Darbandikhan Dam Collapse Scenario and Its Impact on the Areas Along the Diyala River Basin Down to the Hamrin Dam

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Abstract

The study and preparation of dam collapse scenarios is one of the basic things that must be ready for the purpose of preparing emergency plans to confront such collapses in order to spare the population and infrastructure the resulting losses and reduce their impact. In this study, we dealt with the possibility of collapsing the Darbandikhan Dam and its impact on the areas along the Diyala River Basin and on the integrity of the Hamrin Dam, using advanced hydrological modeling software and geographic information systems for the purpose of calculation and display. The hydrological modeling program (WMS9.1), which includes the simplified mathematical modeling of dam collapse (SMPDBK91), was used, and the digital elevation model for the region was used as a basis for preparing the cross-sections along the river and as one of the basic inputs in calculating the mathematical model and then preparing the inundation maps. The results of the mathematical modeling showed that the maximum depth of the flood water near the wall of the Hamrin Dam body at the levels (471 and 485) meters above sea level, is about (5.6, 6.3) meters, respectively. It was found that the collapse of the Darbandikhan Dam had no effect on the safety of the Hamrin Dam as long as the water level in the Hamrin Lake reservoir and the proximity of the dam's body did not exceed (100.7) meters above sea level, at the time of the hypothetical collapse of the Darbandikhan Dam.

Keywords: Inundation Maps, Breach Width, Water Time Arrival and Program (SMPDBK91).

سيناريو انهيار سد دربندخان وتأثيره على المناطق الواقعة على امتداد حوض نهر ديالى وصولا الى سد حمرين

ورقاء ثابت خليل العزاوي **معاذ إسماعيل محمود** **تحرير عدنان عبد المجيد**
لمياء رسول سالم **رنا نايف يوسف**

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بغداد- العراق

الخلاصـــة

تعد دراسة واعداد سيناريوهات انهيار السدود من الامور الاساسية التي يجب ان تكون جاهزة لغرض اعداد خطط الطوارئ لمجابهة مثل تلك الانهيارات لغرض تجنيب السكان والبنية التحتية الخسائر المترتبة على ذلك وتقليل أثرها. تناولت هذه الدراسة احتمال انهيار سد دربندخان وتأثيره على المناطق الواقعة على امتداد حوض نهر ديالى وعلى سلامة سد حمرين، باستخدام برمجيات النمذجة الهيدرولوجية المتقدمة ونظم المعلومات الجغرافية لغرض الحساب والعرض. وقد تم استخدام برنامج النمذجة الهيدرولوجية (WMS9.1) المتضمن النمذجة الرياضية المبسطة الخاصة بانهيار السدود (SMPDBK91)، واعتمد نموذج الارتفاع الرقمي للمنطقة كأساس لإعداد المقاطع العرضية على امتداد النهر وكأحد المدخلات الاساسية في حساب النموذج الرياضي ومن ثم اعداد خرائط الغمر. وقد اظهرت نتائج النمذجة الرياضية ان اقصى عمق لماء الفيضان قرب جدار جسم سد حمرين عند المنسوبين (471 و485) متر فوق مستوى سطح البحر، حوالي (5.6 و6.3) متر على التوالي. ووجد ان لا تأثير لانهيار سد دربندخان على سلامة سد حمرين طالما كان منسوب الماء في خزان بحيرة حمرين وقرب جسم السد لا يتجاوز (100.7) متر فوق مستوى سطح البحر، عند وقت الانهيار الافتراضي لسد دربندخان.

الكلمات المفتاحية: خرائط الغمر، فتحت الكسر، وقت وصول المياه وبرنامج (SMPDBK91).

Introduction

Dams, in general, suffer threats to collapse because of the geological situation of the dams or for natural causes such as earthquakes, or man-made subversive acts. The collapse of water dams, especially those in areas with high seismic activity, are prone to collapse, and have become part of the geographical and historical reality in today's world (Hamdan, 2014). In Iraq, warnings are escalating from the collapse of dams in which several reasons may be man-made, neglect or because of natural disasters represented by earthquakes that may lead to other disasters such as rockslides. On 12/11/2017, an earthquake occurred on the Iraqi-Iranian border near the city of Halabja and Darbandikhan dam in the Sulaymaniyah governorate, with a 7.3 magnitude on Richter scale, it was followed by a large number of aftershocks of various amounts that led to the collapse of some of the rock masses that fall near the shoulders and wall of the Darbandikhan dam, in addition to exposure of the area to movement in two directions, vertical and east-west directions according to the analysis of radar data and differential interference measurements taken by the satellite aperture radar of the Sentinel 1 satellite (SAR Interferometry) (Coseismic Vertical Surface, 2017) which used to detect changes in the Earth's surface and to capture ground movements that resulted from the earthquake. Differential interference is done by combining the topographical information with the radar images taken by the satellite's radar before and after the earthquake, which is represented in the inside of the colored rings associated with the event, as each color cycle indicates a different phase of movement and interpreted as deformation in the ground, with a distance of 2.8 cm. From the measurements of the differential interference, it was found that the southern regions of the dam area have more color rings than the northern areas close to the dam, which indicate the potential land movement between the earth plates. The results of the differential interferometer show that the Arab plate has moved a distance of about a meter, according to the satellite data. It turns out that the displacement of the shock wave is distributed in both perpendicular directions on the areas of shock occurrence, as shown in Figure (1), where the figure shows that the area surrounding the dam, at a distance of 30 Kilometers, was subjected to movement in the vertical direction with an displacement of -30 cm. downward and 90 cm upward and with a distance ranging between 0 and -40 cm in the east direction, while no displacement was observed in the vicinity of the dam, however, the Darbandikhan Dam could be affected by this and be vulnerable to cracks and in its wall, which poses a threat to the region and the surrounding areas. Therefore, it became necessary to work out hypothetical scenarios for the collapse of the Darbandikhan Dam. In order to define and delineate the areas of inundation along the course of the Diyala River downstream towards Hamrin Dam, so that precautions to avoid the danger of a flood disaster can be made. The digital elevation model with a resolution of 90 meters (Alos Global Digital Surface Model) and Landsat 8 images were used to extract the land features. The scenarios input was taken to create a mathematical model using specialized software to represent the case of the collapse, and then determining the areas that will be submerged as a result of this collapse along the course of the river, in addition to calculate the water arrival time required to cover the areas in the Diyala River Basin towards Hamrin Dam. WMS9.1 and SMPDBK91 Software were used to model hypothetical collapse cases for the Darbandikhan Dam, Global

Mapper and ArcMap Software were used to display the results.

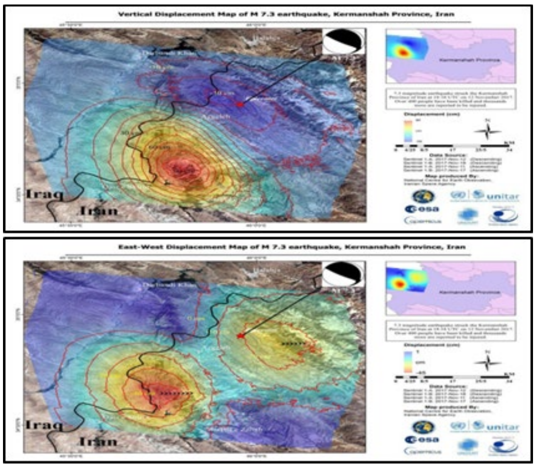


Figure (1) Distribution of the Ground Displacement in both Vertical and Horizontal Directions on the Areas of Occurrence of the Earthquake, (Coseismic Vertical Surface, 2017).

Materials and Methods

The Location and Specifications of the Darbandikhan Dam

The Darbandikhan Dam is located in the Sulaymaniyah governorate, surrounded by chains of mountains, at a distance of 233 Km northeast of Baghdad and 57 Km southeast of Sulaymaniyah and is about 20 Kilometers from the Iraqi Iranian borders, (35° 06' 46" N 45° 42' 23" E) (Figure 2). The dam was built on the Diyala River to form a lake known as Darbandikhan Lake (Al Mazroui, 2013). The height of the dam is about 128 meters, and its length is about 445 meters. As for its maximum width at its top it is about 17 meters, and the maximum area of the dam reservoir is about 110.8 Km^2 with a capacity of 2.6 Km^3. The water level in the dam reservoir in its normal state, reaches 485 meters above sea level, (Al-Mukhtar, 2010) and (Hussein, 2010).

The method

The WMS 9.1 (WMS9.1, Tutorials) Software was used for the purpose of preparing data for the scenario of the collapse of the Darbandikhan Dam and indicating its impact and determining the areas of inundation along the Diyala River Basin, starting from the first cross section of the dam area and up to the ninth cross section of the Hamrin Dam, by implementing the simplified mathematical model for the collapse of the dams SMPDBK91, (Wetmore and Fread, 1981) which requires the following inputs: elevation of water level, elevation of breach bottom, volume of reservoir, surface area of the reservoir at dam crest, width of rectangular breach and amount of secondary drainage in addition to the topographic cross sections of data digital elevation model above sea level and Material Properties, Table (1), in order to calculate the amount of water drainage and the maximum water level and flood depth, Also the time of reaching the maximum depth of water in each region, and then calculating some of the outputs using mathematical equations for the terms and factors related to the flow of water in the river basin, such as calculating the flow rate of water and the time of its first arrival in each region. The highest water level in the reservoir was 485 meters above sea level, with a surface area of reservoir 110.79 Km^2 and the volume of the reservoir is 2.567 Km^3, which are the general specifications of the dam, as well as the elevation of water level 471 meters, whose surface area was calculated, which amounted to 60.0104 Km^2, and its volume which reached 1.427 Km^3 and a width of rectangular breach 150 meters was adopted.

ArcMap Program was used to prepare data for the area's features Material Properties from Landsat 8 images and classify them into agricultural areas, residential areas, water, mountains, and rocky lands, (Al-Khalidi, 2015). The engineering specifications of the course and basin of the river were used, in which the roughness coefficients of the above features were adopted according to (Table 2) (Manning's n Values).

Table (1) Software Implementation Inputs SMPDBK91 and WMS9.1

Elevation of Water Meter	Volume of Reservoir Km^3	Surface Area of Reservoir Km^2	Non-breach Flow m^3/sec	Width of Rectangular Breach Meter
471	1.427	60.0104	0	150
485	2.567	110.79	0	150

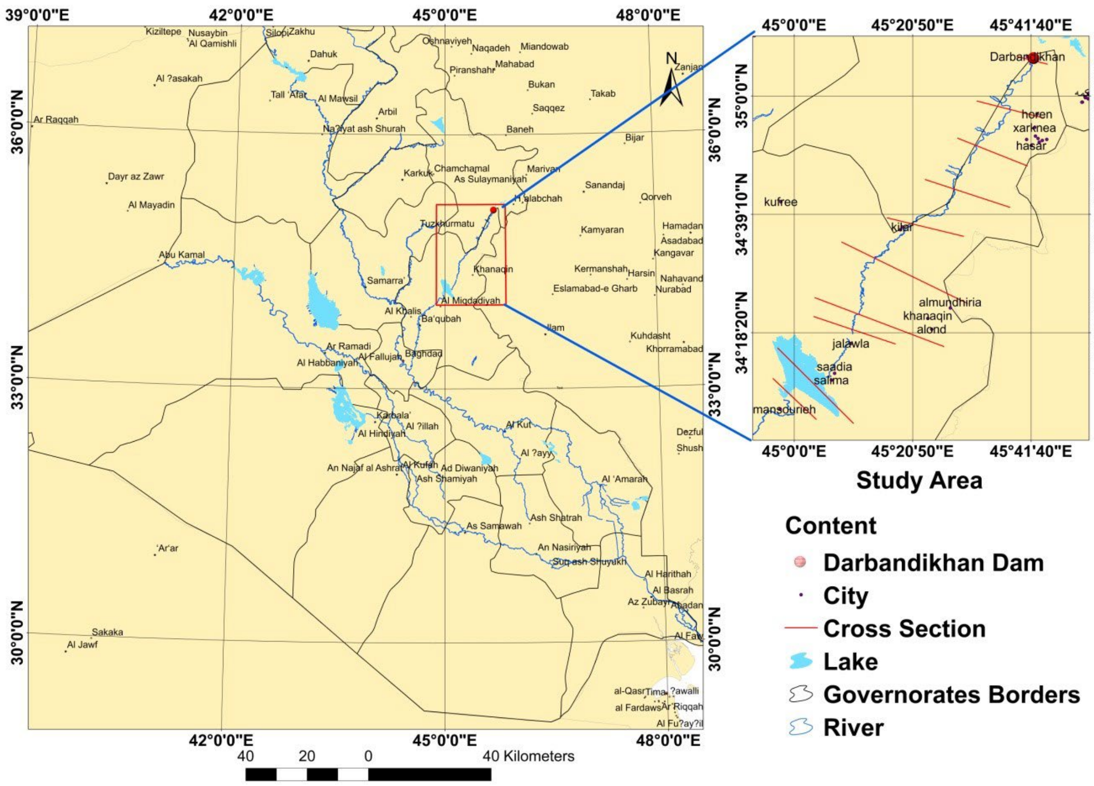


Figure (2) The Darbandikhan Dam Site and the Cross Sections Used in the Modeling.

Table (2) Roughness Parameters

Agricultural Areas	0.06
Residential Areas	0.08
Water	0.05
Mountains	0.08
Rocky Lands	0.07

Results and Discussion

The implementation of the WMS 9.1 Software and the application of the mathematical model SMPDBK91 were carried out for the purpose of preparing a scenario for the collapse of the Darbandikhan Dam at water reservoir elevation 471 and 485 meters above sea level, using some data on the specifications of the dam and the data related to the causes of the collapse, which lead to outputs related to depths water, its arrival times, the time it takes for the water to spread, the start of the flood and its submersion to the areas adjacent to the river, and the time required for it to end, (Wetmore and Fread, 1981) which were illustrated by mathematically representing the resulted data in the form of graphs and finding their proportional relationships with the distance in Kilometers from the dam. Figure (3) shows the relationship between the amount of water flow with the distance that each area is away from the dam, as the amount of water flow decreases with increasing distance. At the water 471 meters above sea level in the dam reservoir with the assumed width of rectangular breach of 150 meters. The amount of water flow in the Darbandikhan Dam area was 210920.9 m^3/sec and it became in the Hamrin Dam area 57002.7 m3/sec. These amounts increase when the reservoir water level in the Darbandikhan dam rises to 485 meters, where the amount of water flow at the Darbandikhan dam becomes 287310.2 m3/sec, and in Hamrin dam 81262.5 m3/sec. The values of the maximum height of the water level decrease as we move away from the Darbandikhan Dam, as shown in Figure (4), and there are few differences between the assumed scenarios of increasing the water level in the reservoir to the water levels in each area during the flood. At the Hamrin Dam, the height value, which here represents the elevation of the water surface in Lake Hamrin Dam, is approximately 85.1 meter above sea level, and at the Darbandikhan Dam, 378.2 meter above sea level. The difference between the water level and this elevation represents the depth of the surplus water in meters, which ranges at the water level 485 meter between 70.1 meter in the Darbandikhan Dam area and 6.3 meter in the Hamrin Dam area. This means that the water level at the Hamrin Dam wall which is Equal to 85.1 meter it will increase by 6.3 meter from the water level in the lake of the dam, and this depth does not represent the critical state of the flood water level in the Hamrin dam, which is 107 meter above sea level, which represents the critical height of the water in the reservoir, (Hamdan, 2014), This indicates that the natural water level in the Hamrin Dam reservoir near the dam body should not exceed 107-6.3=100.7 meters above sea level.

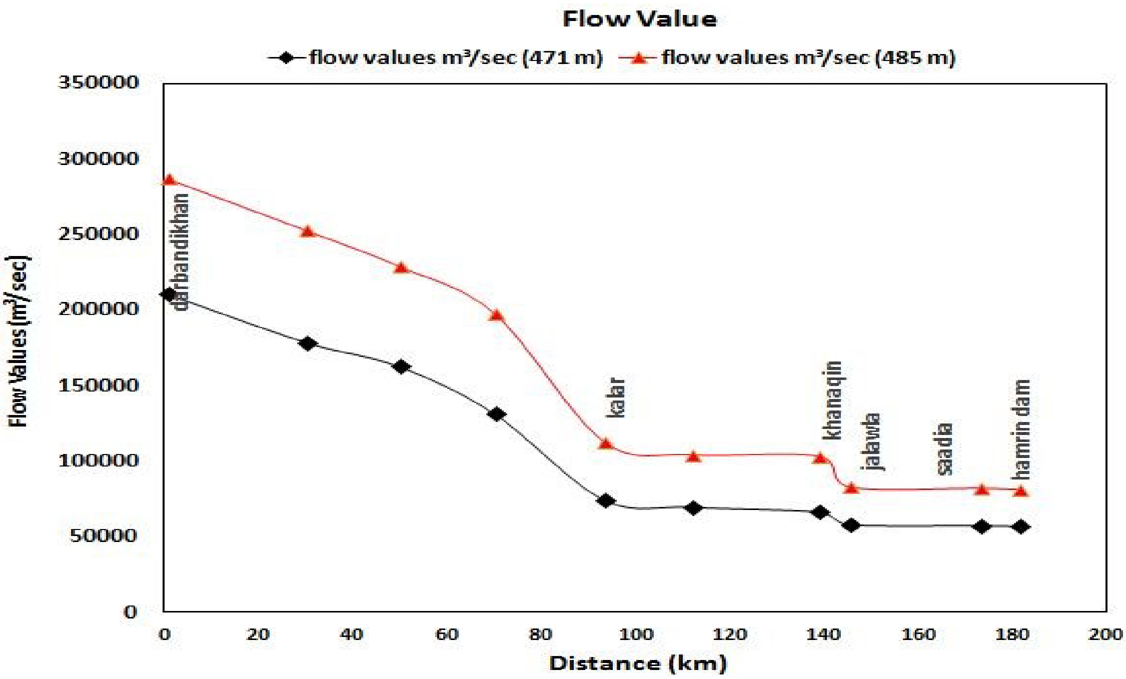


Figure (3) The Amount of the Flow of Water Along the River from the Darbandikhan Dam to Hamrin Dam.

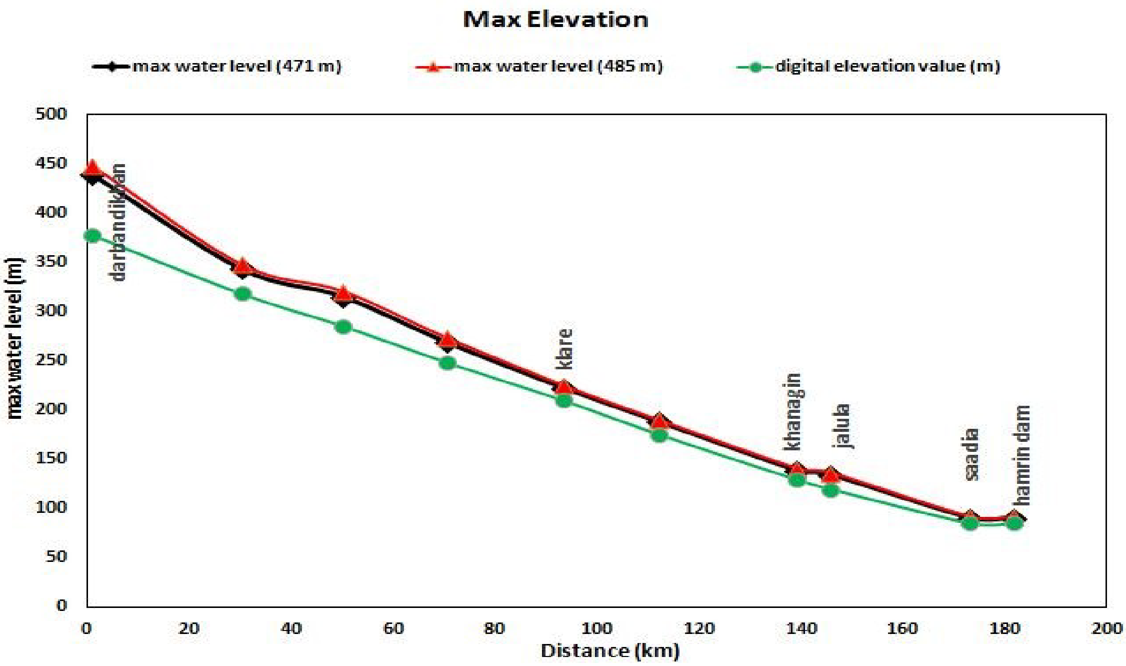


Figure (4) The Maximum Water Level Along the River from the Darbandikhan Dam to Hamrin Dam.

As for the time of the start of the flood and the time of the arrival of the water to its maximum depth and the time of the end of the flood (Deflood), which are shown in Figure (5), it becomes clear that increasing the water level in the reservoir leads to a decrease in the time required for the water to reach the dam lake and the time for the water to reach its maximum depth as the amount of flowing water increases. Whereas the time required for the end of the flood and along the course of the river increases due to the accumulation of large quantities of water with an increase in the water level in the reservoir of Darbandikhan Dam, which makes it take a longer time for the water to retreat or spread. At the water level 471 meter, the time of water arrival to Lake Hamrin Dam was 25.15 hours, and the time for water reaching its maximum depth 27.1 hours, and the times became 22.83 and 24.8 hours when the level increased to 485 meters as for the end time of the flood, it was 38.76 hours and became 40.12 hours as illustrated in Table (3). Figure (5) also shows that the time required for the water to reach its height and reach its maximum depth and then its termination in every region along the course of the river increases with the increase in the distance, as the amount of water flow decreases, which leads to a decrease in the amount of water and thus it takes longer time to reach and rise to maximum depth and back down. It is also noticed that there is a sudden increase in the time of water arrival and its height to the maximum depth and time of the end of the flood in the area between Khanaqin and Jalawla towards Hamrin Dam, which is due to the topographical nature of the area as the topography of the area decreases, which leads to the spread of water on both sides of the river and thus increases the time required for the arrival of the first wave to Hamrin Lake as a result of implementing the program.

Table (3) The Results of the Implemented Scenarios

Elevation Above Sea Level of Water (Meters) at Dam Reservoir	**471**		**485**	
City	Darbandikhan Dam	Hamrin Dam	Darbandikhan Dam	Hamrin Dam
Distance from Dam (Km)	0.89	181.59	0.89	181.59
Max Flow (m^3/sec)	210920.9	57002.7	287310,2	81262.5
Max Depth (Meter)	61.7	5.6	70.1	6.3
Max Elevation (Meter)	439.9	90.6	448.3	91.3
Distance of Water Spread (Meter)	565.4	1089	600.8	1274.4
Time Flood (Hour)	0	25.15	0	22.83
Time Max Depth (Hour)	2	27.1	2	24.8
Time Deflood (Hour)	3.8	38.76	5	40.12

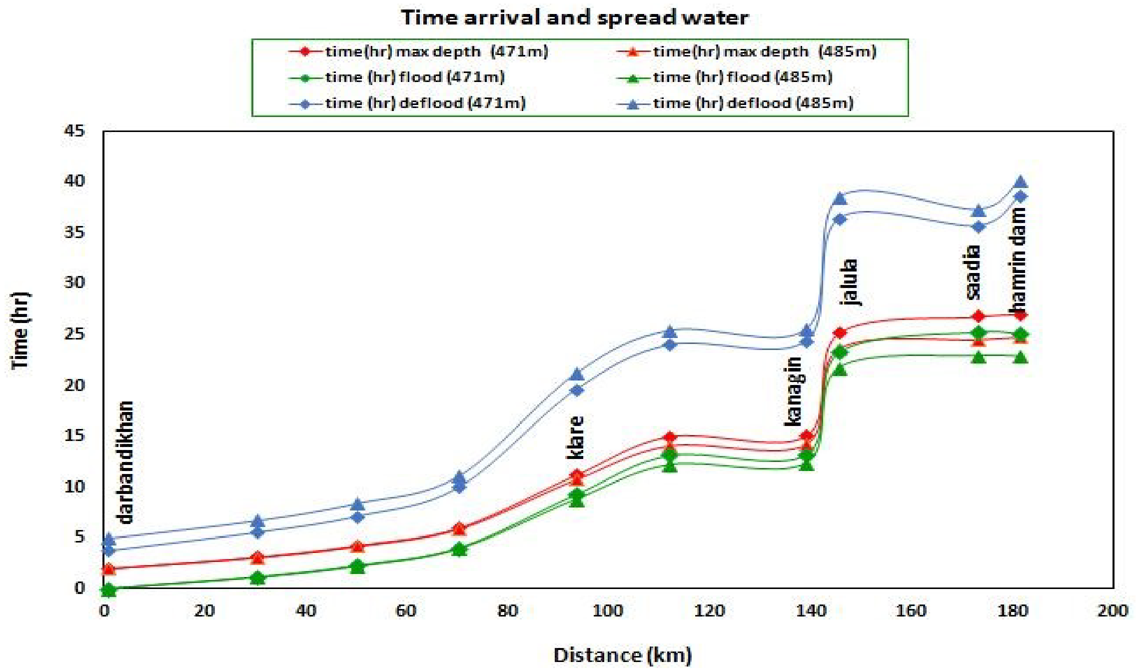


Figure (5) The Necessary Time for Water and Flooding in Every City Along the River from the Dharbkhan Dam to Hamreen Dam.

The speed of water flow is changing along the stream of the river. It is increasing in certain areas and is reduced in other depending on the terrain nature of the area as well as the extent of land use, Figure (6). The speed of water is increasing with increasing water levels, where the speed of water is based on the rise in the water level in the reservoir and water energy when they flow on the dam and the obstacles that oppose or meet that water (Forests, Buildings and Land Use) over the course of the river. The speed of water movement is low and somewhat stable, except in areas where the water recedes between the mountain ranges, where its speed increases greatly. This is in addition to the increase in the slope of the land, especially in the area near the Hamrin Lake, where the water descends rapidly towards the lake to pour into the lake.

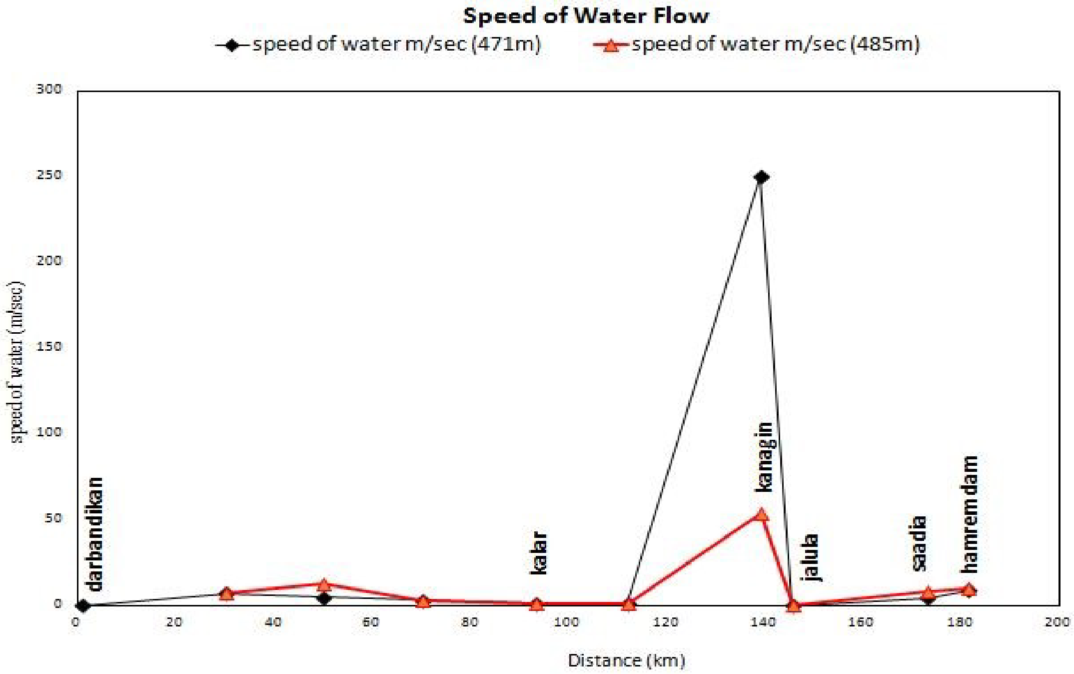


Figure (6) Speed of Water Flow Along the River from the Dharbkhan Dam to Hamreen Dam.

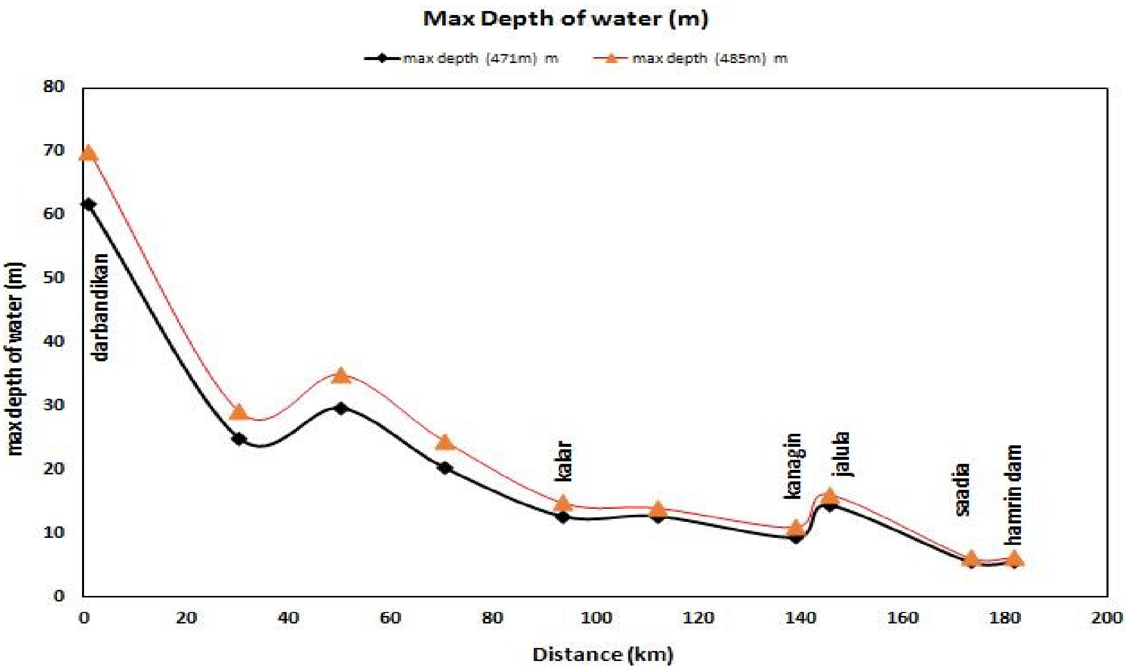


Figure (7) The Maximum Depth of Water Along the River from the Darbandikhan Dam to Hamrin Dam.

It is noticed that the depths of water are different in cities, where the depth of the water depends on the increase in the water level in the lake of the Darbandikhan Dam and on the extent of the spread of water according to the nature of the terrain that it passes through and on the uses of the land. From Figure (7), it appears that the maximum depth of water gradually decreases in cities after Darbandikhan, as this is due to the slop of topography towards the south, and this leads to an increase in the spread of water in it on both sides of the river and thus reduces the depth of the water in it. In the city of Darbandikhan, the maximum depth of water in it was 61.7, 70.1 meters at water levels 471 and 485 meters respectively and in Kalar, Saadia and Hamrin, the maximum depth of water reached 12.7, 5.5, 5.6 meters respectively at the level 471 meters above sea level and 14.9, 6.2 and 6.3 meters respectively at the level of 485 meters above sea level. It is noticed that the depth of water in the region continues to decrease, except in the area between the city of Darbandikhan and Kalar, where the depth of water increases, as the water is confined between a series of mountain heights that limited the spread of water on both sides of the river. Through the multiple scenarios that were implemented using the mathematical model SMPDBK91, to determine the areas of water spreading on both sides of the river. Figure (8) shows the areas of water spreading along the course of the river, whose extensions depend on the area's topography. As it appears that the areas of water spreading are almost equal along the course of the river and the adjacent areas reaching to the lake and the wall of Hamrin dam, except in the Kalar and Saadia areas, in which there is an increase in the spread of water by increasing the water level to 485 meter above sea level, where the land is spread out in these two areas, which helps in increasing the spread of water on both sides of the river. Table (3) shows the results obtained because of implementing the program.

Inundation maps were prepared to show the areas of inundation along the river basin. The data extracted from the application of SMPDBK91 program were adopted and several techniques were used to clarify and highlight the properties of water along and on both sides of the river in terms of depth and spread, Figure (9) illustrates the areas that will be covered Inundation and its depths along the Diyala River basin, and in detail in the cities and regions Darbandikhan, Kalar, Hamrin and that at the levels of 471 meters in the dam reservoir assuming a width of the breach of 150 meter.

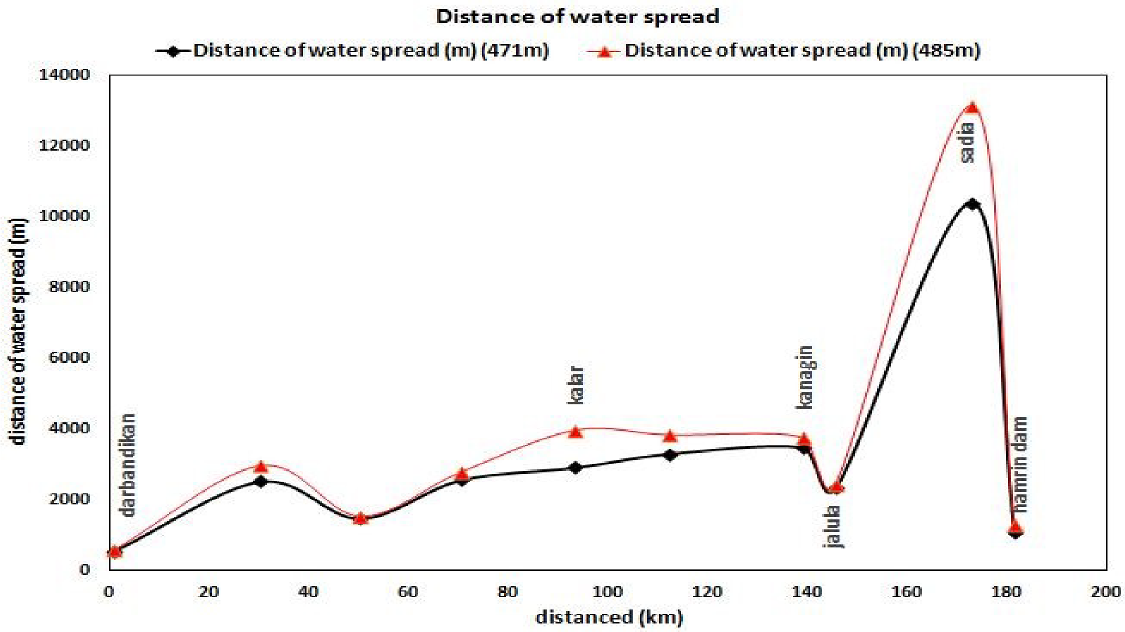
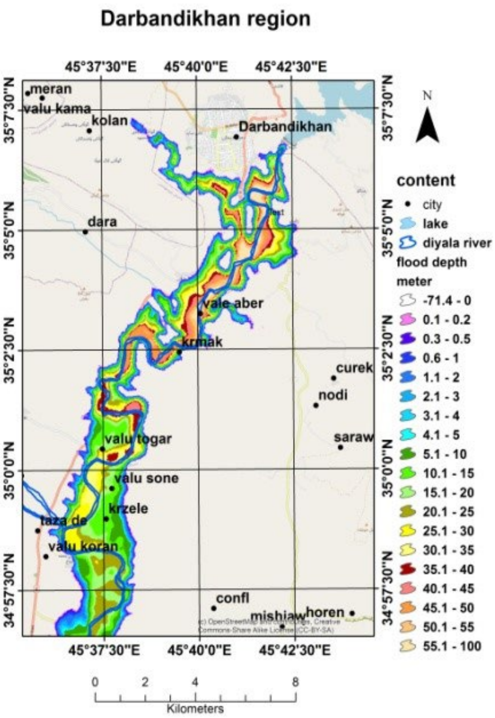


Figure (8) The Distance of Water Spread in Each City Along the River.

Figure (10) illustrates the areas that will be covered Inundation and its depths along the Diyala River basin, And in detail in the cities and regions Darbandikhan, Kalar, Hamrin and that at the levels of 485 meters in the dam reservoir assuming a width of the breach of 150 meter. The depth decreases towards Hamrin Lake and increases in the lake area because it is a low-altitude area and the high depth of the water is observed because it is confined to mountain ranges as mentioned previously as well as the increasing spread of water in the regions of Jalawla, Saadia and Hamrin between 2343.7-1089.0 meters at the level 471 meter and between 2433.2-1274.4 meters at the level 485 meter because the areas near the river are flat compared to other areas. Residents of these areas can also be warned about the time of water arrival, which ranges from 9.3 hours at the south of Darbandikhan to 25.15 hours in the Hamrin area when the water level is 471 meters and it takes 8.8 hours to 22.83 hours at the level 485 meter.



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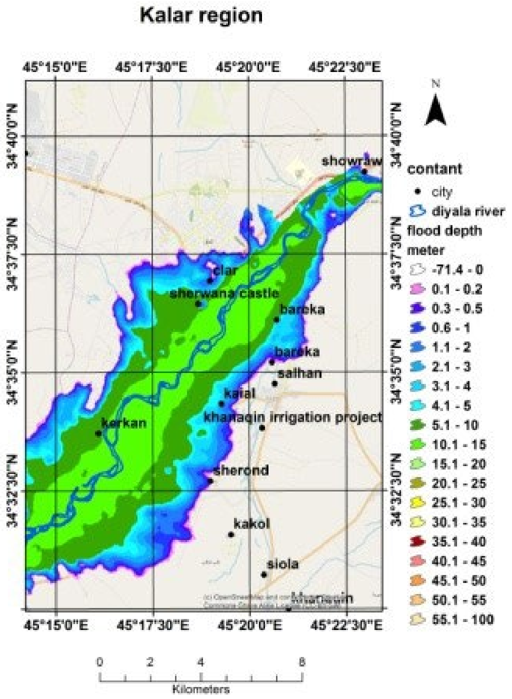

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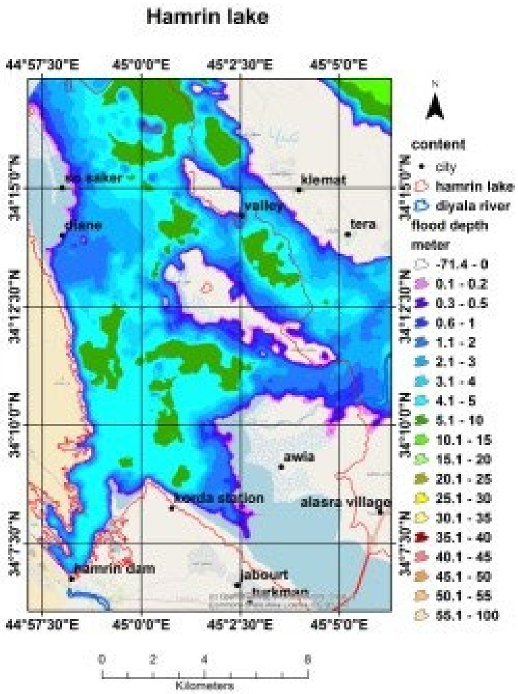
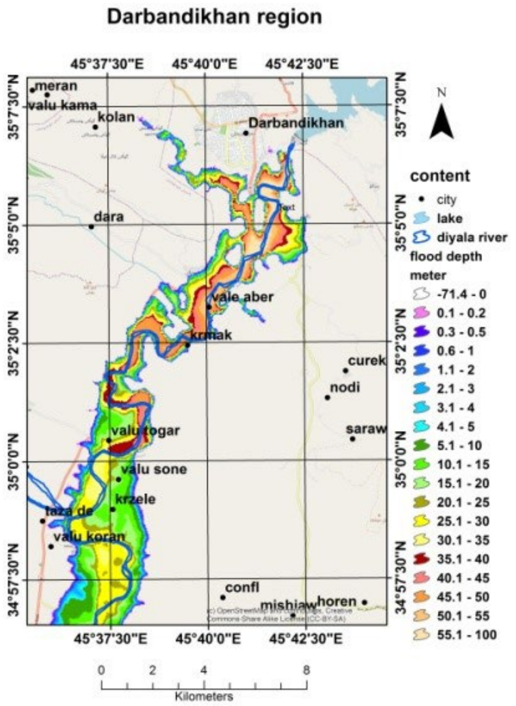


(c)

Figure (9) The Inundation Maps for the Regions of Darbandikhan(a), Kalar(b) and Lake Hamrin(c) at the Levels 471.



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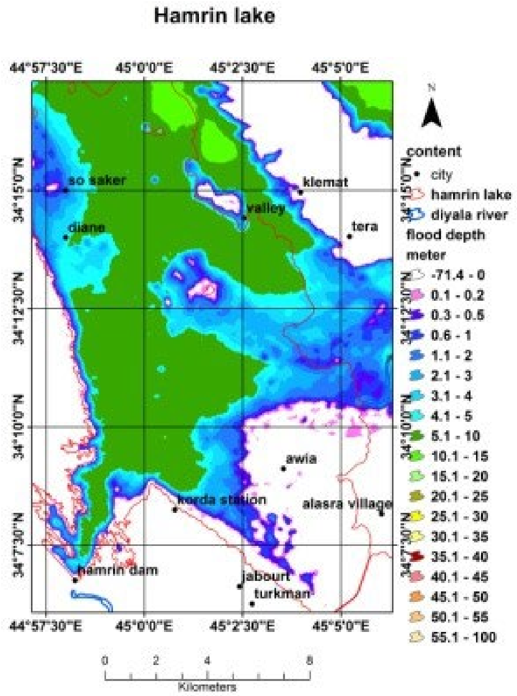
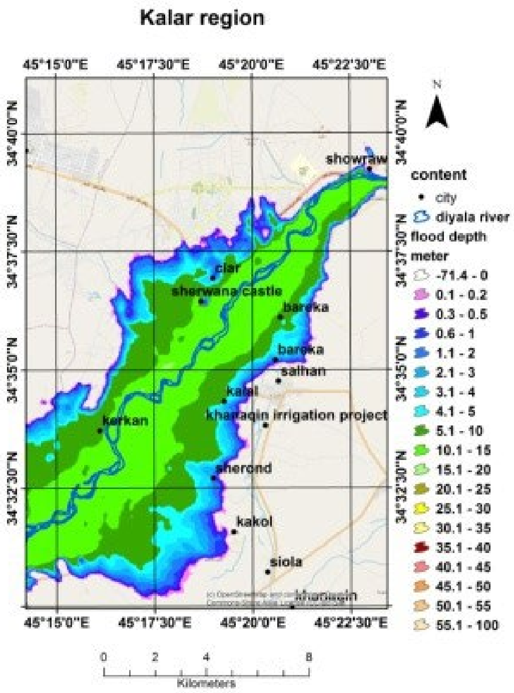


(c)

Figure (10) The Inundation Maps for the Regions of Darbandikhan(a), Kalar(b) and Lake Hamrin(c) at the Levels 485.



(b)

Conclusions

From the foregoing and above, and through the implementation processes of the program for hydrological modeling and analysis of the obtained data, the following can be concluded:

1- Flow decreases with increasing distance. At the reservoir water level 471 meter above sea level in the Darbandikhan dam with assumed width of rectangular breach 150 meter, the amount of water flow in the beginning of the Hamrin Lake was 57578.5 m^3/sec and it became in the Hamrin Dam area 57002.7 m^3/sec, and it increased. These amounts increase when the reservoir water level in the Darbandikhan dam rises to 485 meters, where the amount of water flow at the beginning of the Hamrin Lake becomes 82083.3 m^3/sec, and in Hamrin dam area 81262.5 m^3/sec.

2- The maximum depth of water at the beginning of the Hamrin Lake will be 5.5

and 6.22 meters at Darbandikhan reservoir water levels 471 and 485 meters above sea level.

3- The time for flood to reach the beginning of Hamrin Lake is 25.3 hours, the time for the flood to reach its maximum depth is about 26.8 hours, and the time for water retreat and the end of the flood is 35.8 hours at the level of 471 meters and a breach of 150 meters. while the time takes 22.9, 24.6 and 37.3 hours at the level of 485 meters above sea level, respectively.

4- The time for flood to reach the wall of Hamrin Dam is 25.2 hours, the time for the flood to reach its maximum depth is about 27.1 hours, and the time for water retreat and the end of the flood is 38.8 hours at the level of 471 meters above the water level in the Darbandikhan Dam and a breach hole. 150 meters, and it takes 22.8, 24.8 and 40.1 hours, respectively, at the level of 485 meters above sea level.

5- The collapse of the Darbandikhan Dam has no effect on the Hamrin Dam if the water level in the Hamrin Lake reservoir and near the dam body does not exceed 100.7 meters above sea level.

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