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Numerical simulation of Earthen Dams failure due to Overtopping (Case study: SILVEH Earthen Dam)

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Abstract

Dams break due to an earthquake, bombing, piping, overtopping, or some lack in design and construction process is unavoidable, which could lead to loss of life and property downstream of the dam. This study aims to understand of SILVEH dam break, under the scenario that considers the dam failure, due to overtopping and to prepare a hydrograph and flood zone downstream due to the failure of the SILVEH dam. In this research, obtaining and recognizing high-risk areas downstream of SILVEH Dam, due to dam break is another important goal. NAYS 2D FLOOD software has been used to simulate the failure of the SILVEH dam. SILVEH dam is an earthen dam, located in PIRANSHAHR city, in the West Azerbaijan Province. In the northern part of the study, immediately after the broken axis, the main flood flow dam in the valley is not very deep in the LAVIN River and due to the relatively steep slope, the water depth is not high and rarely rises from the river valley, but in the southern parts and reaching smoother areas are increases in the depth of flow. The maximum flood velocity is estimated at 20 meters per second and the lowest flood flow velocity is estimated at 2 meters per second. MAHABAD-PIRANSHAHR road and power transmission lines and bridges in the mentioned road will suffer the most damage from water floods due to the possibility of breaking the SILVEH dam.

Keywords: Dam failure, Flood mapping, Overtopping, Earthen dam, NAYS 2D FLOOD**.**

1. Introduction

A dam is a structure that is built to create a reservoir to store excess water in wet seasons, control devastating floods, supply drinking water and water needed for agriculture, electricity generation, and other things and has many benefits for human society. But the failure of the dam leads to the release of a large volume of water, which causes huge flood waves downstream of the dam and can cause a lot of human and financial losses (Hassanzadeh *et al.*, 2015). Risk and estimation of damages due to the possible failure of dams have long been considered and studied by researchers (Mohammadnejad *et al.*, 2014). Dam failure due to overtopping is one of the most common failure modes. Thirty percent of dam failures in the United States over the past 75 years have been caused by overtopping. Dam failure analysis is often performed with the two main objectives of determining the output hydrograph of the reservoir and the flow rate of this hydrograph along the downstream route (Wahl, 1998). developed an implicit one-dimensional model to solve the problem of dam failure in dry and wet beds and showed that the results of the numerical model are in good agreement with the available laboratory data (Zhang *et al.*, 1992). Roshandel et al (2010), using the limited volume method simulated the failure of a dam on a dry and wet bed by solving shallow water equations and used a natural solvent to solve the Riemann problem (Roshandel *et al.*, 2016). Jia et al (2010), simulated a massive 2008

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Mississippi River flood using a limited German-based numerical model. Gradual failure of submerged areas was considered in this model and the simulation results were validated using satellite images (Jia *et al.,* 2016). A two-dimensional model based on the solution of shallow-up equations to simulate the currents caused by dam failure was presented and the numerical results with the results of the experimental model were validated (Singh *et al.,* 2011). The failure of the Aparan Dam located in Armenia with a failure time of 10 hours and a gap width of 5 and 50 meters according to the characteristics of the river and the dam body, in HEC-RAS software was simulated (Ludvig, 2011). The simulation results showed that the maximum output flow will be 625 and 4350 meters per second, respectively. The maximum Q is reduced to 614 and 4280 meters per second 28 km downstream of the dam. The water velocity for Scenario 2 was approximately 10 m/s and 10 km with a moderate slope and 16 to 18 m/s at 10 to 20 km downstream with a steep slope. After the necessary hydraulic calculations, they also presented flood zonation maps at the bottom of the dam (Bjerke, 2011). The Muyu reservoir iodine failure in China in two basic steps was studied. In the first step, the main reasons for the destruction of the dam were investigated. In the second step, the numerical analysis of the dam failure is investigated and the effect of parameters such as water level behind the dam, inlet flow to the reservoir, and the presence or absence of embankment downstream on the dam failure and flood zoning is evaluated (Changzhi *et al.,* 2014). An approach based on a combination of hydraulic modeling and GIS to assess the risks of possible failure of the Zardras concrete dam in northeastern Algeria was employed. To extract geometric information, they used GeoRAS-HEC in a GIS environment. Flow simulation of dam failure was performed using HEC-RAS and then the results were zoned using GIS software. Finally, a flood risk map was created based on the water depth and flow velocity map in the GIS environment. According to this plan, a large number of people will be affected by the failure of the Zardzas dam. This study also showed that the use of GIS techniques in combination with hydraulic modeling can play a significant role in improving flood management (Derdous *et al.,* 2015). Flood zoning due to the failure of India's Nirasagar Dam using ArcGIS software was utilized. To do this, they created the river features and other geometric characteristics of the reservoir and basin in HEC-GeoRAS software and then transferred them to HEC-RAS software for hydraulic modeling. Finally, the results were displayed in Google Earth to identify the flood zone (Hajeri *et al.,* 2016). Considering the importance of the dam failure phenomenon and choosing the appropriate method for its analysis, as well as preparing an emergency action plan to evacuate the affected people downstream and minimize potential losses, review, and compare studies have been paid in this regard (Kumar *et al.,* 2017).

2. Materials and Methods

2.1 Location and general objectives of SILVEH Dam

The project area is located in northwestern Iran, in the province of West Azerbaijan, and the city of PIRANSHAHR. SILVEH Reservoir Dam to supply safe drinking water to PIRANSHAHR city with an annual amount of 18 million cubic meters, agricultural water supply to 5700 hectares of lands downstream of the dam (PIRANSHAHR plain), agricultural water supply to 3950 hectares of JALDIAN plain lands (through tunnel and transmission canal JALDIAN water located inside the reservoir), electricity supply of the region at the rate of 18 GWh per year, as well as fish farming, tourist attractions, tourism, control and regulation of flood flows will be constructed. This dam is located on LAVIN Chay River from the tributaries of Zab river in the north of Kelas catchment and in the south of West Azerbaijan province, about 12 km northwest of PIRANSHAHR city and 150 km southwest of Urmia city in a range of longitude+45 to 110 0 45 east and latitude 510 0 36 to 6 656 36 North (see Fig. 1)

Figure 1. Overview of Silveh Dam.

2.2 General specifications of the design

Dam location	12 km from PIRANSHAHR - 2.5 km from SILVEH village
The name of the river	LAVIN (the main source of the Class River)
The average annual yield of the river	220.7 mcm
Reservoir volume at the normal level	84 mcm
Reservoir level at the normal level	655.8 ha
Adjustable water volume	203.5 mcm/year
Water required by the environment	23.8 mcm
Type of dam	Soil with clay core

2.3 Software Presentation

Nays 2D Flood is a flood flow analysis solver that relies on unsteady 2-dimensional plane flow simulation using boundary-fitted coordinates[1] as the general curvilinear coordinates. This solver adopts the 2-dimensional plane flow simulation of the Nays2D Solver developed by Professor Yasuyuki Shimizu of Hokkaido University for flood flow analysis. The data needed for an overflow calculation by Nays 2D Flood are topographic data and data of inflow discharge and roughness of each river or each inflow point.

2.4 Numerical simulation

The first step in analyzing the failure of SILVEH Dam is to investigate how to create and expand the gap in the dam body and, consequently, to determine the hydrograph of the output of the dam site at the time of dam failure. In fact, this hydrograph is the output of the gap created in the body of the dam, which needs to be routed downstream of the dam to analyze the threat of downstream areas. Among the main causes of cracks and fractures in earthen dams, overflow from the dam (Overtopping) is of great importance. The flow overflow scenario is called the Stormy day scenario. In the present scenario, it is assumed that the water level in the first is at the maximum value and the Q flow to the reservoir of the PMF dam. In this research, NAYS 2D FLOOD software has been used to simulate the failure of the SILVEH dam.

[1] Boundary-fitted coordinates are set along the boundaries because a rectangular Cartesian coordinate system has difficulty reproducing complicated, winding boundaries. The governing equations in the rectangular Cartesian coordinate system are mapped to the general curvilinear coordinate system and are calculated. Because of its features, the system is also called a boundary-fitted coordinate system.

2.5 Flood zoning due to failure of SILVEH dam

Due to the type of flood hydrograph - due to the sudden change in flow rate and depth during floods due to the failure of the dam, flow analysis is only possible with dynamic analysis of non-continuous flow. In this research, a 2D non-continuous flow model is used for modeling. Arc GIS software has been used to zone the flood downstream of the dam fracture section. This software is one of the most widely used software in the GIS environment, which can be used to connect descriptive information with spatial information (Hassanzadeh *et al.*, 2015). Figure (2) shows the digital model of the study area. The following coefficient is of great importance as a parameter of current resistance. The main channel is considered in the numerical model with an average roughness coefficient of 0.035. The flood plain is also modeled with the following coefficient of about 0.05. It should be noted that residential areas are also modeled with a high sub-coefficient.

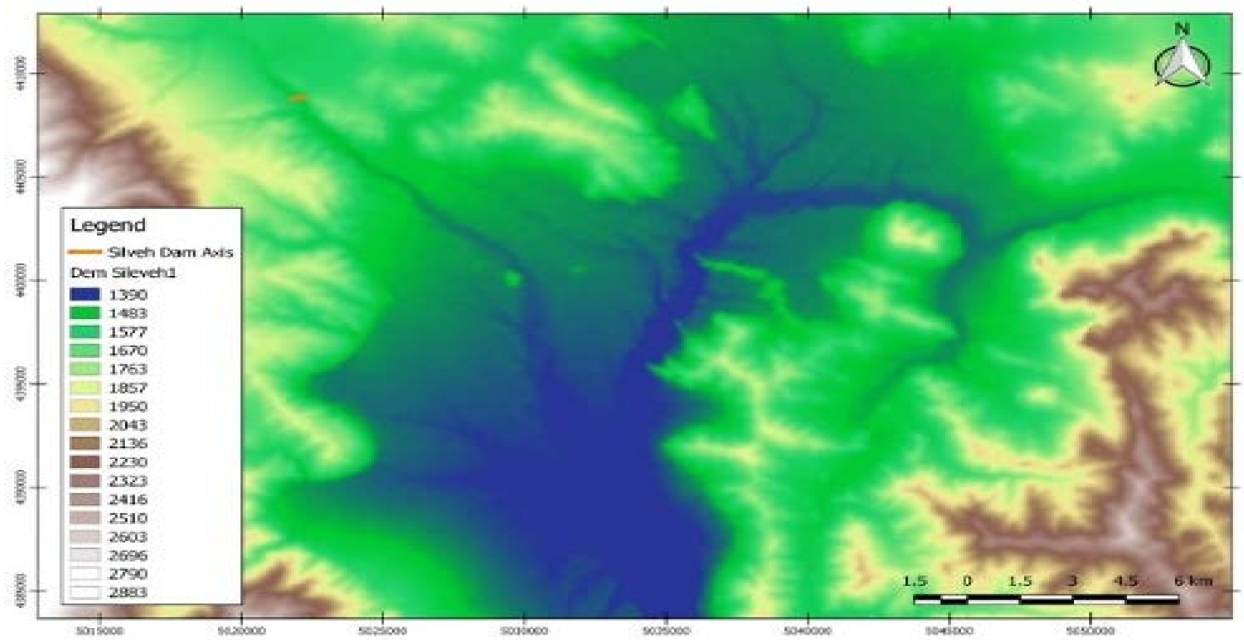

Figure 2. Digital model of the study area.

To solve the equations governing the solution field, the study area is broken into smaller networks and the equations are solved in these elements. Due to the features of the Nays Flood numerical model, regular rectangular grids have been used. This type of meshing causes a rapid solution of the flow field and achieves good results. The elements used in this study had a length and width of approximately 15 meters, which is suitable for solving the field due to the very wide area of the study area. The following figure shows the network range and boundaries of the numerical model. The flood entrance border is located on the axis of the SILVEH dam. This boundary is used as the inlet boundary and failure hydrographs are defined to this boundary. Side borders are considered wall borders. These boundaries are determined by the initial and outline simulations, and it is ensured that in the original flood simulations these boundaries will not be reached. The output boundary is also considered the Output boundary and the current will flow out of this boundary (see Fig. 3).

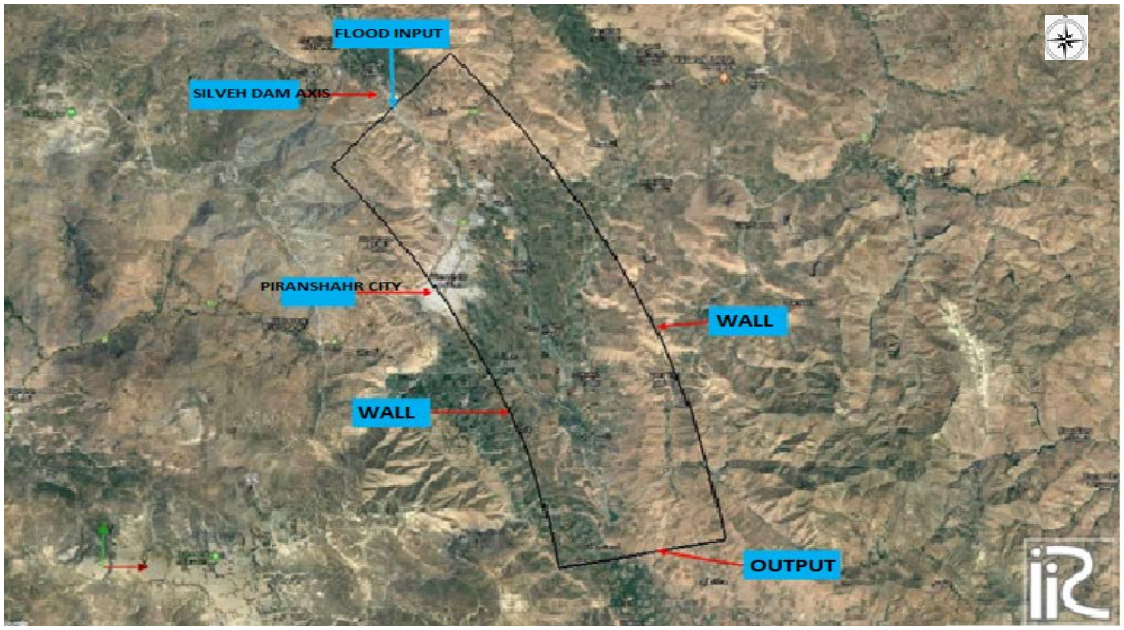

Figure 3. Boundary condition and simulation range.

3. Results

Assessing the risk of failure of SILVEH dam on downstream areas due to flood failure due to high velocity in both longitudinal and wide directions reduces the time and thus increases financial and human losses compared to natural floods. Research shows that the rate of casualties in the area after the dam failure if there are 90 minutes of flood warning time is about 20%, while with the reduction of warning time to 15 minutes, the rate of casualties to 50% increase. According to different scenarios of dam failure, danger zones are classified according to the time between the moment of dam failure and the arrival of the resulting wave (in other words, the scheduled time). Table 1 presents three different risk areas.

Table 1 Danger zones according to escape time

Area	Description	Escape time, t (minute)
1	Very high risk	t <30 -
2	ordinary	30<t<120 -
3	low risk	t>120

Flow velocity plays a major role in flood damage. However, so far, no precise relationships have been found to predict the effect of flow velocity on flood damage and risk. To deal with this problem, risk mapping has been used in various ways, usually using the risk matrix. These include Two Policies (2000), Adrianz (2001), Ross (2003), Faturley et al. (2003), Verotenolder et al. (2003), and Huang et al. (2004) (Huang, 2005).

A factor called the damage parameter was obtained (Harrison, 1864), which is defined as VD in terms of m^2/s, by examining the flood resulting from the failure of the Dal Dike Dam; In this parameter, V is the velocity in m/s and D is the depth in (m) (Roos, 2003).

In the Queensland Reconstruct on Authority project, the following table was prepared by examining at least 5 different sources to present the flood risk classification, and based on this table, 2 were drawn.

Table 2 Flood Risk Rating (Queensland Flood Assist, 2011)

	Low	**Significant**	**Much**	**More than**
Depth (D)	<0.5	<2	<2	>2
Velocity (V)	<1.5	<2	<2	>2
D × V	<0.6	0.8 to 0.6	1.2 to 0.8	>1.2

3.1 Overtopping scenario

In the overtopping scenario, due to the washing of the surface of the earth dam body and the continued passage of water over the body, it destroys the shell and finally the failure of the dam. Due to the maximum depth of flood zoning, in the northern part of the study area and immediately after the broken axis of the main dam, the flood flow in the valley is not very deep in the LAVIN river and due to the relatively high slope, the water depth is not high and rarely rises from the river valley, but in the southern parts and reaching smoother areas, the depth increases and the maximum depth is near the village. Soghanlu is seen. In this region, the velocity parameter has the highest limit due to the high initial velocity of the flow resulting from the failure of the dam and the relatively high slope of the path and the straight path of the flow velocity in this part bypassing the northern region and reducing the flow energy. Also, the flow velocity is minimized by crossing various obstacles and reaching lower areas. The important villages and areas at risk of flooding are as follows.

Table 3 Coordinates of the studied villages

Row	**Village name**	**y**	**x**	**Row**	**Village name**	**y**	**x**
1	ROZGARI	514256	4066093	3	Gelepsin	517023	4061811
2	DRABKE	515651	4065335	4	LAVIN and ZIDAN	517867	4058185

The time of flood reaching ROZGARI village and DRABKE village in the overtopping scenario is about 22 minutes and 28 minutes, respectively. In this regard, the area of these villages is in a very high-risk area due to the time of escape and the villagers do not have much chance to escape to safe areas. The flood flow caused by breaking the dam in ROZGARI village, the valley part of the village is exposed to flood waves with a height of more than 12 meters and a velocity of more than 20 meters per second. It seems that all the structures in this part, as well as the road bridge PIRANSHAHR to MAHABAD, should be destroyed and in the higher part of the stream and the velocity of the flood resulting from breaking the dam in the village of ROZGARI, the depth of the flood will reach 2 meters and the velocity of the flood will reach 2 meters per second, which seems to be damaging. This is especially true in the financial sector, while in the village of DRABKE, the valley part of the village is exposed to flood waves of more than 14 meters high and velocity more than 15 meters per second. All structures in this area should be completely destroyed. Velocity and depth contours in Zargari village as well as flood zoning can be seen for example below (see Fig. 4).

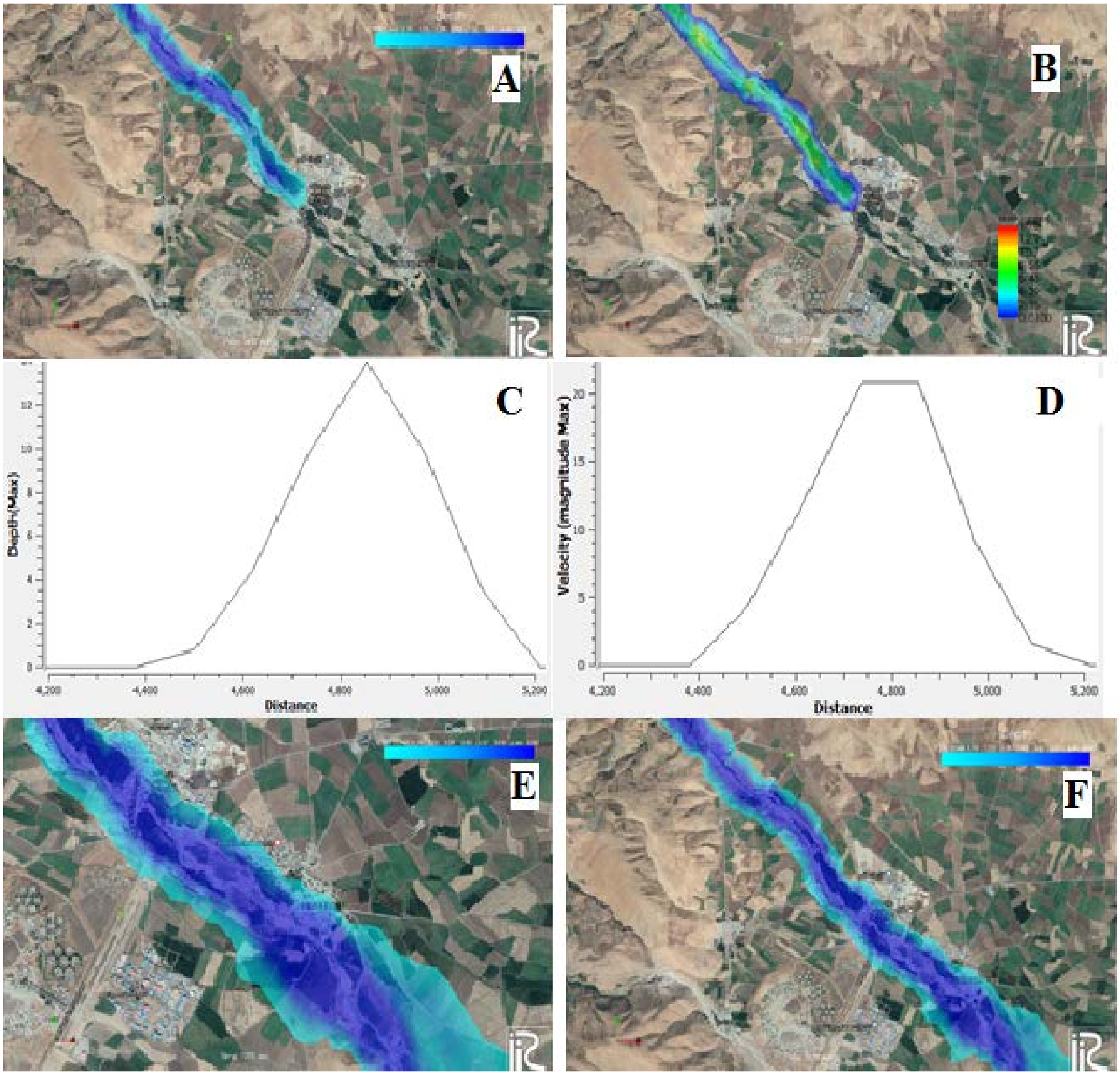

Figure 4. The depth and velocity counters and output graphs of the software. Contour depth flow when reaching the ROZGARI village (A). Flow rate contour when reaching the velocity of ROZGARI village (B). Graph of maximum depth occurred in the section of Rozgari village (C). Graph of the maximum velocity occurred at the intersection of ROZGARI village (D). The contour of the maximum flood zone in the area of DRABKE village (E). The contour of the maximum flood zone in the area of ROZGARI village (F).

In the passing scenario, the time for the flood to reach GALAPSIN village is about 37 minutes. In this respect, the village is within normal limits due to the time and the villagers have a moderate chance to escape to safe areas. In GALAPSIN village, the water level at the time of reaching the village is about 13 meters and the flow velocity currently is 11 meters per second. According to Table 2, GALAPSIN village risk criteria for flood risk is excessive. In Figure 5, flood zoning can be seen in GALAPSIN village.

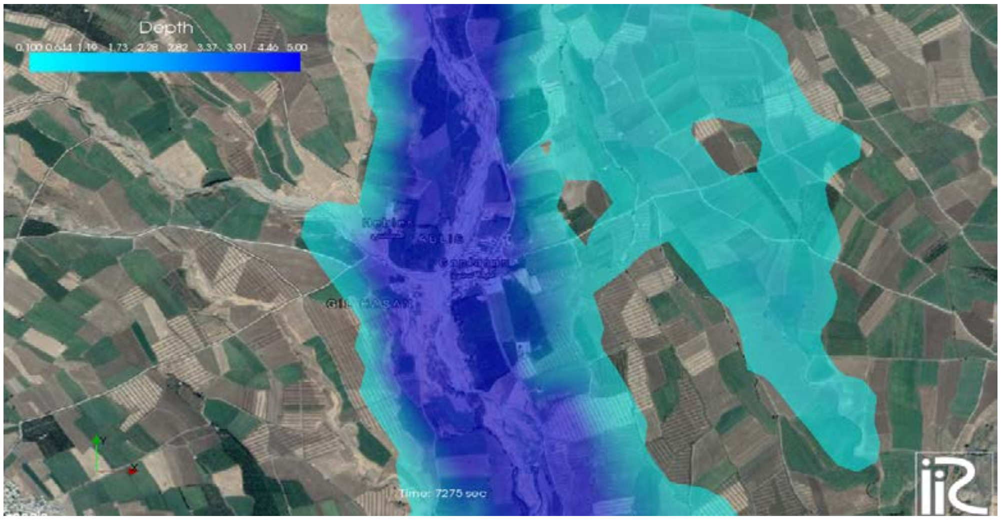

Figure 5. The contour of the maximum flood zone in GALAPSIN village

The flooding time to LAVIN and ZIDAN villages is about 48 minutes. In this regard, the village is within normal limits according to the time and the villagers have a chance to be in safe areas. In LAVIN and ZIDAN villages, the water level is about 5 meters when it reaches the village, and the flow velocity currently is 8 meters per second. According to Table 2, the paternal risk criteria of LAVIN and ZIDAN villages are too high. Figure 6 shows the depth and velocity counters and output graphs of the software.

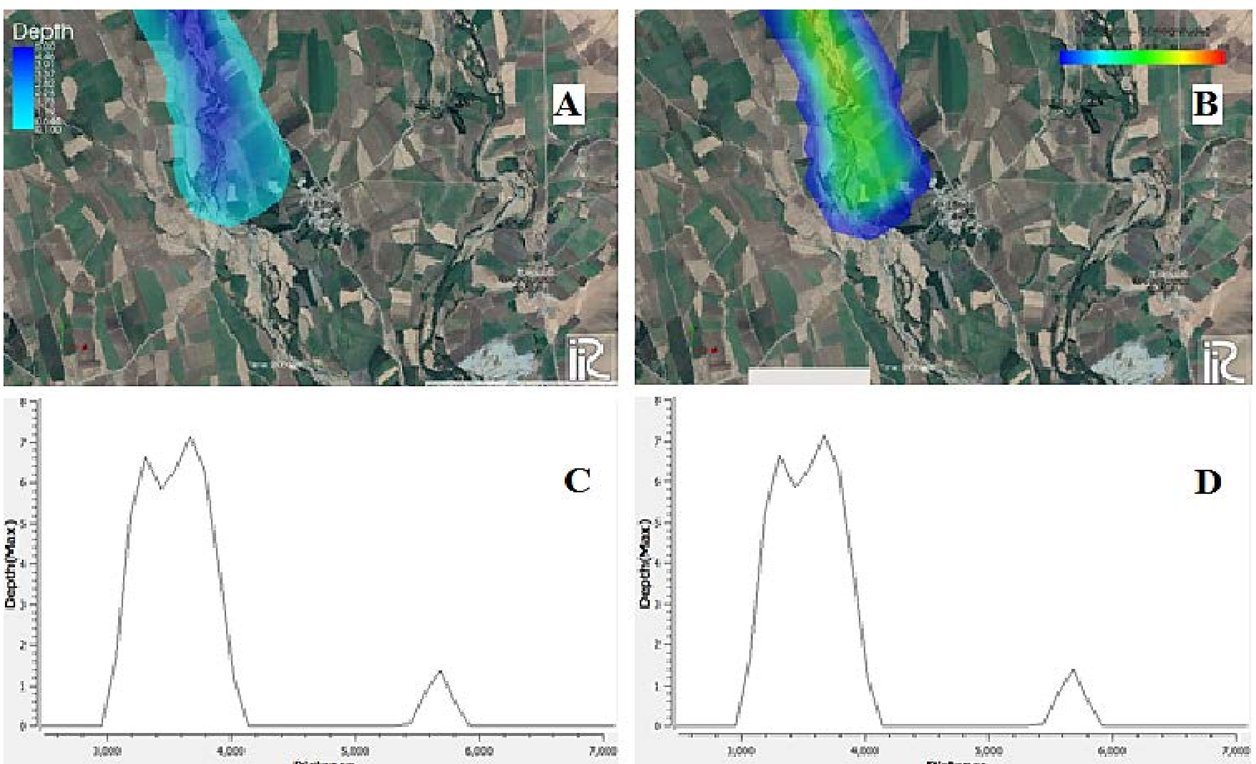

Figure 6. The depth and velocity counters and output graphs of the software. Contour depth flow when reaching the LAVIN and ZIDAN villages (A). Flow rate contour when reaching the velocity of LAVIN and ZIDAN villages (B). Graph of maximum depth occurred in the section of LAVIN and ZIDAN villages (C). Graph of the maximum velocity occurred at the intersection of LAVIN and ZIDAN village (D).

Conclusion

In the northern part of the study area and immediately after the axis is broken. In the southern parts and reaching smoother areas, the depth of flow increases.

The villages of ROZGARI and DRABKE are in a very high-risk area with less than 30 minutes in terms of time, and the rest of the studied villages are in the normal range in terms of escape time or escape time between 30 to 120 minutes.

The maximum depth of flood is estimated at 14 meters and the minimum depth at 1 meter. The maximum flood velocity is estimated at 20 meters per second and the minimum flood velocity is estimated at 3 meters per second.

In terms of flood risk criteria, most of the surveyed areas and villages are in very high-risk areas.

MAHABAD PIRANSHAHR road and power transmission lines and bridges in the said road will suffer the most damage from water floods due to the possibility of breaking the SILVEH dam.

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