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Modified Method for Estimation of Total Risk Factor (TRF) for Selected Dams in Iraq

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Keywords:
Dam overtopping; Risk factors; Scenarios; TRF; Risk class.

Highlights:

- *Risk factors for dams and associated infrastructure should include all hazard elements.*
- *The USBR method evaluates the dam's structural impact despite the absence of historical data.*
- *The USBR method is one of the qualitative approaches that based on the dam features, such as type, age, and size besides the potential risk downstream.*

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Abstract: The main objective of the present study is to determine the risk class of Haditha and Hemrin Dams The weighting points for various risk factors of the selected dams were substituted in Eq. (5) to find the TRF of each dam. For the studied dams, the data related to various risk factors was collected from the State Commission of Dams and Reservoirs (SCODR), Iraq. The studied dams are outside the seismic zone, and flood is considered the main hazard that makes the dams vulnerable to overtopping. Three scenarios that considered different water levels in Haditha and Hemerin Dams reservoirs were analyzed. In the worst scenario, the water levels in the reservoirs of both dams were taken more than the flood control level (152.2 m.a.s.l in the reservoir of Haditha Dam and 107.5 m.a.s.l in the reservoir of Hemrin Dam). The calculated TRFs for the worst scenario were 168 and 216 for Haditha Dam and Hemrin Dam, respectively. The rating for both TRFs showed that the risk category is high (class Ill). The modified method is a simplified method dam engineers use to easily classify a dam's total risk.

طريقة مطورة لتخمين معامل الخطر الكلي لسدود مختارة في العراق

علياء جمعة هادي، ثامر احمد محمد
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الخلاصة
الهدف الرئيسي من هذه الدراسة هو تحديد فئة المخاطر لسدي حديثة وحمرين بشكل منفصل. تم استبدال نقاط الترجيح لعوامل الخطر المختلفة للسدود المختارة في المعادلة. (٥) لايجاد معامل الخطر الكلي لكل سد. بالنسبة للسدود المدروسة، تم جمع البيانات المتعلقة بعوامل الخطر المختلفة من الهيئة العامة للسدود والخزانات، العراق. تقع السدود المدروسة خارج المنطقة الزلزالية ويعتبر الفيضان هو الخطر الرئيسي الذي يجعل السدود عرضة للانهيار. تم تحليل ثلاثة سيناريوهات أخذت في الاعتبار مستويات المياه المختلفة في خزاني سدي حديثة وحمرين. وفي أسوأ السيناريوهات، تم أخذ منسوب المياه في خزاني كلا السدين أكثر من مستوى السيطرة على الفيضانات (١٥٢,٢ متر مكعب في خزان سد حديثة و١٠٧,٥ متر مكعب في خزان سد حمرين). وقد وجد أن معدلات التركيز المستهدفة المحسوبة للسيناريو الأسوأ هي ١٦٨ و٢١٦ لسد حديثة وسد حمرين على التوالي. أظهر تصنيف كل من معاملات الخطر الكلية أن فئة المخاطر المرتفعة هي (الفئة رقم ٣). الطريقة المعدلة هي طريقة مبسطة يمكن أن يستخدمها مهندسو السدود لتصنيف المخاطر الكلية للسد بسهولة.

الكلمات الدالة: تجاوز المياه منسوب قمة السد، عامل الخطر، سيناريوهات، معامل الخطر الكلي، فئة المخاطر.

1.INTRODUCTION

Risk is defined by the Canadian Standards Association [1] as the potential for injury or loss as measured by the probability and seriousness of an adverse effect on health, property, the environment, or other valuable assets. The total risk for dams and associated infrastructures should include all the hazard elements. The sources of dam risk can be categorized as structural, geotechnical, and dam site factors. The structural or geotechnical factors included settlement, internal erosion, leakage, and seepage, while the dam site factors included seismic activity, rockfall, and landslides [2]. According to the Intercontinental Command on Large Dams [3], the type of dam is one of the important parameters affecting the total risk ratio associated with the safety of a dam susceptible to earthquakes. The earthquake may result in loss of dam foundation strength and high soil and embankment material deformations. Furthermore, flooding and overflows are the energetic factors in dam overtopping. It is a significant and influencing overall risk that accounts for around 35% of all earth dam failures caused by overtopping, seepage, and leakage, while other reasons account for the remainder [4]. The Total Risk Factor (TRF) was first used to describe dam risk due to seismic activity; however, the method was improved and developed by (USBR) to evaluate dam risk due to other additional factors [5]. Many studies have been conducted worldwide on dam risk analysis and related factors. Kuo et al. [4] studied the risk of a Dam's overtopping in the context of the inspection program. They determined the optimal amount of time between dam checks by considering the risk due to overtopping while integrating the uncertainty of gate availability, the number of malfunctioning spillway gates, the availability of the gates, and the scheduling of the dam inspection. The findings indicated that the overtopping risk with the availability of spillway gates was higher than the overtopping risk without such gates. Tosun and Seyrek [6] studied the complete risk assessments for dams with large water reservoirs in the Kizilirmak basin, Turkey. They used two methods to analyze the total risk: ICOLD and USBR. The assessment was based on the seismic risk rating of the dam's site, and the results revealed that 23 out of 36 large dams in the Kizilirmak basin were within the high-risk class. Al-Geelawee and Mohammed [7] examined and reviewed the requirements of Total Quality Management (TQM) and risk management in Iraqi construction projects. In addition, open and closed questionnaires were used to get feedback from construction specialists on risk management in Iraqi construction projects. The results showed the possibility of armed conflicts, design flaws, project management problems, and underqualified workers. Aleqabi and Ghalib [8] studied seismic hazard assessment of northern Iraq. Probabilistic Seismic Hazard Analysis (PSHA) was utilized to assess the likelihood of surpassing average ground motion in the region. The Zagros and northeastern regions of Iraq have the highest potential for seismic hazards. The west and south of the northern Mesopotamian Valley has the least seismic risk. The comparison between the acquired data and the results of seismotectonic models applied for Iraq revealed that the distribution of current regional earthquakes was in agreement with that obtained from the seismotectonic models. Adamo et al. [9] studied the risk management concepts in dam safety evaluation, taking the Mosul Dam as a case study. Characterizing potential failure modes, assessing the likelihood that will occur, and predicting the potential categories of repercussions were the cornerstones in the risk analysis and decision-making. The results showed that the risk management study of Mosul Dam identified the technical flaws as well as the most likely watercourse that would result in case of the dam failure. It also assessed the potential consequences of the dam failure and recommended a mitigation plan. Shadhar and Mahmood [10] studied risks at the design stage for Iraqi construction Projects and their impact on construction projects. They found that the design stage significantly impacted lump sum project contracts compared with unit price projects. However, the timely preparation of design documentation by the design team has optimized the workflow and has been found to have the most significant impact on projects. Ghali and Azzubaidi [11] studied the possible risk of the Diyala River flood. The risk management was based on flood modeling based on a flood wave of 1500 m^3/s that may be released from Hemrin Dam. The risk posed by the flood wave to the downstream development is highlighted based on the flood inundation maps. Sadettin and Hasan [2] studied an overview of total risk classifications for dams in Turkey since dams pose a serious risk to downstream development and public safety. They reviewed two methods for total risk assessment: the US Bureau and ICOLD. The risk categorization in ICOLD considers structural aspects only, whereas the Bureau method considers the local conditions at which the dam would be built. Joni [12] identified the risk factors affected by traffic on the Baghdad Expressway. The SPSS program (version 25) and the binary logistic regression model were employed. The results showed that the risk factors were affected by road conditions, parking on a highway, high speed and losing control, paying attention, halting suddenly, driving distractedly, and vehicle body type. Marwa and Altaie [13] studied using the Risk Score Method (RSM) to identify the qualitative criteria for risk analysis in the tendering phase of Iraqi construction projects. Combining probability and impact criteria created a risk matrix to identify the main risk factors for a construction project at a tender phase. Ultimately, 22 sub-risk variables were found. They recommend that the major crucial risk groups were technical, contractual, management, and political. Mhmood et al. [14] simulated the flood wave resulting from the breach or overtopping of the Haditha Dam. The flood wave movement in the Euphrates River and the affected downstream development were simulated using the ArcMap 10.2 and HEC-RAS 5.0.7 models. The simulation results showed the inundated map with affected areas downstream. In addition, the flood wave's maximum flood width, depth, and maximum speed were prepared for the studied areas. The results were used to prepare an emergency action plan to reduce the risks to human lives and the economy.

2. METHODOLOGY

2.1. The Case Study

In this study, two zoned large earth dams in Iraq were selected to assess their safety against failure due to overtopping or breach. The first selected dam is Haditha Dam, while the second is Hemrin Dam. The category of the risk level for each of the selected dams was defined by a factor called Total Risk Factor (TRF). Haditha Dam is the second-largest hydroelectric dam in Iraq. It was constructed on the Euphrates River in Al-Anbar governorate, Iraq, between 1977 and 1987. The dam is about 40 km from Anah City and 120 km from the Syrian border [15]. The main purposes of the dam are to generate electricity, regulate the flow of the Euphrates River, and supply water for irrigation [16]. The dam's crest width is 20 m with an elevation of 154 m.a.s.l (above sea level), while the total length of the dam is 8.7 km. The normal operation level in the dam reservoir is 147 m.a.s.l, with a storage capacity of approximately 8.2×10^9 m^3. The dam core includes an asphaltic concrete cutoff, while the upstream and downstream slopes of the dam are protected by a reinforced concrete slab revetment and a rock-mass revetment, respectively [17]. Hemrin Dam is an important strategic dam in Iraq. It is constructed on the Diyala River, about 120 km northeast of Baghdad [18]. The main purposes of the dam are to control the frequent floods in the Diyala River during the rainy season and to produce power. The discharge capacity for all gates, when the water level is at an elevation of 104 m.a.s.l (normal water level), is estimated to be 2.4×10^9 m^3. The dam core was constructed from hard clay, while the dam's upstream face is protected against waves and rain by pre-cast concrete blocks [19]. Figure 1 shows the locations of the studied dams.

2.2. Method for Estimation of Total Risk Factor (TRF) for a Dam

The Total Risk Factor (TRF) of a dam is an important factor used to categorize the degree of the dam risk. The category of a dam risk class is determined based on the TRF's total estimated weighting points. The TRF's estimated total weighting points depend on dam features for structural description (type, age, and size), risk potential for downstream, and dam vulnerability. The TRF is described by the following equation [21].

$$\boldsymbol{TRF = (S + D)\theta} \qquad \textbf{(1)}$$

where S is the weighting points of dam structure description risk, D is the weighting points of risk description for downstream socio-economic development, and θ is the weighting points due to predicted flood damage. However, weighting points of the dam structure description risk are affected by the dam's capacity, height, and age. The following equation is used to determine the weighting points due to the structural risk of a dam.

$$\boldsymbol{S = C + H + A} \qquad \textbf{(2)}$$

where C is the weighting points due to dam capacity risk, H is the weighting points of dam height risk, and A is the weighting points of dam age risk. The weighting points of the structural description risk, such as C, H, and A, can be determined from Tables 1 and 2 [21]. However, Table 1 shows that the weighting points for C and H are identical.

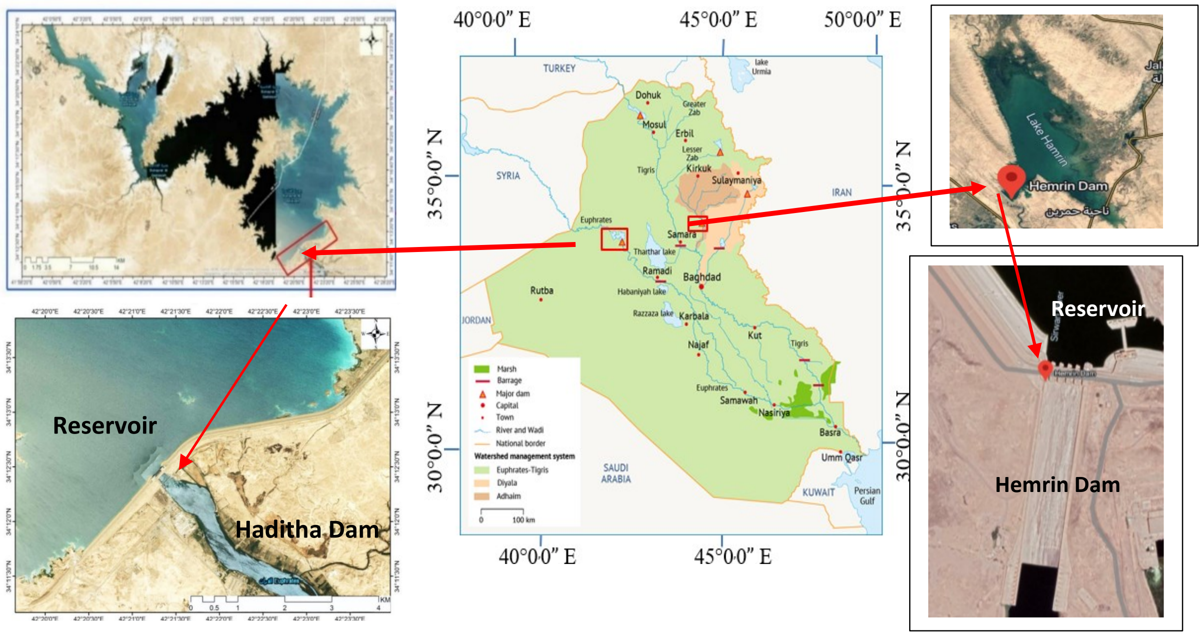

Fig. 1 Location of Haditha and Hemrin Dams on the Map of Iraq.

Table 1 Weighting Points of the Dam Structure Description Risk [21].

Type of Dam Structural Risk	Dam risk class			
	Extreme	High	Moderate	Low
Dam capacity, C (10^4 m^3)	>6170	6170–123	123–12.3	<12.3
Dam height, H (m)	>70	70–30	30–15	<15
Weighting Points	6	4	2	0

Table 2 Weighting Points of the Dam Age Risk [21].

Risk Class	Extreme	High	Moderate		Low	
Year of construction	<1900	1900–1925	1925–1950	1950–1975	1975–2000	>2000
Weighting points of dam age risk *(A)*	6	5	4	3	2	1

However, Eq. (3) is used to determine the weighting points that describe the dam risk due to downstream socio-economic development (D) [21].

$$D = P + G \qquad (3)$$

where P is the weighting point of population density, and G is the weighting point of gross domestic product density. Table 3 is used to determine the weighting points of P and G for a dam. However, Table 3 shows that the weighting points for P and G are identical. The flood damage factor (θ) for a dam can be determined using Eq. (4) [21].

$$\partial = R + Z \qquad (4)$$

where R is the weighting point due to flood damage, and Z is the weighting point due to flood zoning.

Table 3 Weighting Points of Risk Description for Downstream Socio-Economic Development [21].

Risk description	Dam risk class			
	Extreme	High	Moderate	Low
Population density, P(person/km^2)	>500	500–100	100–10	10–0
Gross domestic product density, G (ID/km^2)	>185x10^6	185x10^6–73x10^6	73x10^6–18.25x10^6	18.25x10^6–0
Weighting points	12	8	4	1

Table 4 shows the weighting points for R, while Table 5 shows the weighting points for Z. Figure 2 shows the water levels in a dam reservoir that should be compared with the possible key water levels that may occur in the reservoirs for the studied dams to determine placement danger classifications. Figure 2 shows the water levels in a dam reservoir that should be compared with the possible key water levels that may occur in the reservoirs of a dam to determine placement danger classifications. However, the key water levels in Fig. 2 are the dam height (DH), the design flood level (DFL), the check flood level (CFL), the upper water level for flood control (UL), the normal water level (NL), and the flood control level (FCL). The weighting points in Table 5 are given for several reservoir water level conditions, including water level >DH, water level between CFL and DH, water level between DFL and CFL, water level between UL and DFL, and water level between FCL and NL. After substituting Eqs. (2), (3), and (4) into Eq. (1), the final equation for TRF is shown below:

$$TRF = (C + H + A + P + G)(R + Z) \qquad (5)$$

In this study, Eq. (5) is modified to estimate the TRF for dams at the risk of overtopping or breach. After the weighting points of *C*, *H*, *A*, *P*, *G*, *R*, and *Z* are determined from Tables 1-5, the TRF of a dam can be estimated from Table 6. The ranges of TRF with the related risk classes or categories can be determined from Table 6.

A dam risk ranges from low-risk class (class I) to extreme risk class (class IV). The steps of the methodology for determining TRF for Haditha and Hemrin Dams are summarized in a flow chart, as shown in Fig. 3.

Table 4 Weighting Points Due to Flood Damage Rating for Various Dam Types [21].

Dam Type	Dam Type Indicator	Weighting points for Flood Damage Rating (*R*)
Concrete Arch, Gravity Arch	1	1
Multiple Arch, Arch Buttress	1	3
Concrete Gravity	2	2
Concrete Gravity Buttress	2	3
Masonry	2	4
Timber Crib	Not Assigned	4
Earthfall, Composite	3	3
Concrete Face Rockfill	4	1
Earth Core Rockfill	4	2
Hydraulic Fill, Tailing	5	6
Unknown or unidentified	6	5

Table 5 Weighting Points of Flood Zoning for Different Reservoir Water Levels (WL) [5].

Category	Dam risk class					
	Extreme	High	Significant	Moderate	Low	Very Low
Reservoir Water Level, WL	>DH	CFL~DH	DFL~CFL	UL~DFL	NL~UL	FCL~NL
Weighting Points for Flood Zoning, *Z*	6	5	4	3	2	1

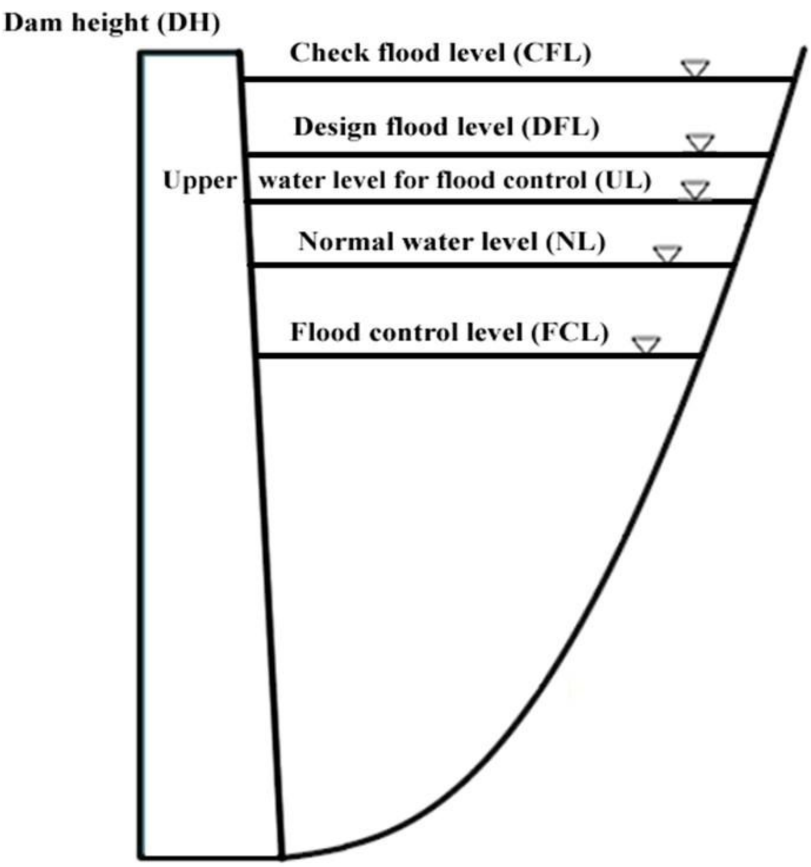

Fig. 2 The Sketch Profile of Key Water Levels for a Dam [5].

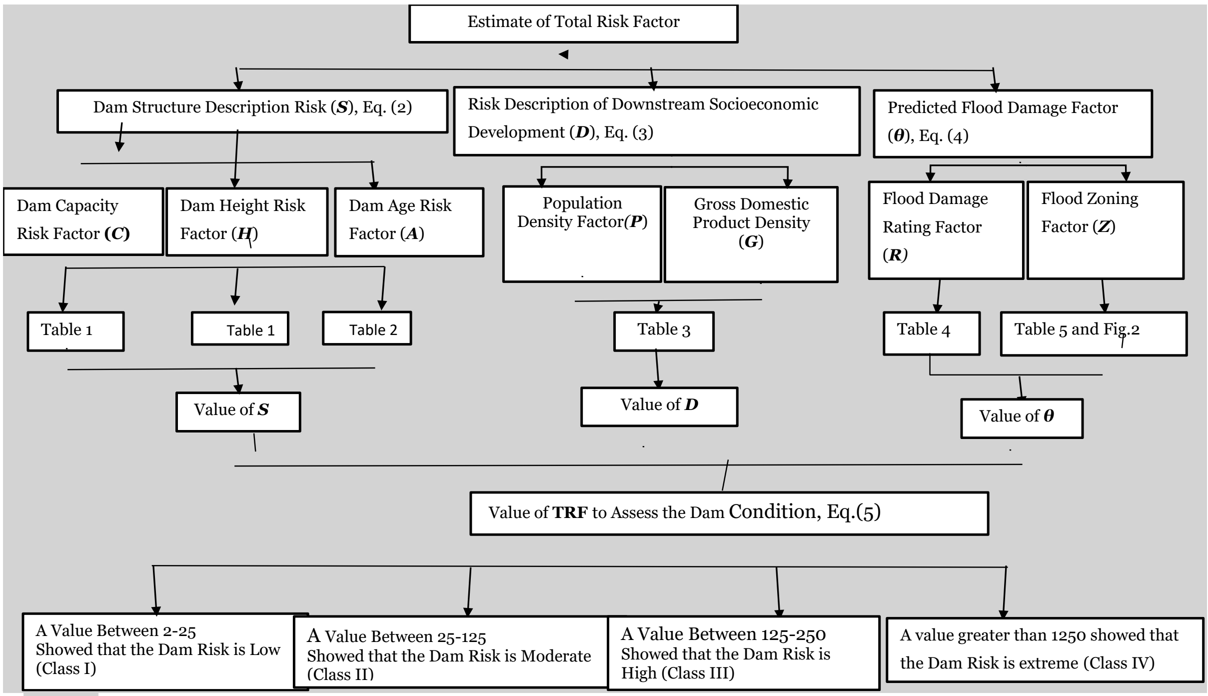

Fig. 3 Flow Chart Summarizes the Methodology Used to Determine the TRF Class for Haditha and Hemrin Dams.

Table 6 Definition of Dam Risk Class [21].

Total Risk Factor (TRF) of a Dam	Dam Risk Class
2–25	I (low)
25–125	II (moderate)
125–250	III (high)
>250	IV (extreme)

3.RESULTS AND DISCUSSION

Many procedures for quantitative analysis of the total risk of dams vulnerable to overtopping or breach were proposed. The procedures are either based on probabilistic risk analysis that requires extensive historical records to solve complex nonlinear problems or on analyzing risk rating indicators obtained directly from equations and Tables. The well-known ICOLD method depends on rating the total risk after separately evaluating the seismic hazard of a dam site and dam structural risk [3]. However, the United States Bureau of Reclamation (USBR) proposed a factor called total risk factor (TRF) that combined the seismic hazard from a dam site with the risk from the dam structure. Chen and Lin [5] modified the USBR method and used it to assess the risk of dams vulnerable to flood in China. In this study, the modified method was applied to rate the risk due to the failure of the Haditha and Hemrin Dams in Iraq by overtopping since the dams are outside the seismic zone, as shown in Fig. 4**.** The modified method requires the determination of the total risk factor (TRF) of dams vulnerable to overtopping by knowing the weighting points of each factor included in Eq. (5). However, the risk factors included in Eq. (5) are dam capacity (*C*), Dam height (*H*), dam age (*A*), population density at downstream (*P*), downstream gross domestic product density (*G*), flood damage (*R*), and flood zoning (*Z*). Figure 3 summarizes the methodology used for this purpose. After determining TRF for Haditha and Hemrin Dams, Table 6 is used to rate the risk class of each dam. Figures 5 and 6 show the various capacities of the reservoirs of Haditha Dam or Hemrin Dams affected by the rise or drop in water levels.

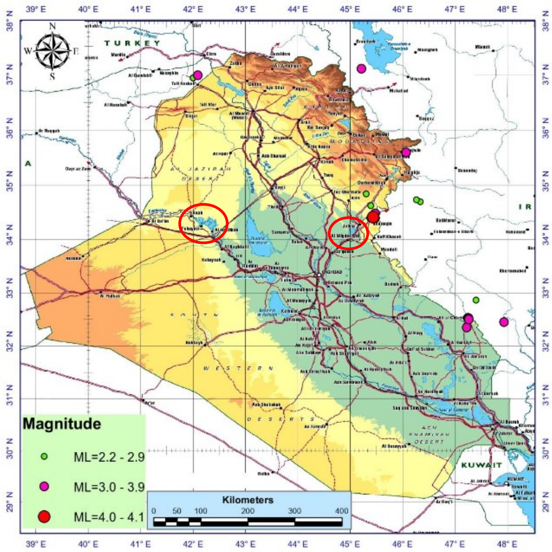

Fig. 4 The Seismic Map of Iraq [22].

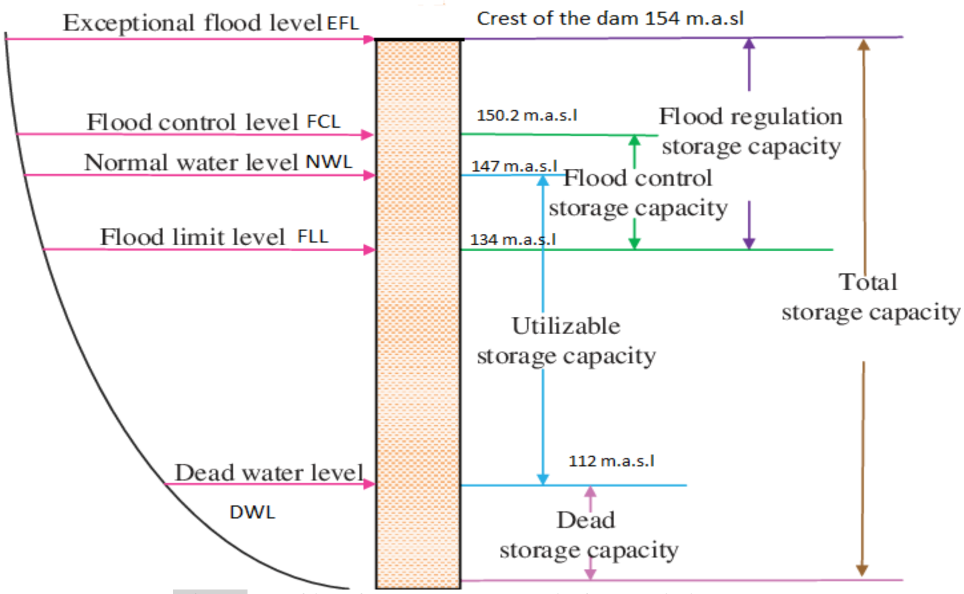

Fig. 5 Profile of Key Water Levels for Haditha Dam.

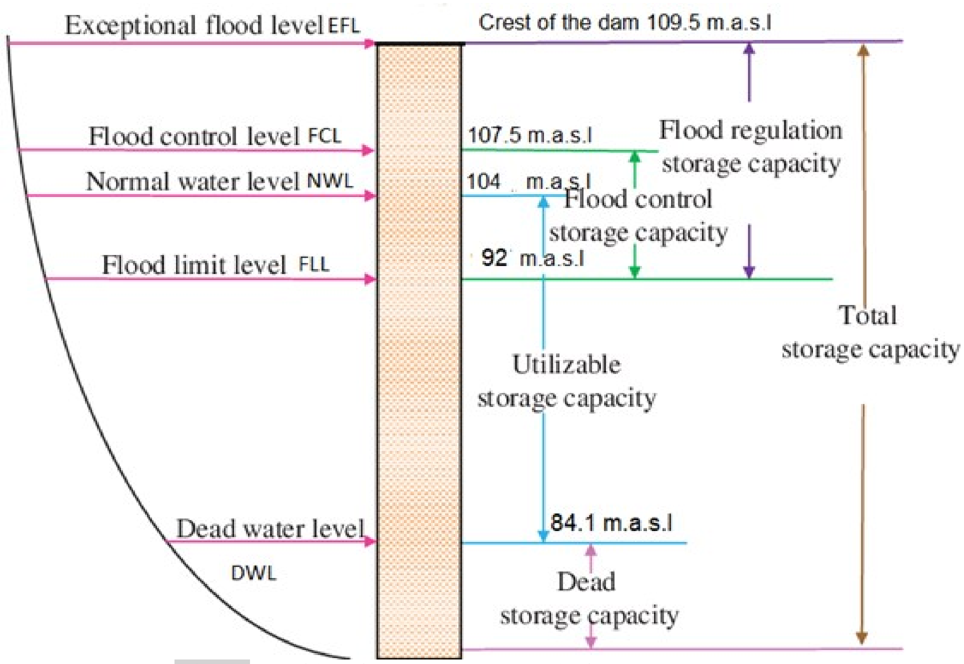

Fig. 6 Profile of Key Water Levels for Hemrin Dam.

3.1.The proposed Scenarios

In Eq. (5), the dam capacity (*C*) and flood zoning (**Z**) are the only risk factors affected by various water levels in a dam reservoir. However, other risk factors are not affected. In this study, the collected data on water levels in the reservoirs of Haditha and Hemrin Dams are shown in Figs. 5 and 6. Scenarios for various water levels that may occur in the reservoirs of the above dams were considered since they directly affect TRF. Table 7 shows the scenarios' water levels, dam capacities, and weighting points. For the first scenario, the water level in the reservoirs of the above dams was assumed between flood limit level (FLL) and normal water level (NWL). For Haditha Dam, the collected Data showed that the FLL and NWL were 134 and 147 m.a.s.l, respectively. While for Hemrin Dam, the FLL and NWL were 92 and 104 m.a.s.l, respectively. In the second scenario, the water level was assumed to be between normal water level (NWL) and flood control level (FCL). Data showed that the flood control level (FCL) in Haditha and Hemrin Dams reservoirs were 150.2 m.a.s.l. and 107 m.a.s.l., respectively. However, in the third scenario, the water level in the reservoirs of the selected dams was assumed to be greater than the flood control level. For all scenarios and based on the weighting points of the capacity risk factor (*C*), the risk class for the studied dams was extreme, as shown in Table 7. On the other hand, the weighting points for the flood zoning factor (*Z*) for the selected dams were very low, low, and moderate for the first, second, and third scenarios, respectively. For various scenarios, Tables 1 and 5 were used to determine the weighting points for the capacity risk factor and flood zoning factor, respectively. In the case of the overtopping of Haditha Dam, the downstream cities inundated by the flood are Haditha, Al-Baghdadi, Heet, Al-Ramadi, Al-Fallujah, and Al-Hinduja. These cities' average downstream population density was estimated to be 366 persons/km². The overtopping of the Hemrin Dam caused the inundation of many cities downstream, such as Baqubah, Muqdadiya, South of Baghdad, and Al-Essaouira. The average population density for these cities was estimated to be 600 person/km² [23], confirming that the population density of cities located downstream of Hemrin Dam is greater than that of the cities located downstream of Haditha Dam. According to Table 3, the weighting points for the risk description of socio-economic development (*P*) downstream of Haditha Dam were 8 (rated as high). While the weighting points for the risk description of socio-economic development (*P*) downstream of Hemrin Dam were 12 (rated as extreme).

Table 8 shows the weighting points of the risk factors considered in the safety assessment of Haditha and Hemrin Dams under FCL. For Haditha and Hemrin Dams, the weighting points for *C*, *H*, *A*, *R*, and *Z* used to determine the TRF risk class were identical. However, the weighting points for *P* and *G* used in the determination of the risk class of TRF were identical for the same dam. For example, the weighting points for *P* and *G* for Haditha Dam were 8 (the class risk is rated as high), while the weighting points for the same risk factors of Hemrin Dam were 12 (the class risk is rated as extreme). The difference in weighting points of *P* and *G* for Haditha and Hemrin Dams can be attributed to the difference in population density and estimated flood damage at the downstream cities, as shown in Table 8. Table 9 shows that the weighting points for the total risk factors for Haditha and Hemrin Dams were 168 and 216, respectively. According to Table 6, a dam class risk is rated as high (Class Ill) when the weighting points for TRF are between 125 and 250. Therefore, the total risk for both studied dams is categorized as high (Class Ill). Chen and Lin [5] determined the risk factor weights for six cascade dams on Dadu River, China, under two different rainfall scenarios. The results of the calculated TRF for the six dams showed that five of them were under high risk (Class Ill), while only one of them was found under moderate risk (Class Il). Figure 7 compares the TRF of the cascade dams in Dadu River, China, and that of Haditha and Hemrin Dams on the Euphrates and Diyala Rivers, respectively. The comparison showed that the calculated total risk factors for the Haditha and Hemrin Dams in Iraq agreed with those determined by Chin and Lin [5] for the five dams in China. The total risk factors for the dams in China that fall under high-risk classes ranged between 126 and 175. Figures 8 and 9 show the calculated TRFs for Haditha and Hemrin Dams due to various water level scenarios. It can be seen that the lower water levels in the reservoirs of both dams in scenario I are reflected by relatively lower TRFs; however, the risk of dams of the selected dams risk was still high (Class Ill). In addition, the TRFs for the Il and Ill scenarios were higher than Scenario I; however, the risk rating of the dams was still in the high category and Class Ill.

Table 7 The Possible Scenarios for Various Water Levels in the Reservoirs of Haditha and Hemrin Dams.

	Scenario	Range of water Level (m.a.s.l)	Range of reservoir capacity (10^9 m³)	Average reservoir capacity (10^4 m³)	Weighting points for dam capacity (*C*)	Weighting points for flood zoning (*Z*)
Haditha Dam	I Water level From (FLL) to (NWL)	From 134 to 147	3.97 to 8.2	608500	6	1
	II Water level from NWL to FCL	From 147 to 150.2	8.2 to 9.7	895000	6	2
	III Water level more than FCL	More than 150.2	More than 9.7	More than 970000	6	3
Hemrin Dam	I Water level From (FLL) to (NWL)	From 92 to 104	0.25 to 2.4	132500	6	1
	II Water level from NWL to FCL	From 104 to 107.5	2.4 to 3.95	317500	6	2
	III Water level more than FCL	More than 107.5	More than 3.95	More than 395000	6	3

Table 8 Weighting Points for Various Risk Factors for the Haditha and Hemrin Dams.

Risk Description and Unit	Values (Haditha Dam)	Weighting points	Values (Hemrin Dam)	Weighting Points	Risk Class
Dam Capacity, *C* (10^4 m^3)	970000	6	395000	6	Extreme
Dam height, *H* (m)	57	4	53 m	4	High
Dam Age, *A*	In operation since 1987	2	In operation since 1981	2	Moderate
Population Density at Downstream, *P* (Person/km^2)	366	8	600	12	High for Haditha Dam Extreme for Hemrin Dam
Downstream Gross Domestic Product Density, *G* (ID/km^2)	133 x 10^6	8	More than 185x10^6	12	High for Haditha Dam Extreme for Hemrin Dam
Flood Damage, *R*	Earth fill, Composite	3	Earth fill, Composite	3	Moderate
Flood Zoning, Z	More than 150.2 m.a.s.l (More than FCL)	3	More than 107.5 m.a.s.l (More than FCL)	3	Moderate

Table 9 Total Risk Factor and Risk Class for the Haditha and Hemrin Dams.

			Risk Class
Haditha Dam	$C+H+A+P+G$	6+4+2+8+8=28	III (High)
	$R+Z$	3+3=6	
	TRF	28x6=168	
Hemrin Dam	$C+H+A+P+G$	6+4+2+12+12=36	III (High)
	$R+Z$	3+3=6	
	TRF	36x6=216	

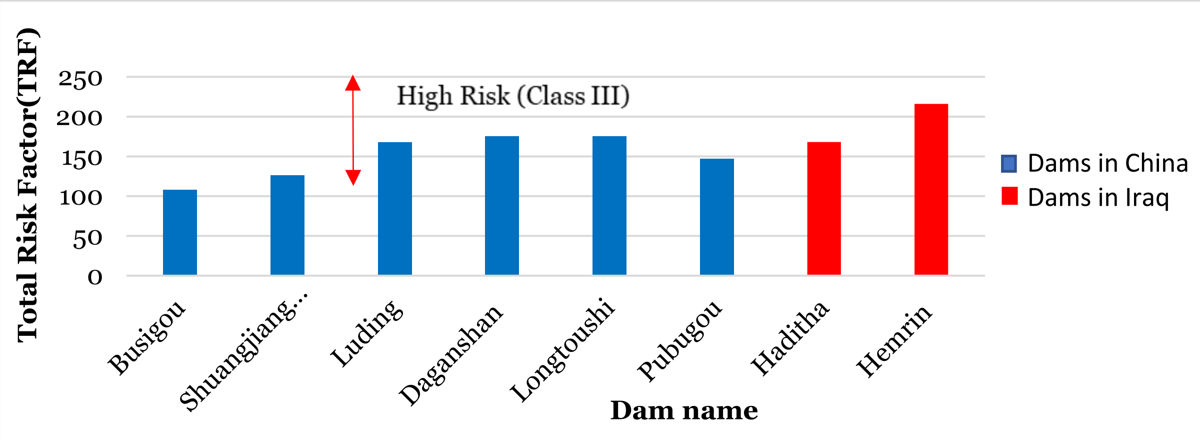

Fig. 7 Comparison between the TRF for Dams in China and Selected Dams in Iraq.

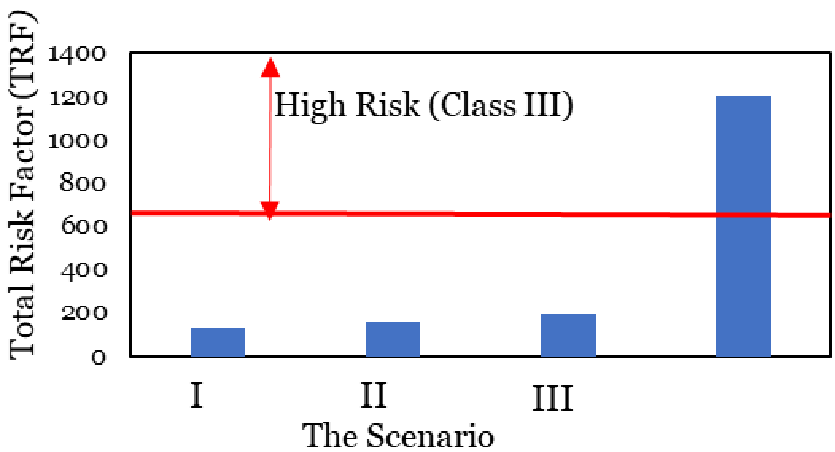

Fig. 8 The TRFs for Haditha Dam due to Various Water Level Scenarios.

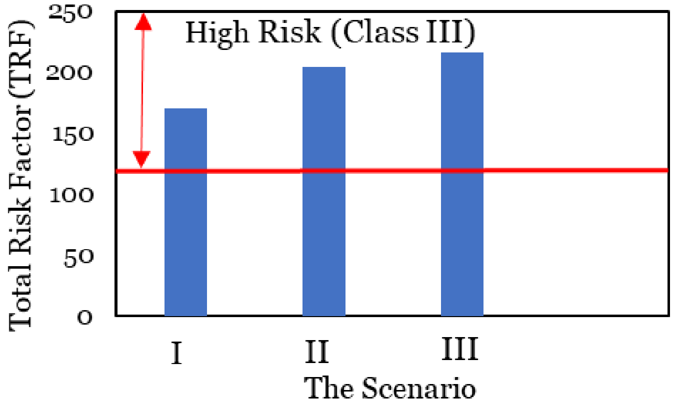

Fig. 9 The TRFs for Hemrin Dam due to Various Water Level Scenarios.

In the calculation of TRF, the modified method implicitly considered the impacts of vertical alignment and settlement in the dam age (Table 8), while the Brazilin method gave weightage to the significant presence of the cracks on the dam body and its impact of the dam safety, as shown in Table 10. The presence of cracks on the dam body can only be noticed through the surveillance and monitoring processes. For Haditha and Hemrin Dams, the surveillance and monitoring procedures include collecting data on settlement and vertical alignment from devices installed on the bodies of the studied dams and then compared with the design criteria. Samples of the data on settlement and vertical alignment are shown in Figs. 10 and 11. The design criteria for settlement and that for vertical alignment were recommended by the consulting firms. Following the recommended procedure, either by the modified method or the Brazilin method, the data on settlement and vertical alignment shown in Figs. 10 and 11 cannot be used to determine the TRF. It is worth mentioning that the periodical reports prepared by the dam administration to the central senior management authority concerning the Haditha and Hemrin dams confirmed that the dams are safe in terms of settlement, dam vertical alignment, seepage, and foundation condition.

Table 10 Consideration of Settlement in the TRF as Required by Brazilian Method [26].

Impact of Settlement Condition on Dam	Weightage
Significant presence of cracks and depressions that may lead to sinkholes, requiring additional studies or monitoring	5
The significant presence of cracks, sinkholes, or slides, with potentially compromised structural safety	8

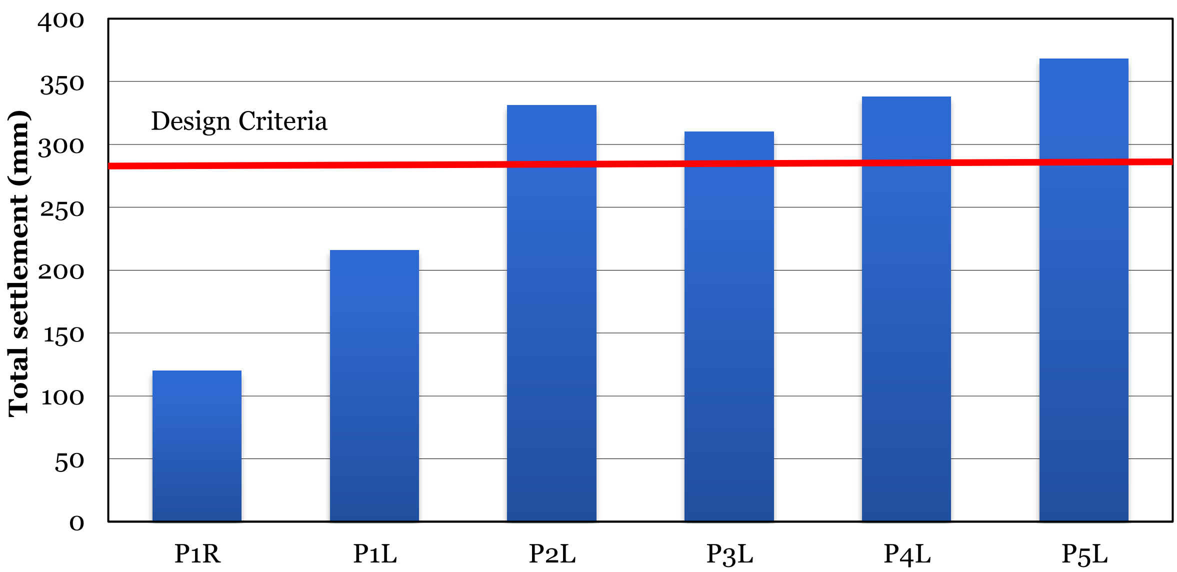

Fig. 10 Recorded Total Settlement at the Haditha Dam from 1/1/1987 to 19/11/2020 [20].

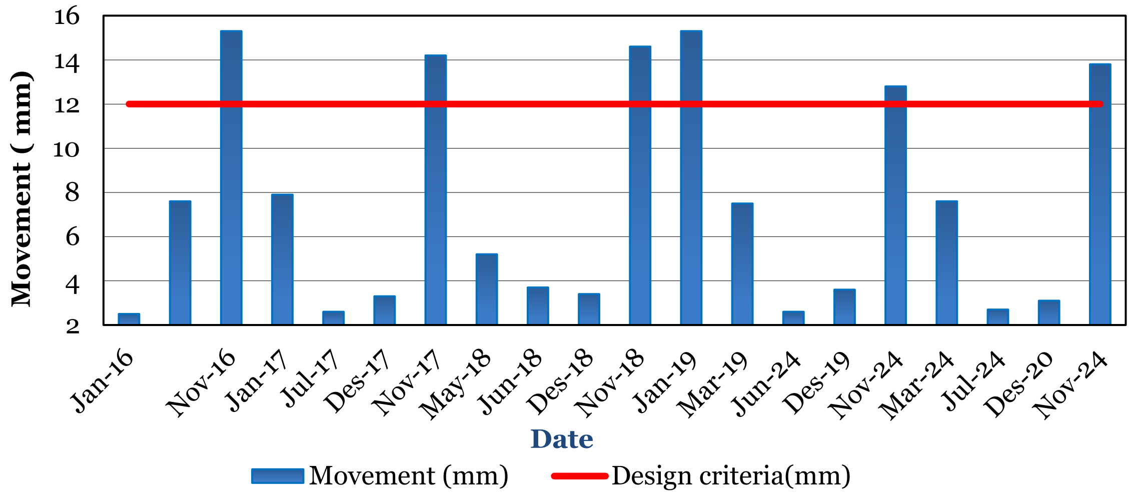

Fig. 11 Measurement of Vertical Movement at the Location of Joint Meter Installed on the body of Hemrin Dam [20].

The risk factor for seepage and piping is not considered in the modified method used to calculate the TRF for dams. However, seepage is one of the important parameters that should be considered in dam safety assessment since many dams were constructed on deep limestone beds, and seepage through these dams may cause their failure. For example, according to Abbas and Altarawne [24], the leakage through the foundation and abutments of Anchor Dam, northwest Wyoming, USA, was related to the combination of gypsum karsts, limestone karsts, and other geologic features that exist in the dam site, although only a small quantity of water has been held in the reservoir. In this study, the risk factor due to seepage or piping is not included in the calculations of TRFs for Haditha and Hemrin Dams, as shown in Eq. (5). Geologically, Haditha Dam was constructed on varying degrees of limestone beds of the Euphrates and Ana formations in the shape of fissures, cracks, and nearly isolated sinkholes. Adamo et al. [25] reported the development of sinkholes at the site of Haditha Dam. In case of the collapse of sinkholes, the dam will be subjected to the risk of failure by seepage. The existence of limestone was confirmed at the Hermrin Dam site. Currently, the Brazilian Index for dam safety assessment is the only procedure that includes weighting points for the description of seepage conditions of dams, as shown in Table 11.

Table 11 Weighting Points for Seepage in the Brazilian Index [26].

No.	Description of Dam Condition	Weighting Points for Seepage
1	Seepage is totally controlled by a drainage system	0
2	Stabilized and monitored wet areas in downstream areas, slopes, or abutments	3
3	Wet areas in downstream areas, slopes, or abutments without treatment or under investigation	5
4	Seepage emerging in downstream areas, slopes, or abutments with soil migration or increasing flow	8

However, the seepage conditions shown in Table 10 are too descriptive and subjective, and they mainly depend on visual inspection at a dam site. In addition, no clear rating analysis for the dam risk index and class was found in the Brazilin method. Conversely, ICOLD and USBR are described as indicator-based risk methods. The safety assessment used for calculating TRF for dams is described as quantitative, totally different from the surveillance and monitoring procedures followed by well-known methods, such as USBR, ICOLD, New Zealand, and Malaysia. The latter methods are focused on evaluating the values and frequency of measurement of dam safety parameters affecting a dam's stability, including geotechnical, structural, hydrological, and environmental parameters. According to the surveillance and monitoring procedures used in the Haditha and Hemrin Dams, the seepage water quality was analyzed and compared with the Iraqi Standards to check the degree of environmental pollution caused by discharging the seepage water downstream. Table 12 shows the concentrations of the Sulphates in the seepage water of Haditha Dam and Hemrin Dam. The modified and Brazilian methods do not include weightage for the impact of sulfate or other ions on the foundation of a dam. Therefore, the data on sulfate concentration in Haditha and Hemrin dams can be used to indicate its effect on the dam foundation.

Table 12 The Concentrations of Sulfates in Seepage Water of the Haditha and Hemrin Dams [20].

Concentration of Sulfates in the Seepage Water of Haditha Dam from 7/1/2020 to 15/12/2020 (mg/l)	Concentration of Sulfates in the Seepage Water of Hemrin Dam from 2020 to 2021 (mg/l)	Maximum Allowed Concentration by Iraq Standard (mg/l)
197	83	400

4.CONCLUSIONS

In this study, a modified method for calculating the total risk factor (TRF*)* for dams vulnerable to overtopping was applied to assess the risk rating of Hadith and Hemrin Dams. Three scenarios that consider different possible water levels in the reservoirs of the selected dams were tested. In the worst scenario, the water levels in the reservoirs of both dams were taken more than the flood control level (152.2 m.a.s.l in the reservoir of Haditha Dam and 107.5 m.a.s.l in the reservoir of Hemrin Dam). The calculated TRFs for the worst scenario were 168 and 216 for Haditha Dam and Hemrin Dam, respectively. The rating for both TRFs falls in the high-risk category (class III). However, the risk rating for the other two scenarios was also high (class III), although the water levels in the reservoirs of the selected dams were lower. The risk rating for Haditha and Hemrin Dams agreed with that found for cascade dams constructed on Dadu River in Chania. Notably, the risk factor for seepage was not included in estimating the TRFs for Haditha and Hemrin Dams. However, the surveillance and monitoring procedures included the frequency and rate of seepage in their assessment.

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NOMENCLATURE

m^3	Cubic meter
s	second
m.a.s.l	meter above sea level
km^2	Square kilometer

REFERENCES

[1] Canadian Standards Association. **Risk Management: Guidelines for Decision-Makers (CAN/CSA-Q850-97).** Ottawa: CSA; 1997:6.

[2] Sadettin T, Hasan T. **An Overview on Total Risk Classifications for Dams.** *5th Dam Congress* 2021.

[3] International Commission on Large Dams. **Selecting Seismic Parameters for Large Dams: Guidelines (Revision of ICOLD Bulletin 72).** Paris: ICOLD; 1989.

[4] Kuo JT, Hsu YC, Tung YK, Yeh KC, Wu JD. **Dam Overtopping Risk Assessment Considering Inspection Program.** *Stochastic Environmental Research and Risk Assessment* 2008; **22**(3):303-313.

[5] Chen Y, Lin P. **The Total Risk Analysis of Large Dams under Flood Hazards.** *Water* 2018; **10**(2):140.

[6] Tosun H, Seyrek E. **Total Risk Analyses for Large Dams in Kizilirmak Basin, Turkey.** *Natural Hazards and Earth System Sciences* 2010; **10**:979-987.

[7] Al-Geelawee EK, Mohammed AN. **Application of Total Quality Management (TQM) Requirements in Risk Management in Construction Projects in Iraq.** *Journal of Engineering* 2016; **22**(6):1-15.

[8] Aleqabi GI, Ghalib HAA. **Seismic Hazard Assessment of Northern Iraq.** *Journal of Zankoy Sulaimani - Part A* 2016; Special Issue:319-330.

[9] Adamo N, Al-Ansari N, Laue J, Knutsson S, Sissakian V. **Risk Management Concepts in Dam Safety Evaluation: Mosul Dam as a Case Study.** *Journal of Civil Engineering and Architecture* 2017; **11**(7):635-648.

[10] Shadhar AK, Mahmood BB. **Risks of Design Stage in Iraqi Construction Projects.** *Journal of Engineering* 2018; **24**(3):114-121.

[11] Ghali HM, Azzubaidi RZ. **Flood Management of Diyala River.** *Journal of Engineering* 2021; **27**(8):32-42.

[12] Joni HH. **Identifying Risk Factors Influencing Traffic Accidents for Baghdad Expressways.** *Journal of Engineering* 2022; **40**:802-809.

[13] Marwa M, Altaie MR. **Use Risk Score Method to Identify the Qualitative Risk Analysis Criteria in the Tendering Phase in Construction Projects.** *Journal of Engineering* 2022; **28**(7):31-42.

[14] Mhmood HH, Yilmaz M, Sulaiman SO. **Simulation of the Flood Wave Caused by Hypothetical Failure of the Haditha Dam.** *Journal of Applied Water Engineering and Research* 2023; **11**(1):66-76.

[15] Al-Ani IA, et al. **Multi-Criteria Decision-Making to Optimize the Best Runoff Control Measures for the Haditha Dam Reservoir, Iraq.** *Journal of Environmental Hydrology* 2014; **22**:1-12.

[16] Ali AM, Odaa MN. **Analysis of Mosul and Haditha Dam Flow Data.** *Journal of Engineering* 2014; **20**(5):61-75.

[17] Sulaiman SO. **Numerical Modeling of Flood Wave Behavior with Meandering Effects (Euphrates River, Haditha-Hit).** *Journal of Hydraulic Research* 2009; **29**(7):1227-1240.

[18] Al-Nedawi W, Al-Hadidi M. **Finite Element Analysis of Seepage for Hemrin Earth Dam Using Geo-Studio Software.** *Diyala Journal of Engineering Sciences* 2020; **13**(3):66-76.

[19] Al-Mohammed TH, Al-Nada NM. **Seepage and Slope Stability Analysis for Hemrin Earth Dam in Iraq Using Geo-Studio Software.** *Solid State Technology* 2020; **63**(3):2539-2549.

[20] State Commission of Dams and Reservoirs. **Technical Report for Haditha Dam and Hemrin Dams.** Baghdad: Ministry of Water Resources; 2020.

[21] URS Corporation. **Comprehensive Seismic Risk and Vulnerability Study for the State of South Carolina.** Columbia: URS; 2001:609.

[22] Iraqi Meteorological Organization and Seismology. **Seismic Data Report.** Baghdad: IMOS; 2020.

[23] Hameed G, Alameer HA, Fakhry A, Aljabar FA. **Emergency Action Plan for Haditha Dam.** Baghdad: Ministry of Water Resources; 2016.

[24] Abbas ZI, Altarawne ES. **Stability of Earthfill Dams of Materials Containing Soluble Gypsum.** *Journal of Earth Sciences and Geotechnical Engineering* 2020; **10**(1):1-13.

[25] Adamo N, Sissakian VK, Al-Ansari N, Knutsson S, Laue J, Ezz-Aldeen M. **Comparative Study of Mosul and Haditha Dams, Iraq: Foundation Treatments in the Two Dams.** *Journal of Earth Sciences and Geotechnical Engineering* 2018; **8**(2):53-70.

[26] World Bank Group. **Good Practice Note on Dam Safety.** Washington: World Bank; 2023.