reservoir volume at the time of failure	X	Distance along reach
n	Manning's roughness coefficient	V	Flow velocity
g	Gravitational acceleration	v_t	Horizontal eddy viscosity coefficient
C_f	Bottom friction coefficient	f	Coriolis parameter
t	Time	C	The Courant number
c	The celerity ($L\ T^{-1}$)		

7. Declarations

7.1. Author Contributions

Conceptualization, I.R.K. and Z.F.H.; methodology, I.R.K., Z.F.H., H.H.A. and I.A.A.; software, I.R.K., H.H.A. and I.A.A.; validation, I.R.K. and Z.F.H.; formal analysis, I.R.K. and Z.F.H.; investigation, I.R.K., Z.F.H.; H.H.A. and I.A.A.; resources, I.R.K., H.H.A. and I.A.A.; data curation, H.H.A. and I.A.A.; writing—original draft preparation, I.R.K., Z.F.H., H.H.A. and I.A.A.; writing—review and editing, I.R.K. and Z.F.H.; visualization, I.R.K. and Z.F.H.; supervision, I.R.K.; project administration, I.R.K.; funding acquisition, I.R.K. and Z.F.H. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

Part of the data is contained within the article and the other part of the data is available on request from the corresponding author.

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7.5. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Froehlich, David C. "Peak Outflow from Breached Embankment Dam." Journal of Water Resources Planning and Management 121, no. 1 (January 1995): 90–97. doi:10.1061/(ASCE)0733-9496(1995)121:1(90).

[2] Army Corps of Engineers, HEC-RAS River Analysis System, User's Manual, Version 5.0.7, Hydrologic Engineering Center, (February 2016).

[3] Quirogaa, V. Moya, S. Kurea, K. Udoa, and A. Manoa. "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, no. 1 (January 2016): 25–33. doi:10.1016/j.riba.2015.12.001.

[4] Joshi, Mrunal M., and Shahapure S.S. "Two Dimensional Dam Break Flow Study Using HEC-RAS for Ujjani Dam." International Journal of Engineering and Technology 9, no. 4 (August 31, 2017): 2923–2928. doi:10.21817/ijet/2017/v9i4/170904032.

[5] Kumar, Neeraj, Mukesh Kumar, Arpan Sherring, Shakti Suryavanshi, Ajaz Ahmad, and Deepak Lal. "Applicability of HEC-RAS 2D and GFMS for Flood Extent Mapping: a Case Study of Sangam Area, Prayagraj, India." Modeling Earth Systems and Environment 6, no. 1 (November 20, 2019): 397–405. doi:10.1007/s40808-019-00687-8.

[6] Sattar, Ashim, Ajanta Goswami, and Anil V. Kulkarni. "Hydrodynamic Moraine-Breach Modeling and Outburst Flood Routing - A Hazard Assessment of the South Lhonak Lake, Sikkim." Science of The Total Environment 668 (June 2019): 362–378. doi:10.1016/j.scitotenv.2019.02.388.

[7] Albu, Liviu-Marian, Andrei Enea, Marina Iosub, and Iuliana-Gabriela Breabăn. "Dam Breach Size Comparison for Flood Simulations. A HEC-RAS Based, GIS Approach for Drăcșani Lake, Sitna River, Romania." Water 12, no. 4 (April 12, 2020): 1090. doi:10.3390/w12041090.

[8] Pilotti, Marco, Luca Milanesi, Vito Bacchi, Massimo Tomirotti, and Andrea Maranzoni. "Dam-Break Wave Propagation in Alpine Valley with HEC-RAS 2D: Experimental Cancano Test Case." Journal of Hydraulic Engineering 146, no. 6 (June 2020): 05020003. doi:10.1061/(asce)hy.1943-7900.0001779.

[9] Říha, Jaromír, Stanislav Kotaška, and Lubomír Petrula. "Dam Break Modeling in a Cascade of Small Earthen Dams: Case Study of the Čižina River in the Czech Republic." Water 12, no. 8 (August 17, 2020): 2309. doi:10.3390/w12082309.

[10] Sarchani, Sofia, Konstantinos Seiradakis, Paulin Coulibaly, and Ioannis Tsanis. "Flood Inundation Mapping in an Ungauged Basin." Water 12, no. 6 (May 27, 2020): 1532. doi:10.3390/w12061532.

[11] Shahrim, M F, and F C Ros. "Dam Break Analysis of Temenggor Dam Using HEC-RAS." IOP Conference Series: Earth and Environmental Science 479 (July 14, 2020): 012041. doi:10.1088/1755-1315/479/1/012041.

[12] Psomiadis, Emmanouil, Lefteris Tomanis, Antonis Kavvadias, Konstantinos X. Soulis, Nikos Charizopoulos, and Spyros Michas. "Potential Dam Breach Analysis and Flood Wave Risk Assessment Using HEC-RAS and Remote Sensing Data: A Multicriteria Approach." Water 13, no. 3 (January 31, 2021): 364. doi:10.3390/w13030364.

[13] Government's Strategy for Water and Land Resources in Iraq (SWRLI). (2014). Final Report.

[14] MacDonald, Thomas C., and Jennifer Langridge‐Monopolis. "Breaching Charateristics of Dam Failures." Journal of Hydraulic Engineering 110, no. 5 (May 1984): 567-586. doi:10.1061/(ASCE)0733-9429(1984)110:5(567).

[15] Froehlich, David C. "Embankment Dam Breach Parameters and Their Uncertainties." Journal of Hydraulic Engineering 134, no. 12 (December 2008): 1708–1721. doi:10.1061/(ASCE)0733-9429(2008)134:12(1708).

[16] Von Thun, J. Lawrence, and David R. Gillette. "Guidance on breach parameters, unpublished internal document." US Bureau of Reclamation (1990): 17.

[17] Xu, Y., and L. M. Zhang. "Breaching Parameters for Earth and Rockfill Dams." Journal of Geotechnical and Geoenvironmental Engineering 135, no. 12 (December 2009): 1957–1970. doi:10.1061/(ASCE)gt.1943-5606.0000162.

[18] Basheer, Talal A., Aimrun Wayayok, Badronnisa Yusuf, and Md Rowshon Kamal. "Dam Breach parameters and their influence on flood hydrographs for Mosul Dam." Journal of Engineering Science and Technology 12, no. 11 (2017): 2896-2908.

[19] State Commission of Dams and Reservoir (SCDR), Hydrological study of the Al-Udhaim Dam, Iraq, (September 2019).

[20] Bellos, Vasilis, Vasileios Kaisar Tsakiris, George Kopsiaftis, and George Tsakiris. "Propagating Dam Breach Parametric Uncertainty in a River Reach Using the HEC-RAS Software." Hydrology 7, no. 4 (October 3, 2020): 72. doi:10.3390/hydrology7040072.

[21] Brunner, G. W. "HEC-RAS River Analysis System 2D Modeling User's Manual" (Vol. 5), (2016a), Davis, CA.

[22] Gibson, S. "Unsteady HEC-RAS Model of the downtown reach of the Truckee River." HEC, PR-58, 39, (2005).

[23] Mihu-Pintilie, Alin, Cătălin Ioan Cîmpianu, Cristian Constantin Stoleriu, Martín Núñez Pérez, and Larisa Elena Paveluc. "Using High-Density LiDAR Data and 2D Streamflow Hydraulic Modeling to Improve Urban Flood Hazard Maps: A HEC-RAS Multi-Scenario Approach." Water 11, no. 9 (September 3, 2019): 1832. doi:10.3390/w11091832.