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Dam Breakdown and Response of Protection Dam, Case Scenarios of Mosul-Badush Dams, Northern Iraq

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Keywords:
Mosul Dam Failure; Badush Dam; Regulatory Dam; Reservoir.

Highlights:

- *The first mathematical model of Breakdown Scenarios of Mosul.*
- *Estimating the Mosul Dam reservoir level before the breakdown.*
- *The program work limits ranged from minimum to maximum levels of the Mosul Dam reservoir at which the failure happened.*

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Abstract: In this study, a program was built to simulate the sudden and complete collapse of the Mosul and Badush Dams behavior towards this collapse and predict the level at which the water will balance in the two dams after the collapse, compared to different levels at the Mosul Dam before the collapse. Two mathematical models were built as inputs to this program. The first predicted the water level in the Mosul Dam reservoir in terms of its storage volume before the collapse, and the second predicted the water level in the Badush reservoir after the collapse, according to the level in the Mosul reservoir before the collapse. For each collapse scenario, the program was organized according to sequential steps summarized assuming the water level in the Badush Dam reservoir when the level stabilizes, and from it determining the water volume in Badush reservoir based on the geometric analysis of the reservoir, then the volume of water transferred from Mosul reservoir to Badush reservoir, and thus the volume of water inside Mosul reservoir before the collapse. From the first mathematical model, the level of the Mosul Dam reservoir was determined before the collapse. The second mathematical model determined the level of the Badush Dam reservoir after the collapse. The results showed that the program has high flexibility in predicting what will happen in the Badush Dam reservoir after the collapse based on the water level in the Mosul Dam reservoir before it collapses and that the limits of the program's work extend from the minimum to the maximum level in Mosul Dam at which the failure can occur. Also, the storage volume in Mosul Dam will be distributed to the two reservoirs after the failure until the level stabilizes. Badush Dam, at a level of 330.4 m (a.s.l), can expand the maximum flood wave resulting from the total and sudden collapse of Mosul Dam at its maximum level of 333 m (a.s.l).

سيناريوهات انهيار سد الموصل واستجابة سد بادوش، شمالي العراق

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قسم الجيولوجيا التطبيقية / كلية العلوم / جامعة تكريت / تكريت – العراق.

الخلاصة

في هذه الدراسة تم بناء برنامج لمحاكاة حالة الانهيار المفاجئ والكامل لسد الموصل، وسلوك سد بادوش تجاه هذا الانهيار والتنبؤ بالمنسوب الذي سيتوازن عنده السدان بعد ذلك الانهيار على مناسيب مختلفة من سد الموصل قبل الانهيار. تم بناء نموذجين رياضيين كمدخلات لهذا البرنامج، الأول للتنبؤ بمنسوب المياه في خزان سد الموصل بدلالة حجم التخزين فيه قبل الانهيار، والثاني للتنبؤ بمنسوب المياه في خزان بادوش بعد الانهيار، بدلالة منسوب خزان الموصل قبل الانهيار. لكل سيناريو من سيناريوهات الانهيار تم تنظيم البرنامج وفق خطوات متسلسلة تلخصت بفرض منسوب المياه في خزان سد بادوش بعد الاستقرار، ومنه تحديد حجم المياه في خزان بادوش بناءً على التحليل الجيومتري للخزان، ثم حجم المياه المنقولة من خزان الموصل إلى خزان بادوش، وبالتالي حجم المياه داخل خزان الموصل قبل الانهيار، ومن النموذج الرياضي الأول، يتم تحديد منسوب خزان سد الموصل قبل الانهيار، ومن النموذج الرياضي الثاني، يتم تحديد منسوب خزان سد بادوش بعد الانهيار. أظهرت النتائج أن البرنامج يتمتع بمرونة عالية في التنبؤ بما سيحدث في خزان سد بادوش بعد الانهيار، من خلال منسوب المياه في خزان سد الموصل قبل الانهيار، وأن حدود عمل البرنامج تمتد من أدنى إلى أقصى مستوى في سد الموصل يمكن أن يحدث عنده الانهيار، وأن حجم التخزين في سد الموصل سيتم توزيعه على الخزانين بعد الانهيار حتى يستقر المستوى، وأن سد بادوش عند مستوى ٣٣٠,٤ م (ف.م.س.ب)، يتسع لأقصى موجة فيضان ناتجة عن الانهيار الكلي والمفاجئ لسد الموصل عند منسوبه الأقصى البالغ ٣٣٣ م(ف.م.س.ب).

الكلمات الدالة: فشل سد الموصل، سد بادوش، السد التنظيمي، خزان.

1.INTRODUCTION

Mosul dam is located more than 50 km north-northwest of Mosul city, while Badush dam is located about 40 km to the south of Mosul dam and about 15 km northwest of Mosul city. The regulatory dam is in the middle of the river, reaching between the two dams. Fig. 1 shows the three dams' locations. The traditional reservoir routing is the calculation of the inputs, outputs, and storage difference and their change with time, so the reservoir routing is a mathematical procedure to calculate the changes over time in the volume and behavior of the flood wave movement through the reservoir from the wave entry to the reservoir then to the dam [1].

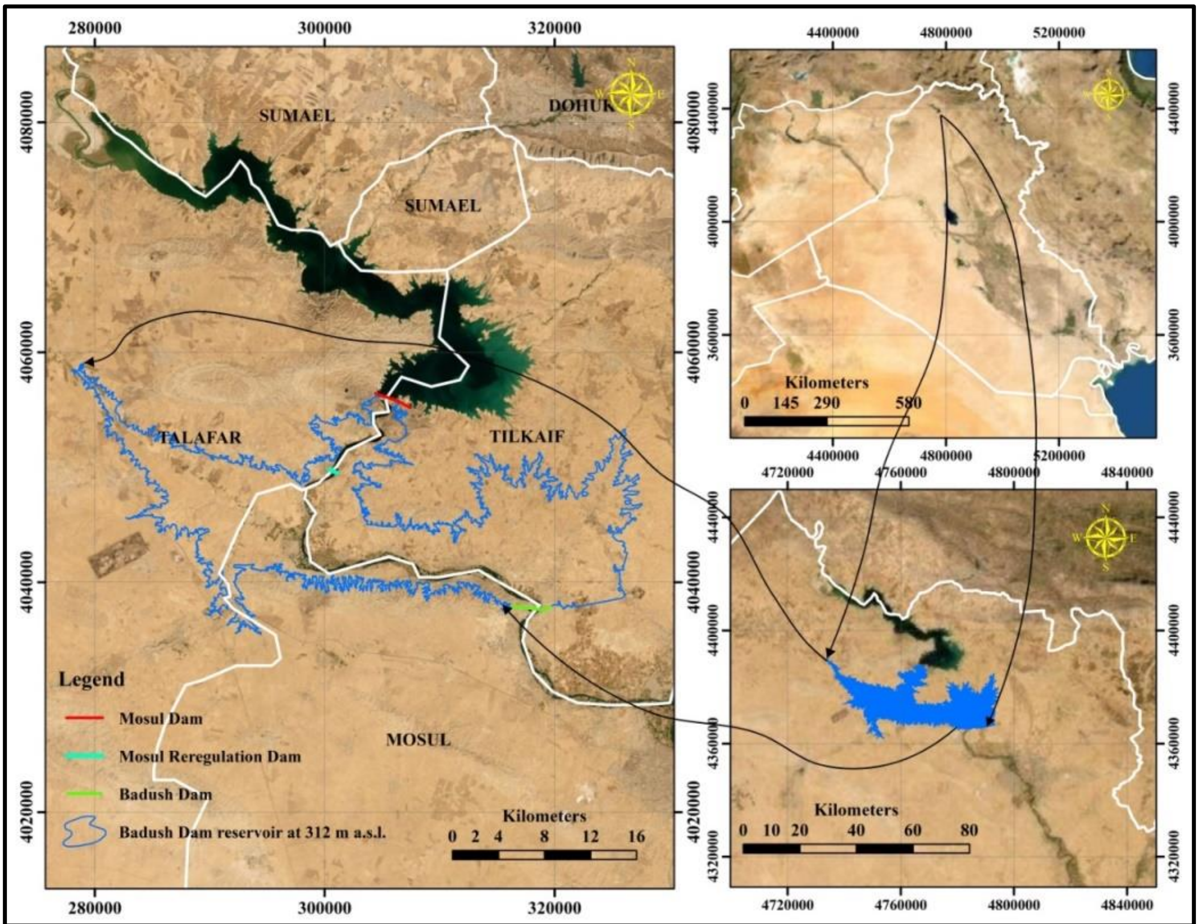

Fig. 1 Location of the Three Studied Dams.

Many mathematical and numerical models derive and solve flood problems on riverbanks. These models draw plans to protect the cities and villages near the river banks; however, the appropriate model must be chosen according to the nature of the available data. Also, these models may take a long time to prepare and get results, so the user must be careful when using each form [2]. Many traditional usable types of reservoir flood simulation were published [3, 4]. There are many methodologies and models to simulate the Mosul dam breakdown, but not assuming the building of the Badush dam as a protection dam [5, 6]. In this study, a new methodology was developed to simulate the reservoirs of the main storage dam (Mosul Dam), the protection dam (Badush Dam), the river reaching between the two dams, and the regulation dam in the middle of this reach, according to geometric data analysis, in the case of Mosul Dam breakdown to reserve the permanence of the protection dam against the possible failure of main storage dam [7, 8]. The immersion and then the damage will cover part or all of the river reach and its banks restricted between the dam expected to breakdown and the protection dam [9-12]. The limits of immersion can be determined or estimated through hypothetical scenarios to simulate the flood wave resulting from the breakdown. Many studies dealt with hypotheses, scenarios of the breakdown, and models to simulate the Mosul Dam collapse [5, 6, 13 - 20]. All of these studies did not assume the existence of Badush Dam as a protection dam, while only the study of Mohammed-Ali and Khairallah [21] simulated the flood risk in the Tigris River downstream to the present study area, particularly the city of Tikrit, using HEC-RAS software, and identified the areas most exposed to flooding to develop a plan to manage the potential flood risks. The Mosul Dam's sudden collapse and the flood wave's movement towards the Badush Dam may decrease its stability, especially its earth parts, its shoulders, and the extent of its foundations [22]. The most important data required in the reservoir simulation is the relationship between the input flow and the volume, and the water level inside the reservoir is the relationship between volume and level with the outflow. As for the channel routing, the flow hydrograph is predicted in several segments on the reach, depending on the inflow and outflow between upstream and downstream sections. The case of the Mosul Dam breakdown will be studied through several scenarios for different levels to preserve the dam and evaluate the Badush Dam's behavior as a protection dam facing each breakdown hypothesis. The relationship of storage volume with the level will be adopted in Mosul Dam, and geometric data will be adopted to determine the relationship of level with volume and vice versa for Badush Dam.

2.METHODOLOGY

2.1.Breakdown Case Hypotheses

The following hypotheses were adopted when the breakdown occurred. These hypotheses are not arbitrary; they are scientifically supported and justified.

1. The breakdown occurs during the water surplus (wet) period, between December and April, according to the Iraqi climatic conditions.
2. The complete and sudden breakdown represents the harshest hypothesis, and all other hypotheses are less dangerous, wide, and fast because the transfer of water mass from the Mosul Dam reservoir to the Badush Dam reservoir will be as fast as possible. It will flood a larger area than the breakdown partial case.
3. Twenty-eight hypothetical water levels reached in the Badush Dam reservoir after the breakdown occurred, starting from 256 m.a.s.l to 310 m.a.s.l., with an interval of 2 meters between one level to another, corresponding to the levels of the Mosul Dam at the moment of breakdown that will be calculated from the program prepared to achieve the methodology. Each selected level represents an independent scenario and has a response calculated in the Mosul and Badush Dams.
4. The Badush and Regulatory Dams are at their maximum operational levels. The corresponding volumes are 15,000,000 (about fifteen million cubic meters) in the regulatory dam reservoir, and 264,875,073 (about two hundred and sixty-five million cubic meters) in the Badush dam reservoir already existed at the moment of breakdown, based on this hypothesis is also the harshest hypothesis.
5. The water mass movement hypothesis was adopted without considering the time taken for the movement of this mass until reaching the moment of balance, based on the fact that the presence of the protection dam restricts the water mass movement and its movement is inaccessible towards the downstream and does not a threat the population areas, noting that the water mass transfer is gradual and not instantaneous.
6. Residential areas located at levels lower than the maximum flood level of Badush Dam, resulting from the Mosul Dam failure, were evacuated to alternative locations before the failure began.

2.2.Mathematical Models Derived to Simulate the Breakdown

Two mathematical models were derived, and a polynomial regression analysis was conducted in this study using the level-volume data of the Mosul Dam and the DEM-based geometric data of the Badush Dam. Dependent variable Y can be used as a function of (N) predictor variables X1, X2,... , XN, as in Eq. (1) [23].

$$Y = \alpha_\circ + \alpha_1 X_1 + \alpha_2 X_2^2 + \alpha_3 X_3^3 + \cdots + \alpha_N X_N^N \quad \textbf{(1)}$$

where Y= Level in Mosul reservoir (m.a.s.l.) in Eq. (2), and Y= Level achieved in Badush Dam reservoir after the breakdown (m.a.s.l.) in Eq.(3). While X= Volume in Mosul reservoir (m3) in Eq. (2), and X= Level in Mosul Dam reservoir at the moment of breakdown (m.a.s.l) in Eq. (3). The GRAPHER 13 statistical software used for the polynomial fitting of these equations: The first predicts the water level in the Mosul Dam reservoir in terms of its storage volume before the collapse, Eq. (2). and Fig. 2. The second predicts the water level in the Badush reservoir after the collapse according to the level in Mosul reservoir before the collapse, Eq. (3). and Fig. 3. The limits of Eq. (1) are the levels from 250 to 343.2 (m.a.s.l), which are the operational limits of the Mosul Dam reservoir.

$$Y = 259.27 + 3.4310^{-8}X - 1.20 \times 10^{-17}X^2 - 2.34 \times 10^{-27}X^3 + 2.36 \times 10^{-37}X^4 + 1.16 \times 10^{-47}X^5 - 2.20 \times 10^{-58}X^6 \quad \textbf{(2)}$$

X= Volume in Mosul reservoir (m3)
Y= Level in Mosul reservoir (m.a.s.l.)
where
Y= Level Achieved in Badush Dam reservoir after the breakdown (m.a.s.l.), and X= Level in Mosul Dam reservoir at the moment of breakdown (m.a.s.l).

$$Y = 24146.80 - 302.37\,X + 1.42\,X^2 - 0.229X^3 + 2.3010^{-6}X^4 \quad \textbf{(3)}$$

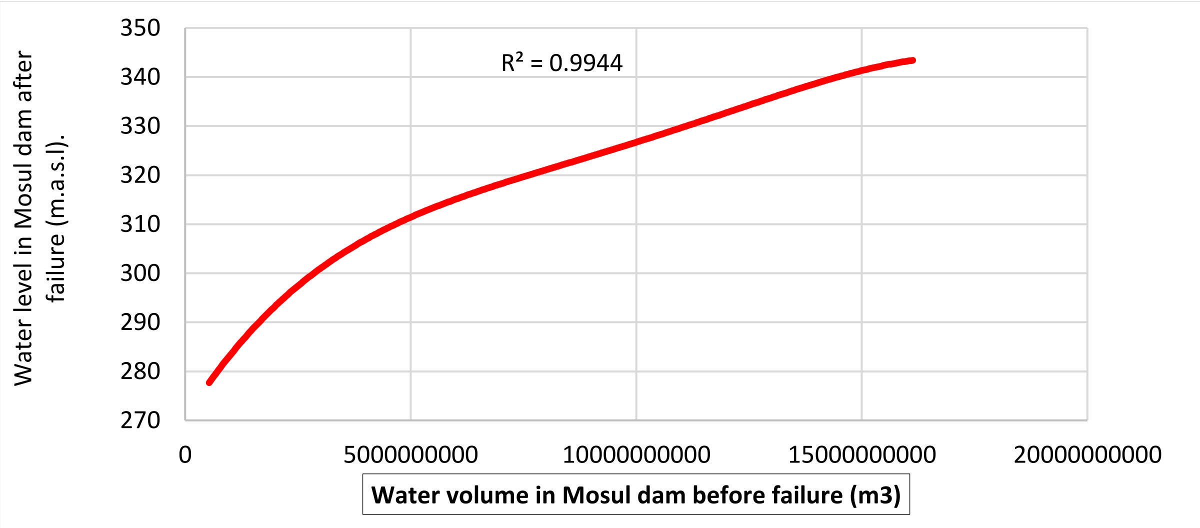

Fig. 2 Curve of the Model of Finding the Level in Terms of Volume in the Mosul Dam Applied in the Breakdown Program According to Eq. 2.

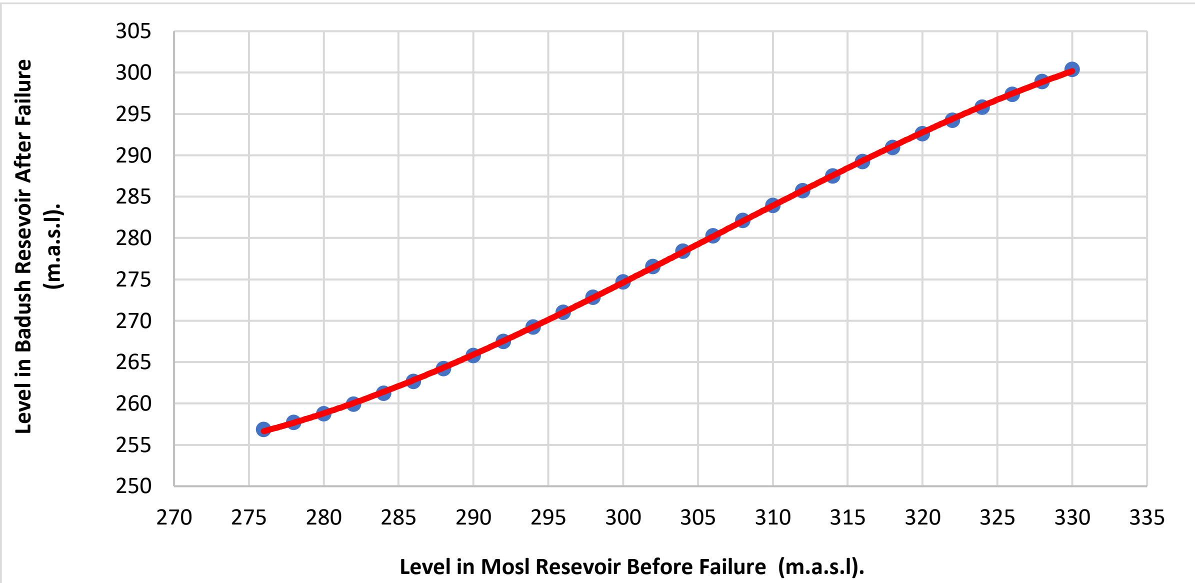

Fig. 3 Curve of the Model for Finding the Expected Level in Badush Dam Reservoir in Terms of the Supposed Levels in Mosul Dam Reservoir at the Moment of Breakdown According to Eq. (3).

2.3.Procedure to Simulate Mosul Dam Breakdown

The geometric analysis of the Badush Dam reservoir was adopted as a basis for the relationship between the water level and the water volume in the reservoir. The EXCEL program was built to simulate the Mosul Dam breakdown and the response of the Badush Dam against this case. The program steps can be summarized in a flowchart, as shown in Fig.4.

2.4. Breakdown Scenario Program

A program was built to predict what would happen in the protection dam (Badush) reservoir at the moment of the Mosul Dam breakdown, Table 1.

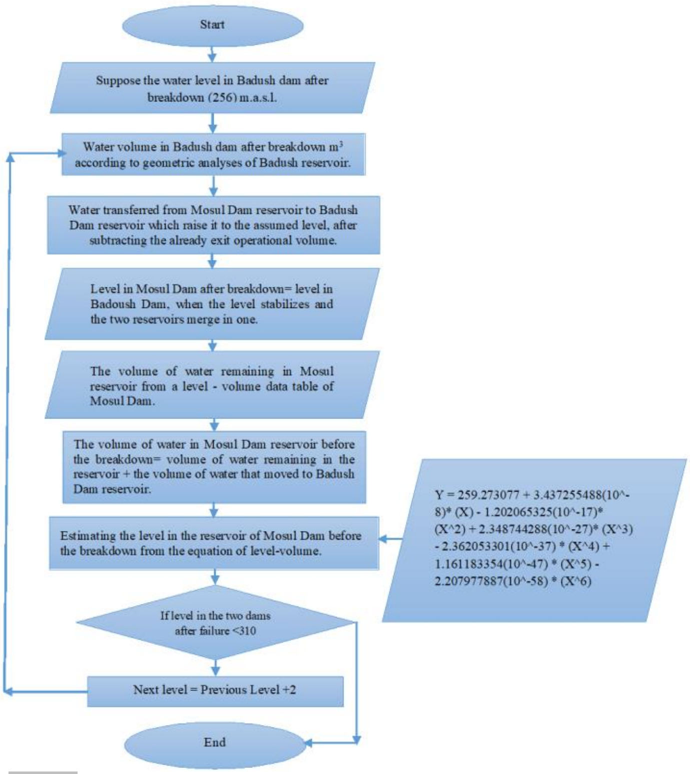

Fig.4 The Flowchart of the Steps Simulates the Case of a Mosul Dam Breakdown and the Response of Badush Dam.

Table 1 An EXCEL System Program Built to Predict the Behavior of the Flood Wave Resulting from the Breakdown of Mosul Dam.

Algorithm of Breakdown Simulation Model Building							**Prediction**	
1	2	3	4	5	6	7	8	9
256 (Lowest level scenario)	According to geometric analysis of Badush dam reservoir.	Volume in column 2 – the volume of water already exist in th Badush reservoir before breakdown (٢٦٤٨٧٥٠٧٢٣)	256 (The same level in Badush)	From the data of level- volume of Mosul dam reservoir	Volume in column 5 + the volume in column 3	274.5	276	256.87
258			258			278.0	278	257.73
↓			↓			↓	280	258.76
↓			↓			↓	↓	↓
300			300			329.2	↓	↓
302			302			330.9	↓	↓
304			304			333.3	↓	↓
306			306			337.0	326	297.40
308			308			341.8	328	298.92
310 (Highest level scenario)			310 (The same level in Badush)			343.8	330	300.40

1. Supposed water level in Badush dam after breakdown (m.a.s.l)
2. Water volume in Badush dam after breakdown m^3 (according to the data of volume-level derived from the DEM of Badush dam).
3. Water volume moved from Mosul to Badush dams (m^3)
4. Water level in Mosul after the breakdown dam (the same level in Badush) (m.a.s.l)
5. Water volume remaining in Mosul dam after breakdown (m^3)
6. Water volume in Mosul dam before breakdown (m^3)
7. Water level in Mosul before failure (m.a.s.l). from Eq. 2.
8. Assumed water level in Mosul dam Before breakdown (m.a.s.l)
9. Predicted water level in Badush dam after (m.a.s.l) from Eq. 3.

3. RESULTS AND DISCUSSION

The dams may breakdown as a result of inaccurate selection of the site on which the dam was built, i.e., lack of integration of all kinds of site investigations, design deficiency or defect, inappropriate geotechnical characteristics of the rocks or soil of the foundations' zone (as expected for Mosul Dam), a lack of site preparation works before construction such as grouting (grouting) works within the zone of the foundations, an executive defect during the implementation of concrete or aggregate works, an operational defect due to the policy of filling and emptying, negligence or a lack of maintenance and periodic monitoring, seismic or volcanic activity in or near the dam or the reserve site, or a deliberate act of sabotage as happens in wars or terrorist acts. In the present study, a hypothetical program was developed for the water mass to move after the collapse from the reservoir of the Mosul Dam to be distributed over the two reservoirs until it is balanced at one mutual level upstream of the Badush Dam. The program mentioned in Table 1. simulated the breakdown in the following steps:

1- Input the hypothetical water level in Badush Dam reservoir after the breakdown of Mosul dam within the limits of (256-310) (m.a.s.l) with two-meter intervals between a selected level to another, Table 2.
2- Input the storage volume in the Badush Dam reservoir in the second column, corresponding to each level in the first column, according to the results of the DEM-based geometric analysis of the Badush Dam.
3- Calculating the water transferred volume from the Mosul Dam reservoir to the Badush Dam reservoir (third column), which raises the level from the state before the breakdown to the assumed level in column 1 after subtracting the operational volume that is already presented in Badush Dam reservoir before the breakdown, which is (264875073 m^3) about two hundred and fifty million cubic meters of the volume in the second column corresponding to the assumed level.
4- Input the level in Mosul Dam after the breakdown (fourth column), which is the same level in Badush Dam, on the basis that the volume of water will be transferred to the Badush reservoir until the level stabilizes. The two reservoirs merge, and part of the reserve remains in the Mosul reservoir (communicating vessels law).
5- Input the volume of water remaining in the Mosul reservoir (the fifth column) from a level-volume data table of the Mosul Dam.
6- Calculating the water volume present in the Mosul Dam reservoir before the breakdown (the sixth column) by adding the volume of water remaining in the reservoir (fifth column) to the volume of water that moved to the Badush Dam reservoir (the third column).
7- Estimating the Mosul Dam reservoir level before the breakdown for each scenario (seventh column), using the mathematical equation of volume level mentioned in Eq. 2 and Fig. 2, which was developed to predict the level in terms of the volume in the sixth column, as the equation was built using data Level-volume of Mosul Dam.
8- Developing a mathematical equation to predict the water level in the Badush reservoir after the breakdown using the data of the first and seventh columns, as in Eq. 3 and Fig. 3, and setting selected levels from the levels of Mosul Dam at the moment of breakdown in the eighth column, and substituting the equation in the ninth column to predict the levels that will be achieved in the Badush Dam reservoir after the breakdown, as shown in Fig. 5.
9- Determine the maximum mutual level of the two reservoirs after the breakdown (about 300.4 m.a.s.l), which ensures the maximum storage capacity of the Mosul Dam reservoir reached about 330 m.a.s.l according to the program data, which is the most important result of this simulation scenarios.

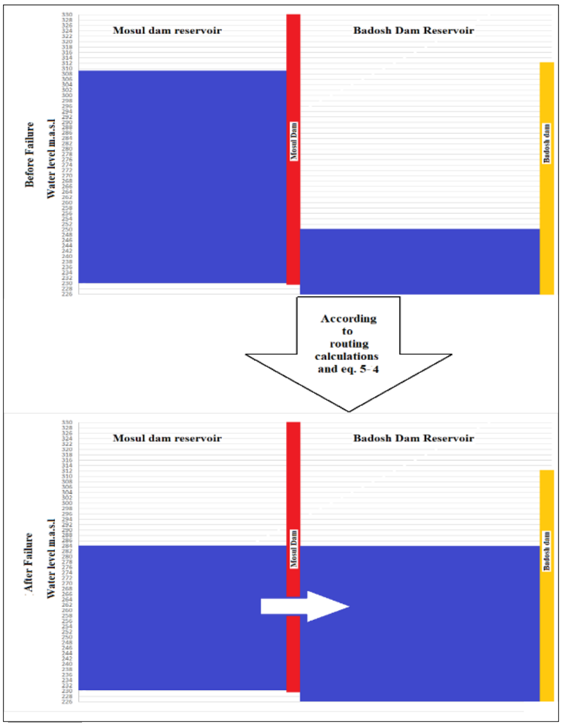

Fig. 5 Sketch Diagram to Explain the Method of Calculations of Water Levels in Mosul and Badush Dams before and after the Breakdown of Mosul Dam.

Table 2 Outputs of the Program to Simulate the Flood Wave Resulting from the Breakdown of Mosul Dam, according to the Scenarios Prepared for 52 Hypothetical Levels of the Dam at the Moment of Breakdown.

Algorithm of Breakdown Simulation Model Building (reverse model)							Prediction	
1	2	3	4	5	6	7	8	9
256	778200361	513325288	256	18663947	531989235	274.5	276	256.87
258	923393552	658518479	258	32187097	690705576	278.0	278	257.73
260	1074925125	810050052	260	51039178.06	861089230.1	281.3	280	258.76
262	1239556228	974681155	262	76105394.29	1050786549	284.6	282	259.94
264	1418551576	1153676503	264	108270950.2	1261947453	287.7	284	261.26
266	1611652608	1346777535	266	148421050.1	1495198585	290.5	286	262.69
268	1820252773	1555377700	268	197440898.6	1752818599	293.2	288	264.22
270	2045955849	1781080776	270	256215700.1	2037296476	295.6	290	265.84
272	2290819579	2025944506	272	325630659	2351575165	297.7	292	267.52
274	2552604329	2287729256	274	406570979.8	2694300236	299.7	294	269.27
276	2831988676	2567113603	276	499921866.9	3067035470	301.4	296	271.06
278	3130754226	2865879153	278	606568524.8	3472447678	303.2	298	272.88
280	3449080153	3184205080	280	727396157.8	3911601238	304.9	300	274.72
282	3790145681	3525270608	282	863289970.5	4388560579	306.8	302	276.58
284	4154517881	3889642808	284	1015135167	4904777975	309.0	304	278.44
286	4544345422	4279470349	286	1183816953	5463287302	311.5	306	280.29
288	4960404824	4695529751	288	1370220531	6065750282	314.3	308	282.14
290	5404684230	5139809157	290	1575231107	6715040264	317.3	310	283.96
292	5875169972	5610294899	292	1799733884	7410028783	320.3	312	285.76
294	6374271765	6109396692	294	2044614068	8154010760	323.2	314	287.53
296	6903618713	6638743640	296	2310756863	8949500503	325.6	316	289.27
298	7463299270	7198424197	298	2599047473	9797471670	327.6	318	290.97
300	8060854343	7795979270	300	2910371102	10706350372	329.2	320	292.64
302	8690657694	8425782621	302	3245612956	11671395577	330.9	322	294.26
304	9354694250	9089819177	304	3605658238	12695477415	333.3	324	295.85
306	10051594157	9786719084	306	3991392153	13778111237	337.0	326	297.40
308	10783214588	10518339515	308	4403699906	14922039421	341.8	328	298.92
310	11550267784	11285392711	310	4843466700	16128859411	343.8	330	300.40

1. Assumed water level in the Badush Dam after breakdown (m.a.s.l)
2. Water volume in Badush dam after breakdown (m3) (according to the data of volume-level derived from the DEM of Badush dam).
3. Water volume moved from the Mosul to Badush dams (m3)
4. Water level in the Mosul Dam after the dam breakdown(m.a.s.l)
5. Water volume remaining in the Mosul Dam after breakdown (m3)
6. Water volume in Mosul dam before breakdown (m3)
7. Water level in the Mosul Dam before failure (m.a.s.l). from Eq. 2.
8. Assumed water level in the Mosul Dam Before breakdown (m.a.s.l)

Predicted water level in the Badush Dam after (m.a.s.l) from Eq. 3.

When predicting the levels that will be achieved in Badush Dam reservoir, after the breakdown at specific levels in Mosul Dam reservoir in each of the scenarios, six of these levels were derived from digital elevation models of Badush Dam reservoir area and converted into shape files and inundation maps for the post-breakdown stage as in Figs. (6-11).

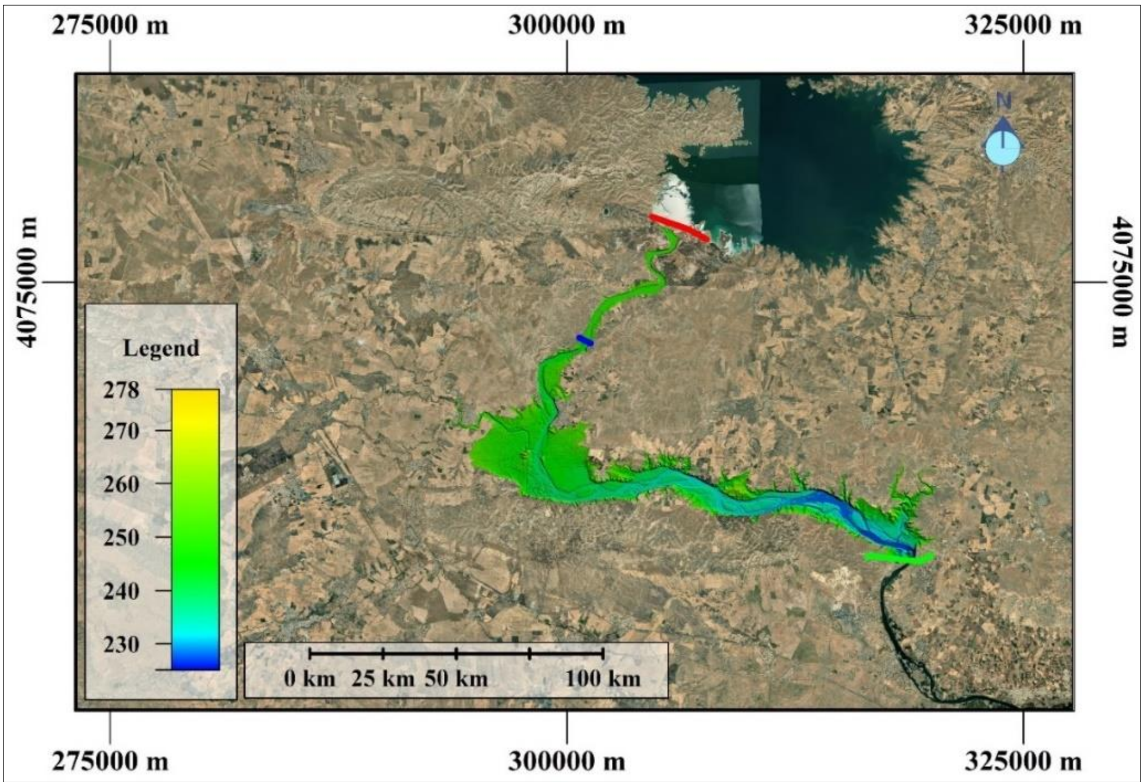

Fig. 6 The Spatial Extension of the Badush Reservoir at a Level of 256.98 (m.a.s.l) Resulting from the Scenario of the Breakdown of the Mosul Dam at a Level of 276.26.

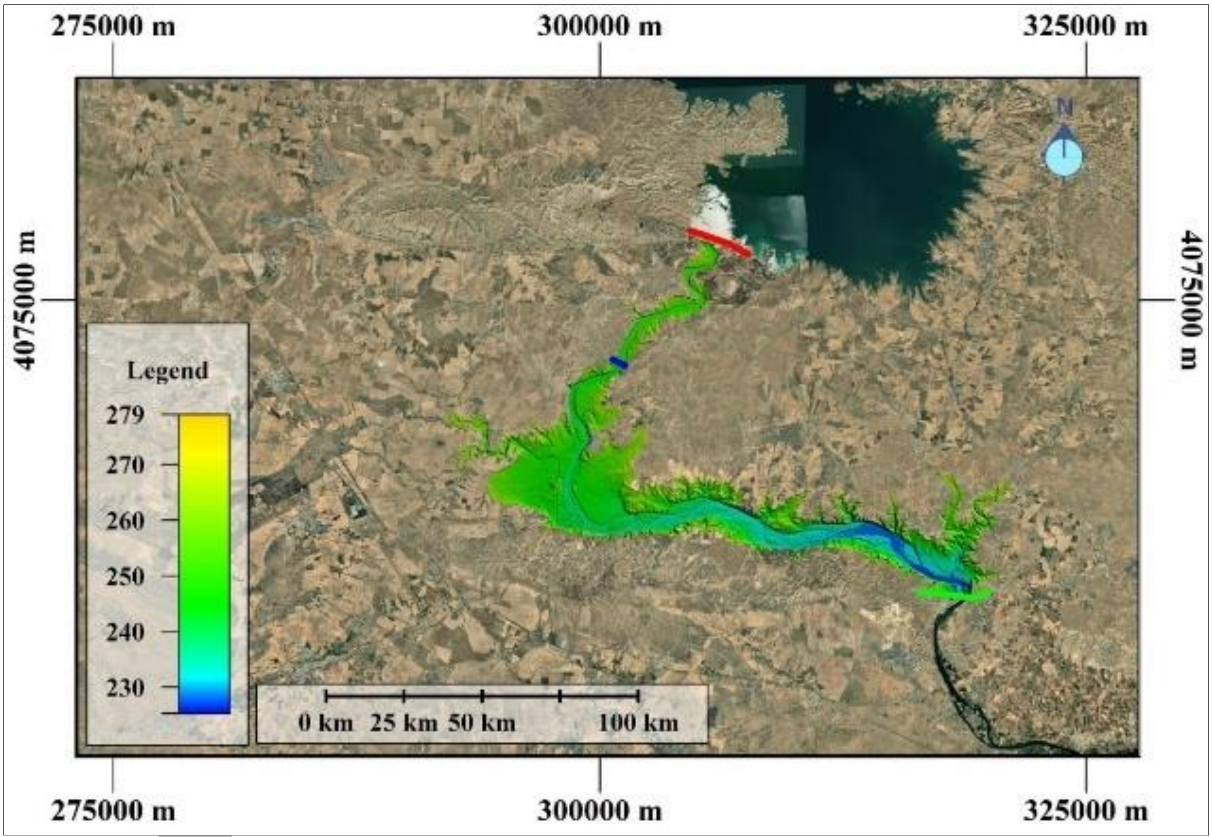

Fig. 7 the spatial extension of Badush Reservoir at a Level of 264.49 (m.a.s.l)
Resulting from the Scenario of the Breakdown of Mosul Dam at a Level of 288.34.

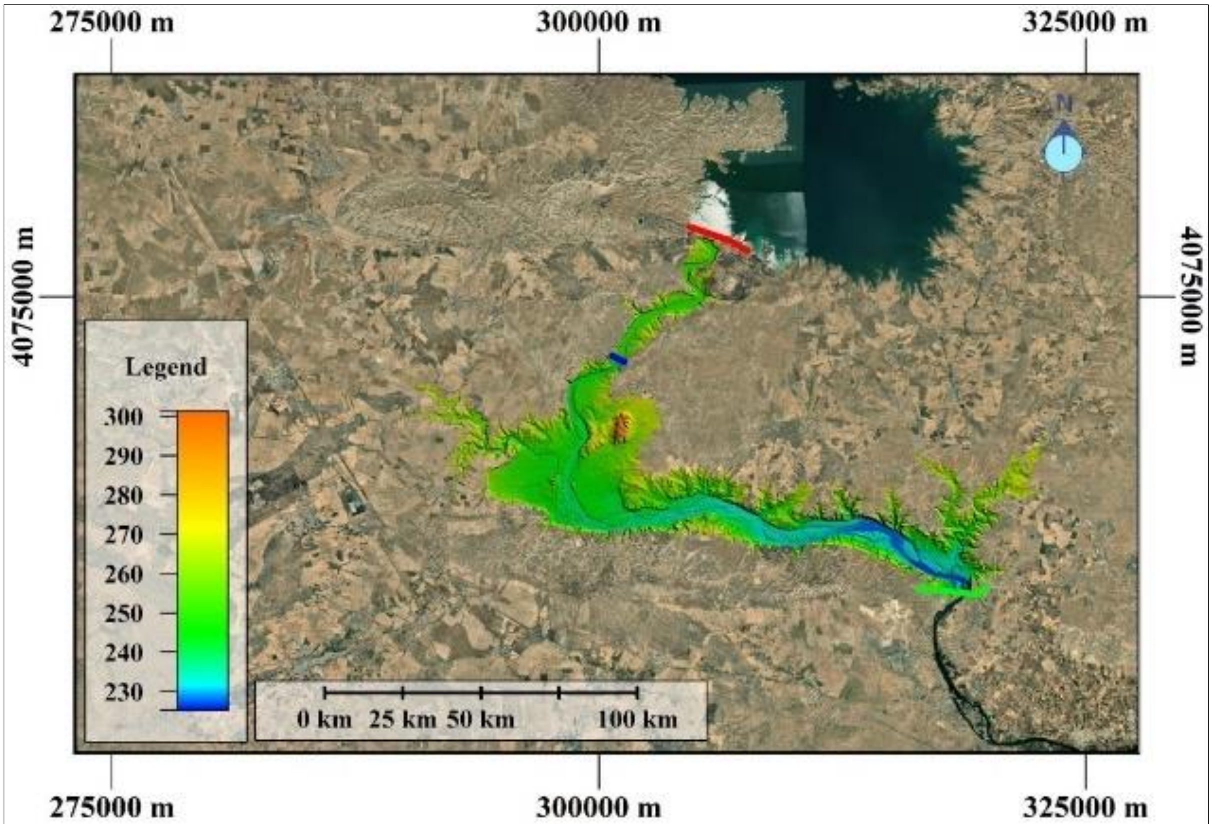

Fig. 8 The Spatial Extension of Badush Reservoir at a Level of 270.66 (m.a.s.l)
Resulting from the Scenario of the Breakdown of Mosul Dam at a Level of 295.56.

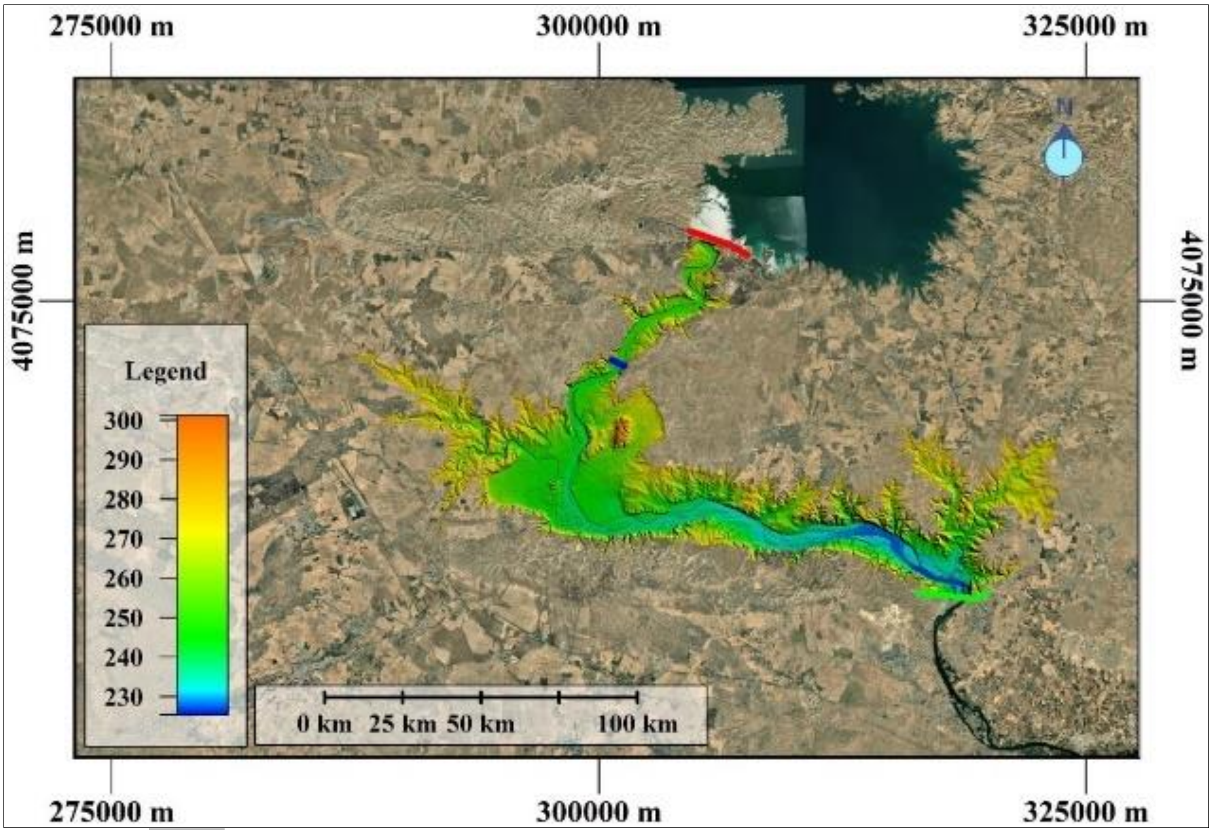

Fig. 9 The Spatial Extension of Badush Reservoir at a Level of 280.66 (m.a.s.l) Resulting from the Scenario of the Breakdown of Mosul Dam at a Level of 306.4.

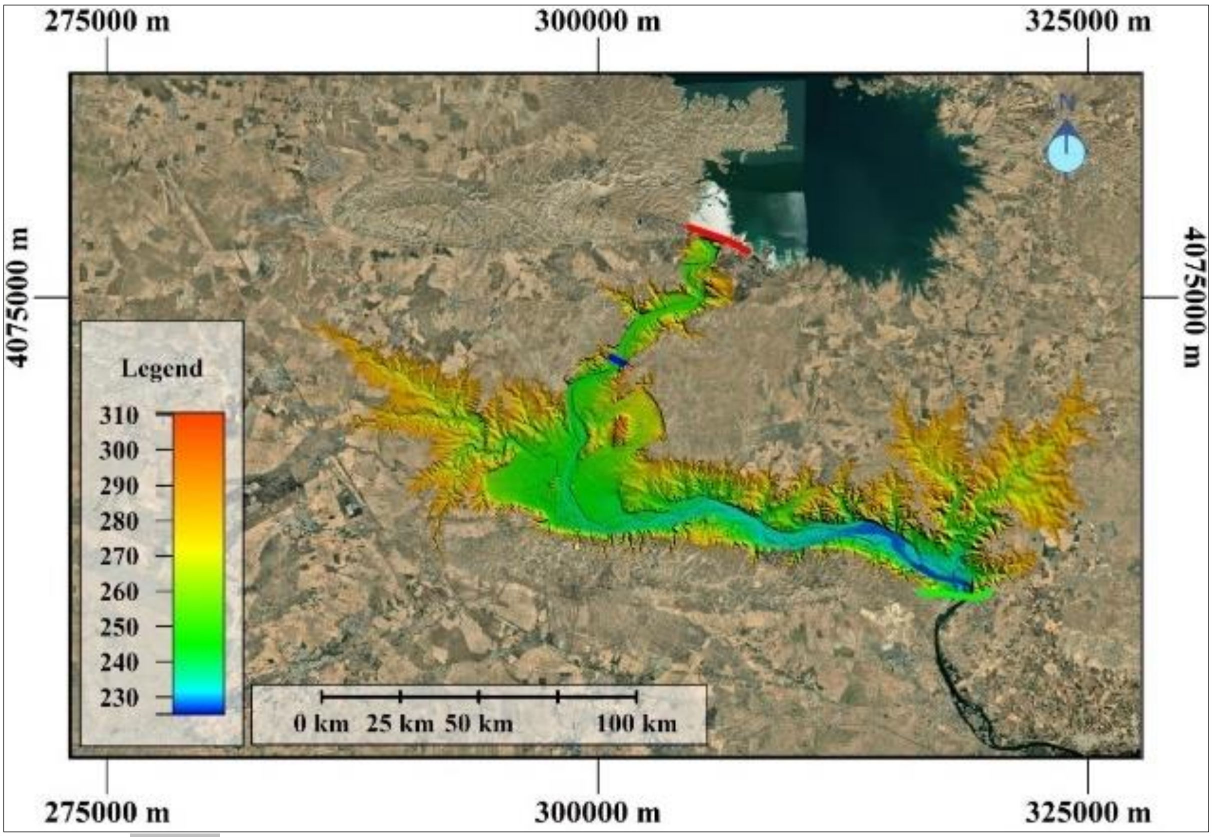

Fig. 10 The Spatial Extension of Badush Reservoir at a Level of 290.58 (m.a.s.l) Resulting from the Scenario of the Breakdown of Mosul Dam at a Level of 317.54.

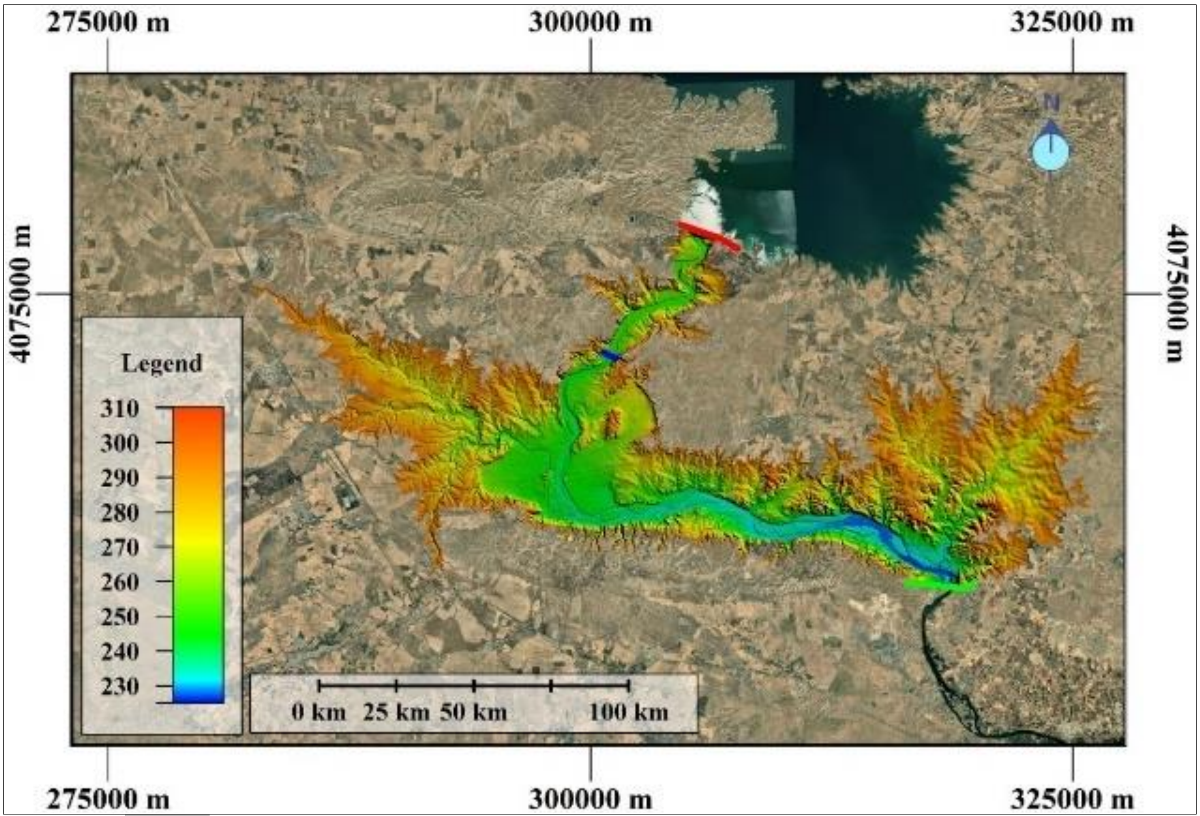

Fig. 11 The Spatial Extension of Badush Reservoir at a Level of 298.14 (m.a.s.l) Resulting from the Scenario of the Breakdown of Mosul Dam at a Level of 326.97.

The areas of villages partially or entirely submerged were also calculated at selected levels from the immersion levels and tabulated in Table 3. The increase in these areas was also represented graphically with increasing immersion levels, as in Fig. 12, then converting the table data into a gradual inundation map with an increase of level, as in Fig. 13.

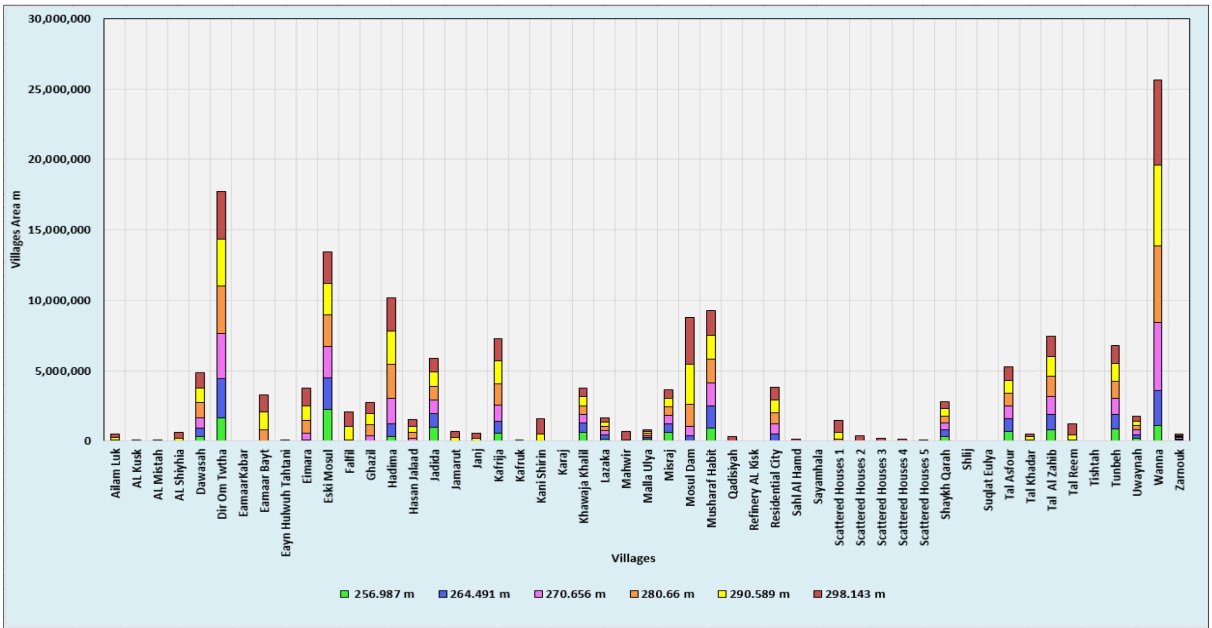

Fig. 12 Cumulative Inundation Areas for Villages Partially or Entirely Submerged in the Badush Dam Reservoir, Resulting from Six Breakdown Scenarios for the Mosul Dam Reservoir.

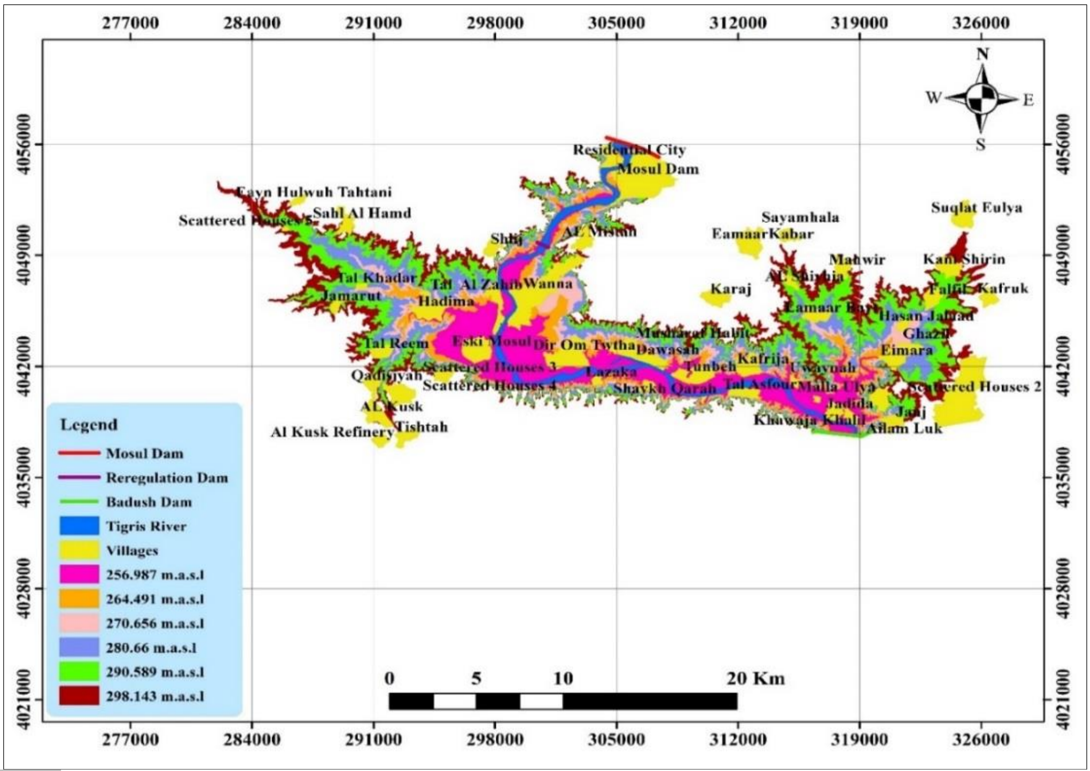

Fig. 13 Cumulative Inundation Areas Map for Villages are Partially or Entirely Submerged in the Badush Dam Reservoir, Resulting from Six Breakdown Scenarios for the Mosul Dam Reservoir.

Table 3 Inundation Areas (m²) for Villages are Partially or Entirely Submerged within Six Different Levels in the Badush Dam Reservoir, Resulting from Six Breakdown Scenarios for the Mosul Dam Reservoir.

Villages Names	256.98 m²	264.49 m²	270.66 m²	280.66 m²	290.58 m²	298.14 m²	Total area
Ailam Luk	0	1438	28612	74593	138255	287048	474974
AL Kusk	0	0	0	0	0	77043	1457343
AL Mistah	0	0	0	0	729	18062	1038860
AL Shiyhia	0	0	0	0	222977	382097	457270
Dawasah	307392	594637	761404	1060898	1060898	1060898	1060898
Dir Om Twtha	1671474	2764846	3198168	3370510	3370510	3370510	3370510
EamaarKabar	0	0	0	0	0	0	2053632
Eamaar Bayt	0	0	12401	817744	1235378	1235378	1235378
Eayn Hulwuh Tahtani	0	0	0	0	0	44	375777
Eimara	191	86370	454761	909044	1070626	1242667	1242667
Eski Mosul	2242713	2242713	2242713	2242713	2242713	2242713	2242713
Falfil	0	0	0	108012	930693	1057770	1057770
Ghazil	0	0	395272	777024	783592	783592	783592
Hadima	324107	923486	1813379	2368974	2383552	2383552	2383552
Hasan Jalaad	0	0	176612	420115	469037	469037	469037
Jadida	978675	978675	978675	978675	978675	978675	978675
Jamarut	0	0	0	25419	255692	428630	525938
Janj	0	0	9327	35275	171318	374379	472324
Kafrija	549720	879146	1106993	1538940	1606463	1606463	1606463
Kafruk	0	0	0	0	0	288	895191
Kani Shirin	0	0	0	0	480439	1112604	1335599
Karaj	0	0	0	0	0	0	1264962
Khawaja Khalil	630684	630684	630684	630684	630684	630684	630684
Lazaka	116206	302753	308255	308255	308255	308255	308255
Mahwir	0	0	0	0	101359	592524	1182952
Malla Ulya	135644	135644	135644	135644	135644	135644	135644
Misraj	606861	606861	606861	606861	606861	606861	606861
Mosul Dam	39080	314446	704676	1543709	2882515	3321538	7323916
Musharaf Habit	946120	1529181	1639060	1708175	1708175	1708175	1708175
Qadisiyah	0	0	0	42	43201	270296	996644
Al-Kisk Refinery	0	0	0	0	0	0	561373
Residential City	1027	522490	700534	812947	872079	898180	1002404
Sahl Al Hamd	0	0	0	0	10047	125336	1035073
Sayamhala	0	0	0	0	0	0	675591
Scattered Houses 1	0	0	11710	129638	481029	844582	1252147
Scattered Houses 2	0	0	0	0	0	380933	7994802
Scattered Houses 3	0	0	0	222	40437	156566	732174
Scattered Houses 4	0	0	0	197	22013	111060	1685688
Scattered Houses 5	0	0	0	0	12215	79548	90942
Shaykh Qarah	351133	465442	491958	492947	492947	492947	492947
Shlij	0	0	0	0	0	0	716494
Suqlat Eulya	0	0	0	0	0	0	1575555
Tal Asfour	695225	873144	908422	925983	926383	926383	926383
Tal Khadar	0	0	8943	97286	211611	211611	211611
Tal Al Zahib	814773	1094856	1259870	1431950	1431950	1431950	1431950
Tal Reem	0	0	0	53774	380548	812332	851214
Tishtah	0	0	0	0	0	0	878542
Tunbeh	843003	1056754	1122975	1250228	1250228	1250228	1250228
Uwaynah	173155	280491	326488	326488	326488	326488	326488
Wanna	1118741	2457668	4863811	5410034	5751645	6056008	6268052
Zarnouk	71308	80720	82010	82010	82010	82010	82010

4. CONCLUSIONS

The results indicated that the program and scenarios had high flexibility in predicting what would happen in the Badush Dam reservoir after the breakdown of the Mosul Dam, according to the water level in the Mosul Dam reservoir before the failure. The program work limits ranged from minimum to maximum levels of the Mosul Dam reservoir at which the failure happened. The storage volume in Mosul Dam was redistributed to the two reservoirs after the failure until the level stabilized. Badush Dam, at a level of 330.4 m (a.s.l), can accommodate the maximum flood wave resulting from the total and sudden collapse of Mosul Dam at its maximum level of 333 m (a.s.l). Through the ideas presented in this paper, it is possible to recommend adopting this procedure to simulate the hypothesis of the collapse of other dams and the response of protection dams. Also, it is recommended to develop the approved EXCEL program into special software to simulate the protection dams' behavior against the storage dams' collapse.

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