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Article

The Evaluation of Flood Hazard of a Hypothetical Duhok Dam Failure

Nazeer Abdulah [1,*] Hindreen Mohammed Nazif [1]

[1] Highway and Bridge Engineering Department, Duhok Polytechnic University, Duhok, Iraq
* Correspondence: nazeer.abdulah@dpu.edu.krd

Abstract

Duhok Dam is one of the considerable hydraulic structures in the northern Iraq, located northwest of Duhok city. It is an earth-fill embankment dam, standing 60.5 meters high with a reservoir capacity of approximately 52,000,000 m3. It performs a crucial role in irrigation, water supply and flood control. However, due to its geological and hydrological patterns, it has been selected as a case study to assess flood hazards resulting from a hypothetical dam failure, with its direct effect on Duhok city. In this study, Watershed Modelling System (WMS) was used to simulate a theoretical failure of Duhok Dam. To the best of our knowledge, this is the first study to investigate the Duhok Dam break and its discharge reaching the Mosul Dam reservoir. A single failure scenario is considered, corresponding to the normal water level of 615.75 m.a.s.l. The simulation results indicate that Duhok city would experience severe flooding. The peak flood discharge at the door to Duhok city is estimated to reach 40977 m^3/s, at the coordinate system of (36°52'02.5"N 43°00'07.0" E). Within 21 minutes of the dam failure.

Keywords: Dam Break Simulation; Inundation Mapping; Flood Hazard Assessment; Disaster Risk Management; GIS

1. Introduction

The nature of the dams' constructions and their focal point of engineering and hydrological studies, due to their dual benefits in water management and storage, irrigation, and flood control, also poses a significant risk when they fail. The construction of large dams with some dating back to around 4000 years B.C., in regions like Jawa, Jordan has been documented throughout history [1]. However, the dam failure remains a serious concern with a destructive consequence for downstream communities. Famous examples of dam's failure such as Johnstown Dam in the United States of America in 1889, (causing over 2,000 deaths), and in 1975 the Banqiao Dam failure in China, (caused about 171,000 fatalities), highlight the catastrophic potential of dam breaches [2, 3]. Dam breaks are typically much more destructive than floods caused by surface runoff or rainfall, emphasizing the critical need for effective flood hazard prediction and management [4, 14, 19]

The modern dam safety approach considers not only the physical and structural elements of dam design but also predictive models and simulations to assess the potential outcomes of a breach. Hydrological models such as HEC-RAS, SMPDBK, and others play a pivotal role in simulating dam failure scenarios and flood propagation. Utilization of these programs assist to analyze drowned depths, discharge and elevation of flood, giving an important and fundamental information for emergency actions and masterplans of the city [7, 8]. Integrating the mentioned models by Geographic Information Systems (GIS) allow for better illumination and assessment of flood risks [9]. One of the case studies on Elmali and Yabous dams in Turkey and Algeria explain how changes in breach properties such as flood behavior, slope,

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width at downstream, break formation time, reservoir simulation inputs and importance of accurate data specially type of break in flood risk evaluation [10, 11].

Recent studies focus on how climate changes effect on hydrological criteria, especially flood hazard scenarios and reviewing dam safety instructions [13, 14]. Development in flood model simulation technologies by integrating with climate change models allow for more Up to date, flexible and comprehensive risk assessments [14], especially global dynamic models of mapping the flood hazards created by European Union [15, 16].

The analysis in this study shows a scenario of Duhok dam break by integrating Watershed Modelling System (WMS) and Simplified Dam Break (SMPDBK) model to simulate the flood shock from Duhok dam to the downstream area. This investigation uses Digital Elevation Model (DEM) as GIS data, land use maps and satellite imagery to analyze the potential effects of a dam failure on Duhok city and its surrounding areas in addition to the Mosul Dam reservoir. The results highlight the importance of anticipating flood risks through advanced modelling techniques to show the hypothetical results of dam breach.

2. Materials and methods

2.1 Case study description

Duhok Dam, located on the Duhok River in the Kurdistan Region, northern part of Iraq, as shown in Figure 1. Duhok Dam is an essential infrastructure for water storage, drinking water supply, irrigation and flood control during periods of heavy rainfall. The dam is positioned at geographical coordinates (36°52′33.1″N, 43°00′13.2″E) within a catchment area of 132 km². As an earth-fill embankment dam, it stands 60 meters high and has a storage capacity of 52 million cubic meters, as shown in Table 1. By utilizing hydraulic modeling tools and GIS techniques, this study provides insights into the potential flooding effects that could arise from a dam breach due to any reason, which helps to prepare for and mitigate risks associated with such a disaster on Duhok center citizens with a population of approximately 350000 inhabitants; which is nearly around 1/4 of the entire governorate population of 1461457 people.

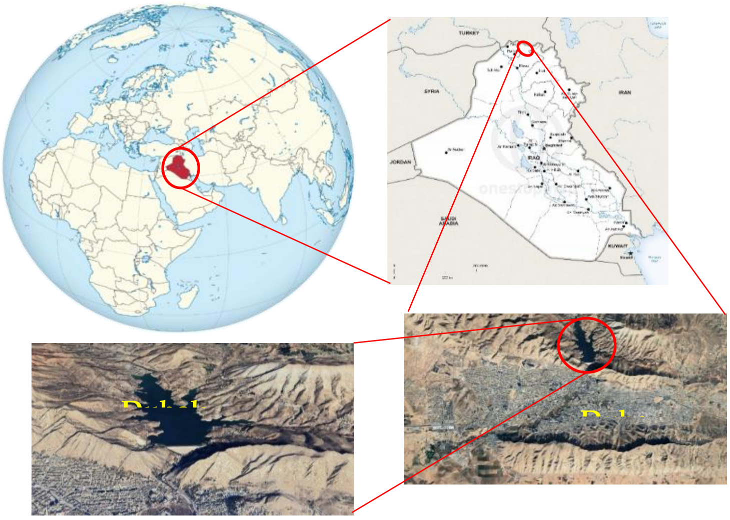

Figure 1. Iraq map and study area.

Table 1. Duhok Dam Information

Type of Duhok Dam: High Earth Fill Dam with Gravel Shell and Central Clay Core		
Dam	**Level of Crest**	**619.75 m**
	Width of Crest	**9 m**
	Crest Length	**613.43 m**
	Height of Dam from Bed of the River	**60.5 m**
Reservoir	**Level of Maximum Water**	**618.8 m**
	Normal Water Level	**615.75 m**
	Dead Storage Level	**584 m**
	Normal Reservoir Surface Area	**2,560,000 m2**

	Volume of Normal Reservoir	52,000,000 m3
	Volume of Maximum Live Storage	47,510,000 m3
	Dead Storage Volume	4,390,000 m3
	Watershed Area	132 Km2
Spillways and Outlets	Height of Spillway	55.47 m
	External Diameter of Spillway Opening	24 m
	Maximum Discharge of Spillway	81 m3/sec
	Maximum Discharge of the bottom outlet gate	62.5 m3/sec
	Time for Evacuation of Useful Storage	11 Days

2.2 Simplified dam break model overview (SMPDBK)

In 1983 The National Weather Service (NWS) built a model called Simplified Dam Break Model (SMPDBK) which has 1-D numerical model assigned to simulate the effects of dam failure at downstream of the dam. The model is depended on Saint-Venant's equations, which consist of the continuity and momentum of unsteady flow equations, taken from mass conservation principles, which are special for the modeling of flood expansion caused by the dam breach.

The SMPDBK model consider the dam body break in rectangular shape and also the bottom breach elevation to the downstream first cross section.

SMPDBK for running outputs requires two types of data:

- Information of upstream: storage volume, reservoir surface area, breach width, manning's the roughness coefficient, breach duration and also (spillway, overtopping and turbine) flows are taking in the considerations.
- Downstream information: cross-sections, river's centerline and land use properties downstream of the simulated channel.

The software outputs related flood parameters such as maximum discharge flow, maximum flood elevation, and the time to reach peak discharge at downstream of the dam for each cross-section.

SMPDBK has become a widely utilized tool for anticipation of flood risk management, mitigation efforts and emergency preparedness **[17, 18].**

3. Results and discussion

The Duhok Dam break analysis provides critical insights into the spatial extent of the flood inundation and potential hydrodynamic consequences. The summarized input data indicates that at collapse time, the reservoir water level was at an elevation of 615.75 m, with a failure elevation of bottom with a value of 561.5 m, resulting in a water column height of 54.25 m. The total volume of water released was estimated at 52 million cubic meters, covering a reservoir surface area of 2.56 million square meters. The breach, 165.35 m wide, fully developed within 18.014 minutes, with a non-breach flow of 143.5 m^3/s through the spillway and outlet gates as shown in Table 2.

Table 2. Summarized input data of Duhok dam break analysis

Input dam break details	
Water elevation when the dam breaches (m)	615.75
Breach bottom elevation (m)	561.5
Water height when the dam gets fail (m)	54.25
Storage Volume when the dam gets fail (m3)	52,000,000
Surface area of the Reservoir when the dam breaches (m2)	2,560,000
Rectangular breach width (m)	165.35
Time for breach to develop (minutes)	18.014
Non-Breach flow (Spillway and Outlet Gate m3/s)	143.5

Figure 2 presents a comprehensive view of the flood depth across the overall inundation area between Duhok Dam and Mosul Reservoir. The data indicate that flood depth is greatest near the dam outlet, where the maximum water elevation reaches approximately 604.35 m with a flood depth of around 41.65 m. As the floodwaters progress downstream, both the water elevation and depth gradually decrease, reaching about 333.02 m and 9.72 m, respectively, at approximately 26.86 km from the dam. This gradual tapering demonstrates the dispersion and attenuation of the flood as it moves away from its source.

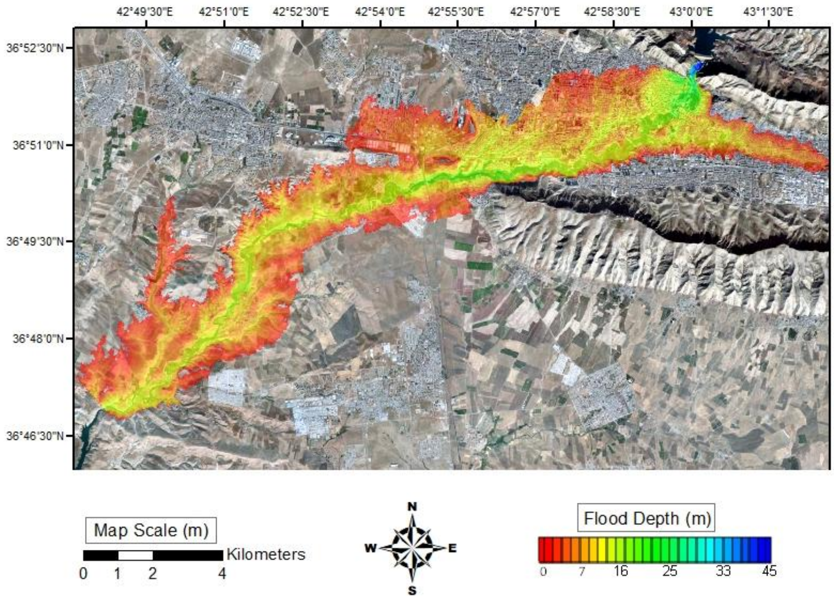

Figure 2. Flood Depth of the overall inundation area between Duhok dam and Mosul Reservoir.

In contrast, Figure 3 focuses on the urban environment of Duhok city, highlighting the localized flood depth variations within the cityscape. Despite the overall downstream reduction in water elevation, certain areas within Duhok city experience significant flood depths due to the complex interplay of urban topography, building density, and drainage limitations. This localized detail is crucial for urban flood risk management, as it underscores the need for targeted mitigation measures in zones where the flood impact remains severe.

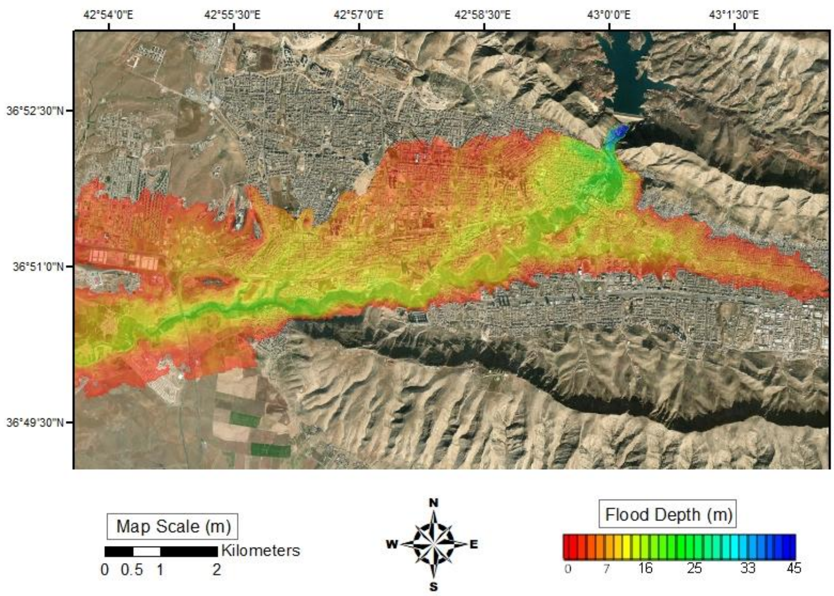

Figure 3. Flood Depth of the overall inundation area of Duhok city

On the left side of the flow direction, between Barzan Highway and Kani Mohamadke Road, the flood is expected to extend up to 4 km from the Hishkaroo River centerline, including (Duhok Valley, Duhok Bazar, Naoori District, Kochara District, Baroshke and Sarhaldan Districts, Duhok Stadium) as appeared in Figure 4.

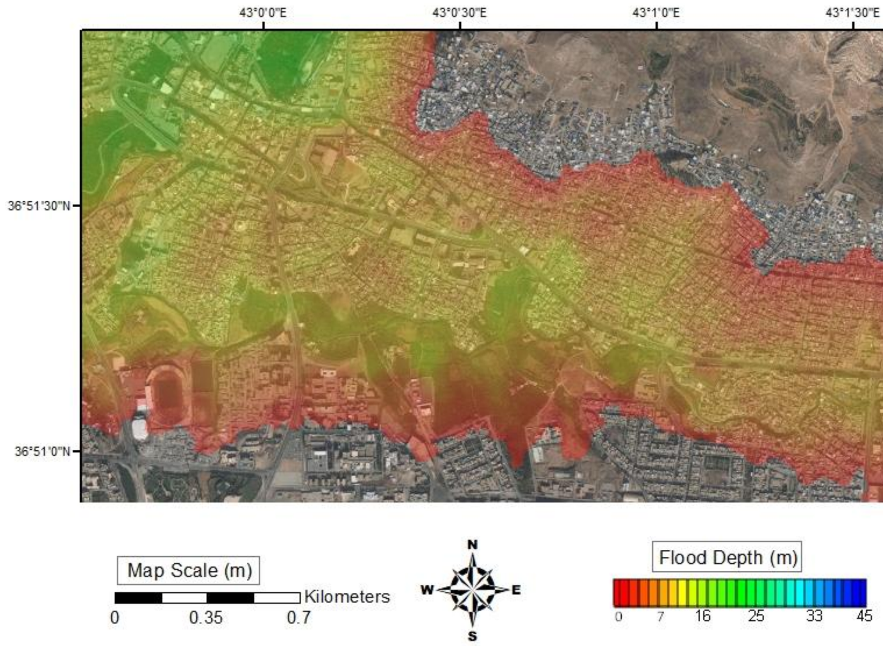

Figure 4. Left inundation area of Duhok River at Duhok city.

Meanwhile, on the right side, it is recommended that people maintain a distance of at least 1.5 km from the river centerline until reaching Malta Mosque (36°51'06.1"N 42°55'56.8" E) including (K.R.O (Horse Roundabout) until Nurseries (Plant) Street and Roj Towers City, Duhok Zoo area and Gavarke District) as shown in Figure 5. Beyond this point, the floodwaters gradually converge back into the river channel and continue toward the Mosul Reservoir.

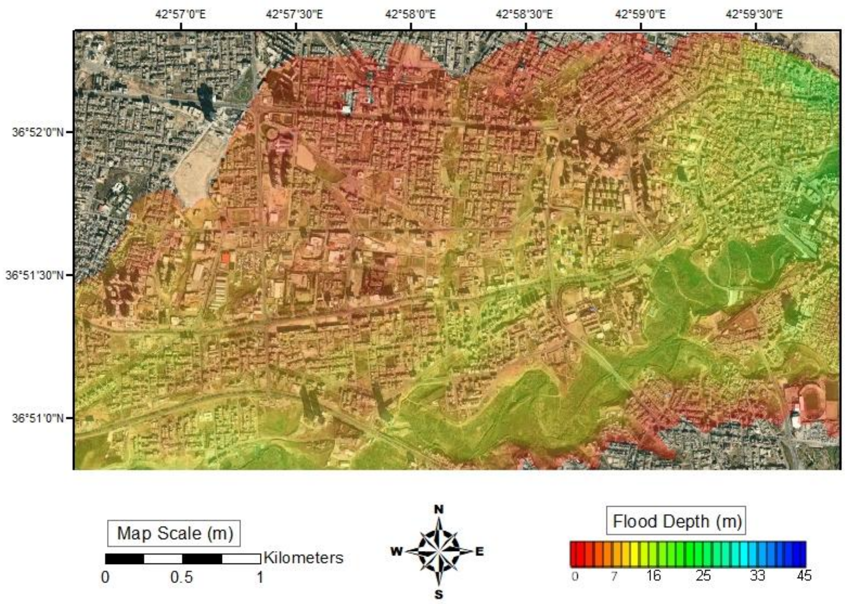

Figure 5. Right inundation area of Duhok River at Duhok city.

The maximum flow analysis, Figure 6 indicates a maximum discharge of 54,772 m^3/s at the dam outlet, which decreases progressively downstream; at 0.84 km, the flow reduces to 40,977 m^3/s, at 8.82 km, it drops further to 24,282 m^3/s, and at 26.86 km, the lowest recorded flow is 15,896 m^3/s.

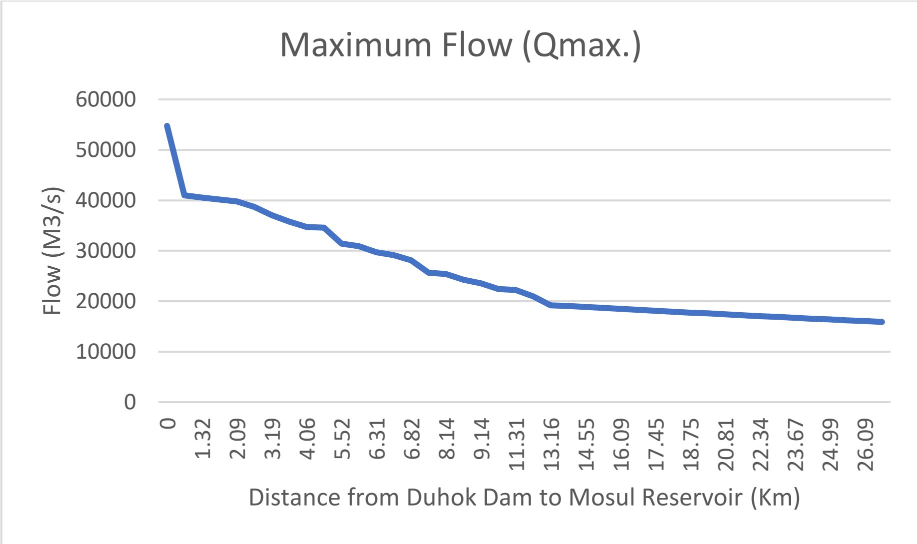

Figure 6. Maximum flow simulated between Duhok Dam and Mosel Reservoir.

The riverbed elevation profile Figure 7 shows a decreasing trend from 562.7 m at the dam outlet to 323.3 m at 26.86 km downstream. Correspondingly, the maximum water elevation decreases from 604.35 m to 333.02 m, while flood depth varies between 41.65 m at the dam and 9.62 m in downstream areas.

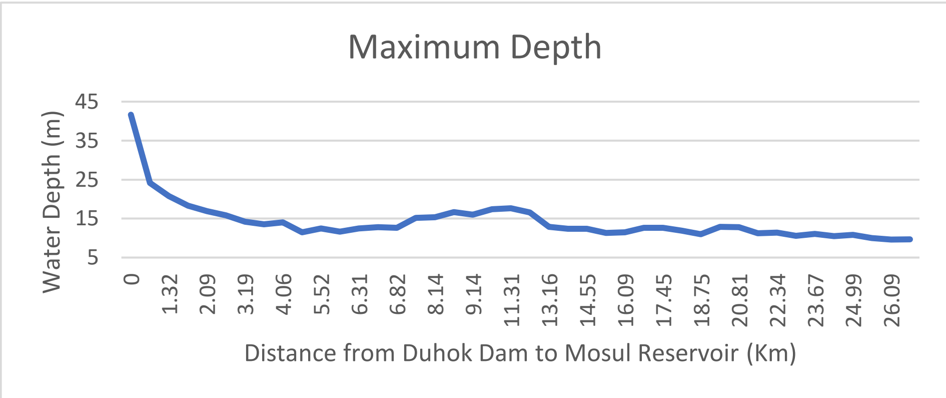

Figure 7. Maximum Depth of water simulated between Duhok Dam and Mosel Reservoir.

The flood travel time analysis Figure 8 reveals a rapid propagation pattern; the flood reaches its maximum depth at the dam outlet in 18.2 minutes, at 5.52 km, the maximum depth is reached in 51 minutes, at 13.89 km, peak flooding occurs in 100.2 minutes, and at 26.86 km, the maximum water level is attained in 132 minutes. The total inundation area across the study domain is extensive, covering multiple districts and infrastructure, with considerable risk to urban settlements.

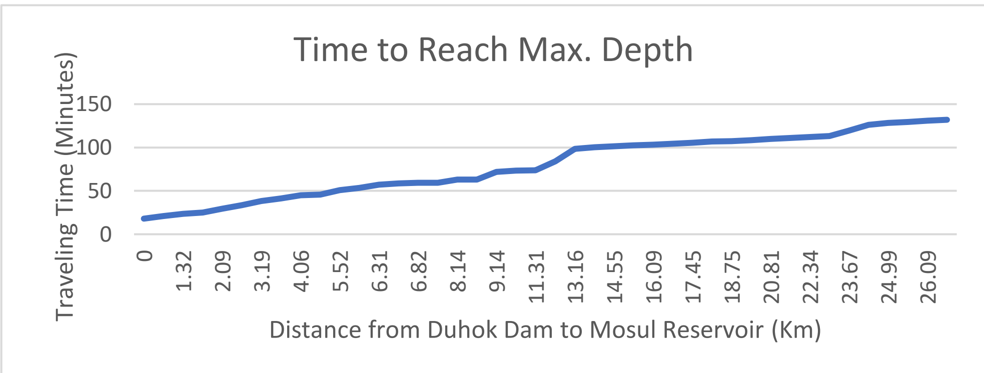

Figure 8. Travelling Time of flood between Duhok Dam and Mosel Reservoir.

The simulated flood elevation profile (Figure 9) illustrates the gradual decrease in flood depth along the river course, correlating with topographic changes and hydraulic resistance.

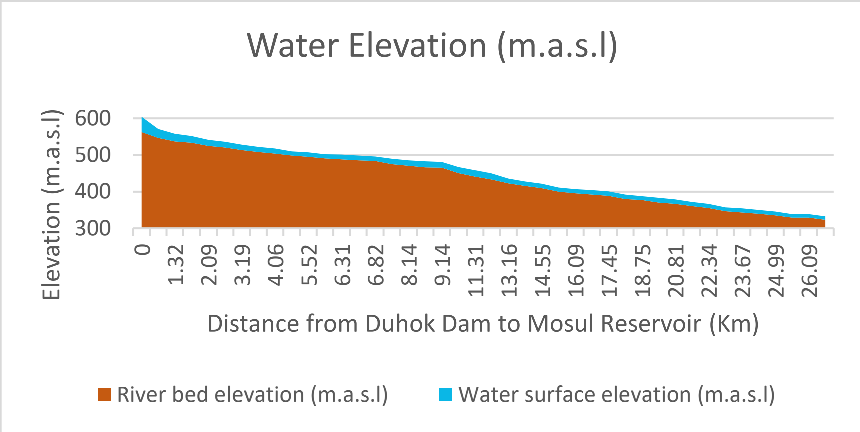

Figure 9. Flood Elevation between Duhok Dam and Mosel Reservoir.

3.1 Life losses

Graham in 2001 proposes an important way to evaluate and anticipate the life loss resulted from failure of dams, depending on numerous dam break cases in the United States of America, which reached to 40 dams. As showed in Table 3, the planners first decide on the severity of the flood at 1st column and then at 2nd column the planners select the suitable time of warning and then in the 3rd column the planners analyze realization of the risk level of the flood. The 4th one shows the fatality rate of the suitable range, which gives the number of deaths. The given calculations give an important guideline that can be utilized when emergency action plans are prepared.

The death from dam break indirectly caused by illness or injury, such as hearts attacks during the evacuation process but also directly caused by flash flood as well (Ayyub, 2003). Repeated warnings before dam failure and social media network usage in communicating and disseminating information is crucial during the critical time **[22]** and it can assist in giving a solution in dangerous situations. These warnings may help for minimizing fatality rate and increasing evacuation rates.

Table 3. The death estimation at to dam break [20]

Flood risk level	Time of Warning (Min.)	Flood Risk Understanding	Death rates (People at risk of death)	
			Suggested	**Suggested range**
HIGH	**No warning**	**Not applicable**	**0.75**	**0.3 to 1**
	15 – 60 min.	**Vague**	**Use these rages, when a number of people remain in the inundation area after warning**	
		Precise		
	> 60 min.	**Vague**		
		Precise		
MEDIUM	**No warning**	**Not applicable**	**0.15**	**0.03 to 1**
	15 - 60 min.	**Vague**	**0.04**	**0.01 to 0.08**
		Precise	**0.02**	**0.005 to 0.04**
	> 60 min.	**Vague**	**0.03**	**0.005 to 0.06**
		Precise	**0.01**	**0.002 to 0.02**
LOW	**No warning**	**Not applicable**	**0.01**	**0 to 0.02**
	15 – 60 min.	**Vague**	**0.007**	**0 to 0.015**
		Precise	**0.002**	**0 to 0.004**

> 60 min.	Vague	0.0003	0 to 0.0006
	Precise	0.0002	0 to 0.0004

Flood risk level: depends on the distance between the place under risk and the dam location.

Flood Risk Understanding: in the case of not applicable, there is no understanding of flood risk either because of short breach time or lack of warning time.

Death rates: depends on the time of dam break, whether it is at day or night, for night dam failure, the high fatality rate is suggested, because in the past all night dam failures had a lot of damages.

The 3rd table is utilized to anticipate people at risk for Duhok City and the nearby Districts below and around it, during the Duhok dam failure on the day time.

Solution:

The total population at Duhok city and the districts below and around it near to Hishkaroo Revir is about 350,000 individuals, and the populations at risk are 29,500 persons, as shown in Table 4.

Time to reach maximum flood depth from the Dam to the length of (3.65 Km), which is nearly at Duhok City Centre, is 41.4 minutes.

Table 4. Fatality rate calculations for Duhok City Centre (District)

District	Flood risk level	Warning Time (Min.)	Understanding of Flood risk	Death rate	Population at Risk	Death expectation
Duhok City	High	More than 60	Precise	0.5	29,500	14,750

A fatality rate of 0.5 is assumed, attributable to the heavy traffic congestion and the prevalence of old-style buildings in the Sarhaldan and Gri-Basse districts.

So, **Total losses of life = 14,750 persons**

3.2 Evacuation and emergency plans

In any dam break catastrophe, the coordinated execution of evacuation plans is critical to reduce the loss of life and property damage. Due to the severity and sudden failures of the dam, local authorities must have clear and well-defined evacuation procedures that are up-to-date and practiced. These plans and procedures should specify the high-risk areas, clearly marked escape routes, and organized transportation for timely evacuations.

Well-trained and equipped emergency response teams (including civil defense and rescue units) are essential to assist the affected population. The evacuation plans must identify safe shelters, adequate resources (like food, water, and medical supplies), and guarantee the availability of reliable transportation, especially for individuals in hard-to-reach areas **[23].**

The actionability of any evacuation plan rely on strong communication and collaboration between local agencies, authorities, and the public. it is important to have real time information ways (such as emergency siren alerts and SMS) to inform folks of a nearby threat. Also, emergency plans should include post evacuation strategies for an efficient evacuation procedure.

Finally, it is crucial that these procedures and plans are frequently updated, and reviewed to consider any changes in, density of the population, emerging risks, and infrastructure **[24, 25].**

4. Conclusions

This case study represents a comprehensive analysis of Duhok dam break scenario, using numerical simulation model consist of Saint-Venant's equations to assess and evaluate the dam failure results. The results show the effect of flood waves, breach formation, and downstream influence of the flood simulation.

With an awareness of the risks of dam failure, the key findings of this study indicate the necessity of having early warning systems, infrastructure safety assessments, and real-time monitoring to mitigate any disaster resulting from dam failure. Another careful thought to take in to the consideration for modelling any dam break scenario is climate change, for exacerbate flood risks. Furthermore, the simulation results indicate that effective emergency response strategies and evacuation planning can significantly decrease damages and property losses.

To better reduce and protect infrastructure damages and human lives from policymakers, catastrophic dam failures, and disaster management authorities must study and plan these aspects for a dam safety.

5. Recommendations

It is recommended to use better resolution DEM data (5 x 5 m, cell size) instead of the currently used freely accessible (15 x 15 m, cell size resolution), to improve the depth predictions and accuracy of flood extent. In addition to operate largely automatic equipment sensors connected to a dynamic hydrological data center to strength early warning capabilities and response time to the people locating downstream of the dam. Also, regular structural inspections and maintenance of the dam body are important to prevent potential failure. Finally, an affective mitigation strategy should be developed and be ready for implementation, including evacuation planning and early warning systems based on hazard zones along downstream of the Duhok dam.

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