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Assessment of Groundwater Response Scenarios for Surrounding Areas After Filling the Proposed Badush Dam Reservoir, Northern Iraq

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ABSTRACT

In the current study, the depth of groundwater was detected in (39) wells in the banks surrounding Tigris River between Mosul and Badush dams, and then the maps of depth and level of groundwater were drawn. To predict the response of groundwater behavior in the banks of Badush reservoir in the strips adjacent to the river when starting the filling process, the lines of selected water levels in Badush dam were plotted on the map of groundwater equipotential lines to detect the areas confined between the water level in the reservoir and the same level for groundwater. It is assumed that these areas are affected by the bank storage; therefore, they are prone to leakage or geotechnical problems within the zone of engineering facilities foundations including Badush Dam itself, the regulatory dam and infrastructure projects. In the pre-storage stage, it is noted that the area of influence of the bank storage is very limited and does not exceed 2 km^2 on each side of the river in the area very close to the dam. When the water level raises more at the beginning of the storage, the area of influence of the bank storage will extend towards the upstream close to the river meandering. The effect on the eastern bank (left) will be wider compared to the situation in the western bank (right) where the effect is limited. The eastern side is characterized by having a higher population density and more urban establishments; therefore, the foundations of these establishments will be more affected. The area affected by the bank storage continues to widen towards upstream with the increase in the level of the dam reservoir until the effect reaches the maximum limit and approaches the shoulders of the regulatory dam, when the water levels in Badush reservoir are more than 245 m above sea level (a. s. l.). The variation in the groundwater extension effect with the continuous or gradual filling of reservoir requires monitoring and caution during filling, for fear of affecting the geotechnical properties of the soil and rocks within the foundations zone, and thus affecting the stability of the two dams.

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تقييم وضع المياه الجوفية للمناطق القريبة لسيناريوهات ما بعد الملء لسد بادوش المقترح، شمالي العراق

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الملخص

تم رصد عمق المياه الجوفية في ٣٩ بئراً، في مناطق الضفاف المحيطة بقطاع نهر دجلة بين سد الموصل وبادوش، ثم رسم خرائط العمق المياه الجوفية ومنسوب المياه الجوفية. وللتنبؤ باستجابة سلوك المياه الجوفية على ضفاف خزان سد بادوش في الشرائط المجاورة لقطاع النهر عند بدء ملء الخزان، تم اسقاط خطوط منسوب المياه المنتخبة في خزان سد بادوش على خريطة خطوط تساوي منسوب المياه الجوفية لتحديد المناطق المحصورة بين مستوى المياه في الخزان ونفس المستوى للمياه الجوفية. هذه المناطق يفترض أنها متأثرة بالخزين الضفافي، وبالتالي فهي عرضة لمشاكل التسرب أو مشاكل جيوتكنيكية داخل نطاق أساسات المنشآت الهندسية بما في ذلك سد بادوش نفسه والسد التنظيمي ومشاريع البنية التحتية.
ويلاحظ عند مرحلة ما قبل التخزين أن مساحة تأثير الخزن الضفافي تكون محدودة للغاية ولا تتجاوز ٢ كم^{2} على كل جانب من جانبي النهر في المنطقة القريبة جدًا من السد. عندما يرتفع منسوب المياه أكثر في بداية التخزين، ستمتد منطقة تأثير الخزن الضفافي باتجاه المنبع بالقرب من تعرج النهر، وسيكون التأثير على الضفة الشرقية (اليسرى) أكثر اتساعًا مقارنةً بـ الوضع في الضفة الغربية (اليمنى) حيث التأثير محدودا، ويتميز الجانب الشرقي بوجود كثافة سكانية أعلى ومنشآت حضرية أكثر، وبالتالي فإن منطقة الأساسات لهذه المنشآت ستكون أكثر تأثراً. تستمر المنطقة المتأثرة بالخزن الضفافي بالاتساع باتجاه المنبع مع زيادة مستوى الماء في خزان السد حتى يصل التأثير الى أقصى حد ويقترب من أكتاف السد التنظيمي عندما يزيد منسوب المياه في خزان بادوش عن ٢٤٥ م (ف.م.س.ب). ان تباين امتداد تأثير المياه الجوفية مع الملء المستمر أو التدريجي للخزان يتطلب المراقبة والحذر أثناء الملء خشية من التأثير على الخصائص الجيوتكنيكية للتربة والصخور في نطاق الأساسات، وبالتالي التأثير على استقرار السدين

Introduction

Mosul Dam is located more than 50 km to the northwest of Mosul city, whereas Badush Dam is located about 39 km to the south of Mosul Dam, and about 15 km to the northwest of Mosul city. The regulatory dam is located between the two above mentioned dams on the river. Figure (1) shows the locations of the three mentioned dams.

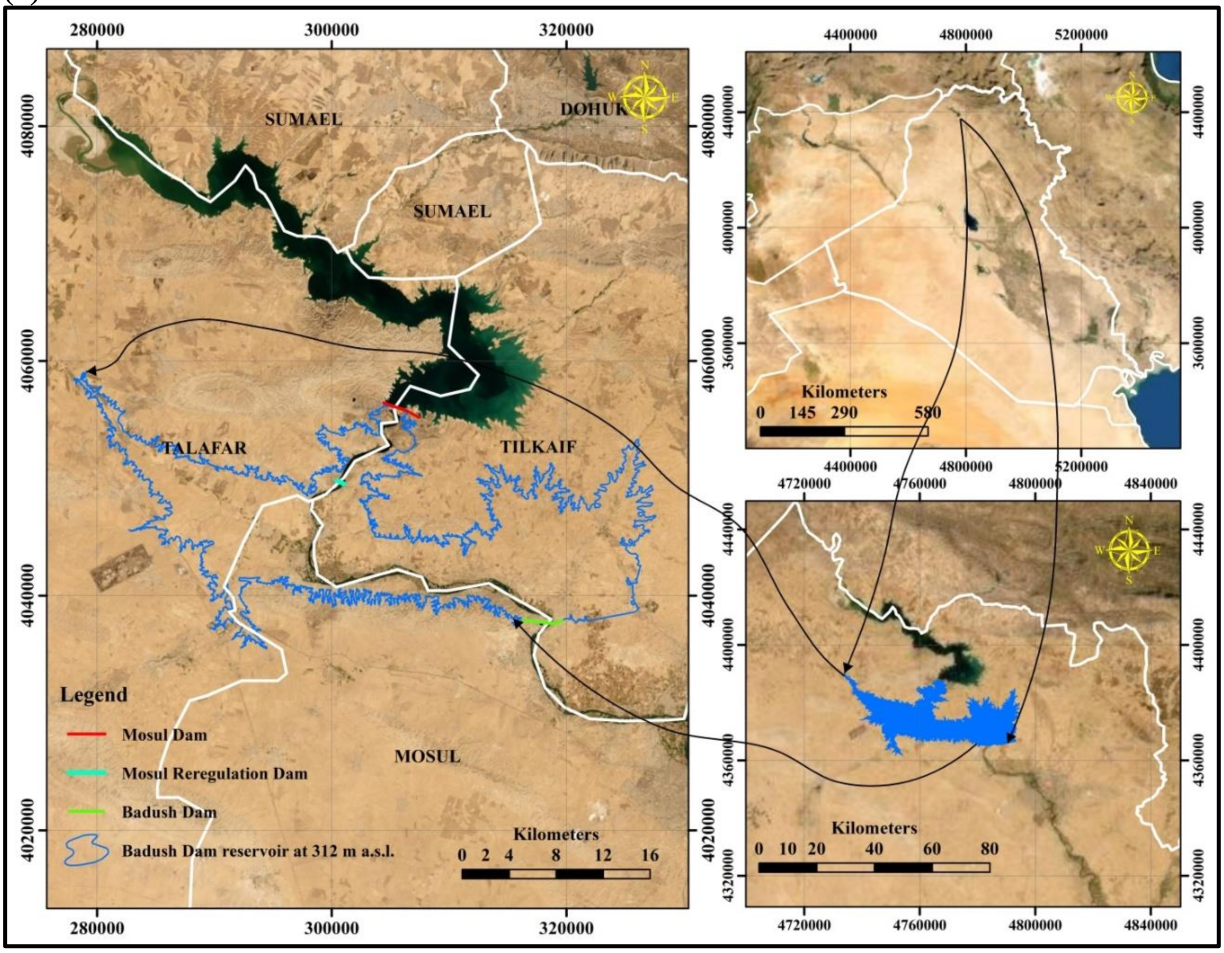

Fig. 1: Location of dams under study

The groundwater is an essential resource for fresh water and comes as a second in the world after rivers and lakes, rather, it is the first in many countries. Thus, usually the hydrogeological and hydraulic conditions are evaluated to predict the impact of bank storage that will flow far from the reach of original river and extend to the strip surrounding the reservoir [1].

Therefore, the groundwater behavior will have significant effects on the engineering and geotechnical properties of the foundations zone, which may lead to subsidence and may be followed by a breakdown in the foundations zone of the dam facilities or engineering facilities established on the banks of the river or the banks of the reservoir [2]. Then, the flow directions will be affected according to the new situation of banks as aquifer [3];[4].

From this perspective, the simulation of groundwater behavior is directly related to the simulation of the reservoir filling scenarios. One of the controlling factors in this case is the topography that controls the boundaries of the submerged areas when starting to fill the reservoir, as well as the depths and levels of groundwater. Figure (2) shows the digital elevation model, which is derived from the boundaries of the contour line of (312 m) ground surface elevation.

Another determining factor is the hydrogeological boundaries of aquifer crossed by the river in the mentioned area on both sides of the river (and reservoir) represented by the river itself and the structures, because they control the recharge and discharge zones and flow directions.

It is important to identify the behavior of groundwater after the start of filling stages, because the extensions of the influenced zone at each stage are affected by the topography of the region [5].

Accordingly, this study aims at predicting the behavior of groundwater in the area adjacent to Tigris River between Mosul and Badush Dams, passing through the regulatory dam under the conditions of the reservoir filling, and then the beginning of the normal operation. This leads to two main aims as follows:

1. Describing the reality of groundwater, the depths and levels, and thus the flownet.
2. Projecting the submersion lines of the reservoir on the underground flow network.

Therefore, the equipotential lines of the flownet will be decisive in determining the zone affected by the bank storage for the stage after the operation of the reservoir.

2. Research Methodology

To predict the response of groundwater behavior in the banks of Badush reservoir when starting the filling process in the strips adjacent to the river reach between Mosul and Badush dams, the following steps were adopted:

1. The depth of groundwater was detected using the groundwater depth indicator in (39) wells, in the banks surrounding the areas near the river range, and then the depth of groundwater was interpolated and mapped using Arc GIS version 10.8.

2. The groundwater levels m (a.s.l) were derived from the monitoring wells, and then the groundwater was interpolated and mapped using Arc GIS version 10.8.

3. The groundwater levels were interpolated using KRIGING method using geostatistical analyst in Arc GIS 10.8 software to draw the equipotential lines map.

4. The equipotential lines map was plotted on the lines of water levels in the reservoir during the filling in the same map.

5. The area bounded between the submerge water line (the water level in the reservoir) and the equivalent groundwater equipotential line was mapped using GIS 10.8 as the affected zone by the groundwater storage in the banks after filling the reservoir.

3. Results and Discussions

3.1. Topography and its relation with groundwater

The watershed of the study area is undulated and topographically complex, the elevations are as high as possible in the southwestern edge, reaching more than (900) m (a.s.l), while in the northwestern edge of the basin, their height exceeds (500) m (a.s.l). Then, the elevations gradually decrease towards the east until reaching the lowest level at the studied range of the river between Mosul and Badush dams, where the heights at the two banks of the river are less than (250) m (a.s.l). As for the area surrounding the reservoir, which is subjected to flooding in case of the breakdown of Mosul Dam, their heights reach more than (300) m (a.s.l), extending towards the west and southeast of the river reach between the two dams. As for the rest of the watershed, which is not subjected to flooding in case of the breakdown, the height ranges between more than (400-500) m (a.s.l).

In general, the region includes a system of valleys that control the discharge of surface water to the east and west directions to Tigris River reach between the two dams (see figure 2). This topographical variation will control, in one way or another, the behavior of groundwater on both banks of the river after the start of the initial operational filling.

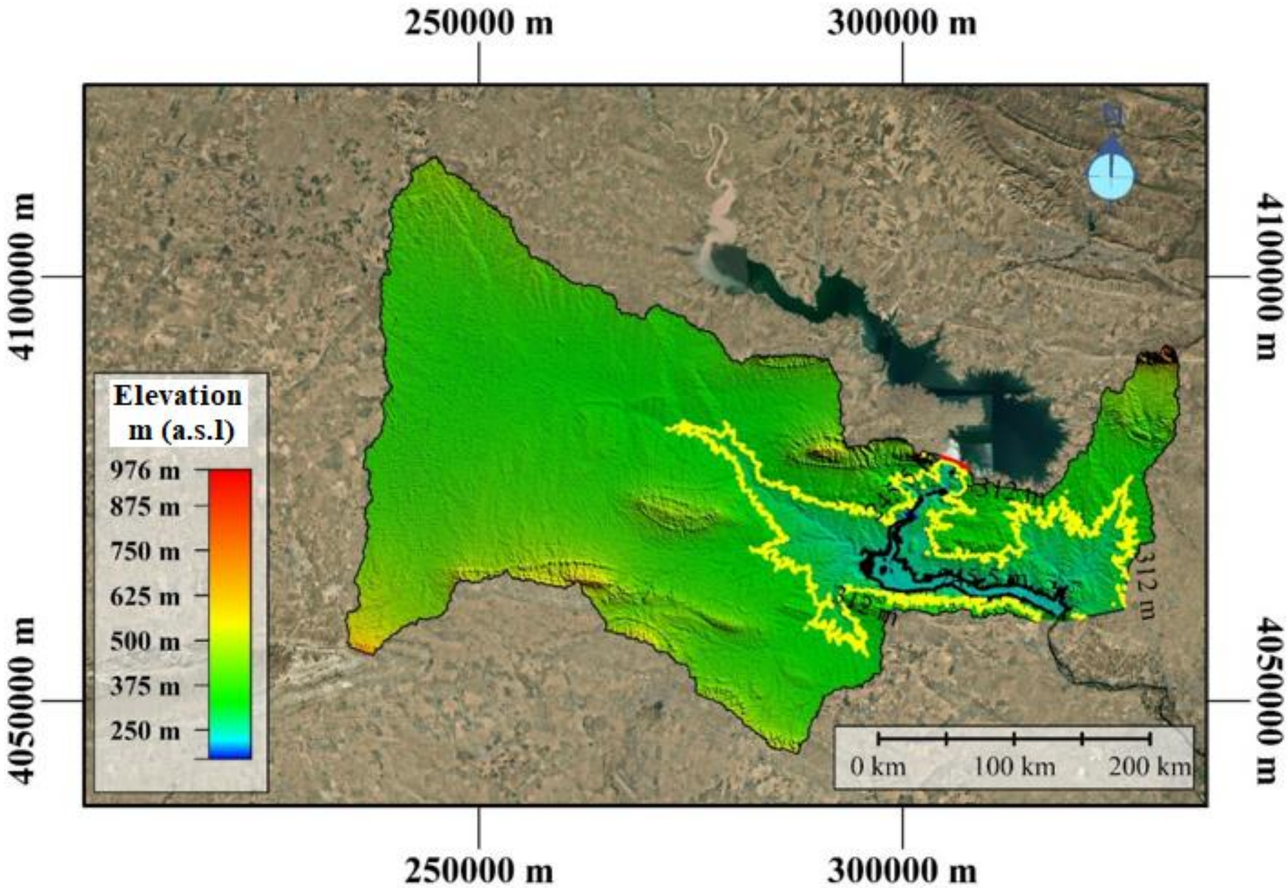

Figure 2: Digital elevation model of the river within the reservoir boundaries, marked by the maximum operational level of the reservoir (in black) and the maximum flood level when the breakdown of Mosul Dam happens (in yellow)

3.2. The Depth of Groundwater

Depth is a key factor in investing the groundwater; therefore, it is focused on in traditional hydrogeological studies. Depth is of great importance in evaluating the engineering effects of fluctuating groundwater on the geotechnical properties of the engineering facilities foundations built on the earth surface. The depths are mainly affected by topographical, geomorphological and lithological features in the aquifer area, as well as the surface drainage system, the recharge and discharge areas and hydraulic characteristics of aquifer, the general direction of flow, hydraulic connection of the aquifer with other aquifers, and the interaction between the surface water and groundwater [6]. From this perspective, it has become necessary to predict the behavior of groundwater and the depths change when the reservoir begins to fill, at least in the adjacent area on both sides of Badush Dam reservoir.

The depth monitored in (39) groundwater wells on both sides of the river reach between Mosul and Badush dams was used to plot a map of the spatial distribution of depths. It was shown that these depths are within the limits of less than two meters, which is the least possible at the strip adjacent to the two banks. Then, these depths begin to increase as moved away from the banks to the east and west of the study area and at the edges to reach more than ٤٠ m within the limits of the immersion line in case of the operation of Badush Dam reservoir. The locations of these wells are depicted in figure (3), while the data of the depth and level of groundwater is listed in table (1).

Table 1: The depth of groundwater and the elevation of water stream in m (a.s.l.) of 39 wells monitored in this study

Well no.	Easting UTM	Northing UTM	Depth of water	Water Stream	Well no.	Easting UTM	Northing UTM	Depth of water	Water Stream
w1	296604	4043188	6.66	239.34	w21	313166	4041805	37.19	234.81
w2	296808	4043207	6.64	239.36	w22	315122	4040930	11.17	233.93
w3	302311	4048518	40.18	246.82	w23	316864	4039241	5	225.548
w4	302843	4048706	44.28	258.816	w24	316818	4039352	7.38	225.62
w5	301770	4047967	37.5	236.5	w25	317187	4039664	9.55	227.764
w6	301193	4047808	36.18	236.775	w26	313007	4040123	26	259
w7	299312	4044615	16.8	237.2	w27	311954	4040202	34.28	263.355
w8	300580	4042922	8.33	234.92	w28	307503	4040565	4.15	239.172
w9	302021	4043021	34.08	234.92	w29	306669	4040806	17.44	252.413
w10	295253	4046115	28.68	248.32	w30	306422	4040552	26.76	262
w11	297452	4046712	25.26	255.241	w31	304455	4040511	46.64	293.498
w12	297680	4049793	12	305.75	w32	303134	4041147	1.76	239.139
w13	304643	4043242	23.58	234.42	w33	301909	4047398	33.08	269
w14	305653	4043751	45.5	229.5	w34	301723	4045679	24.5	260.799
w15	307495	4043443	35.63	245.623	w35	301916	4044345	31.42	269
w16	309721	4041847	27.5	233.5	w36	301143	4044366	16.5	262
w17	310449	4041707	31.33	232.669	w37	306450	4043290	27.38	264.588
w18	310499	4042508	37.73	232.954	w38	307263	4043644	46.4	289
w19	312806	4042281	16.92	238.297	w39	310551	4042995	34.38	269
w20	312915	4042677	30.52	240.979					

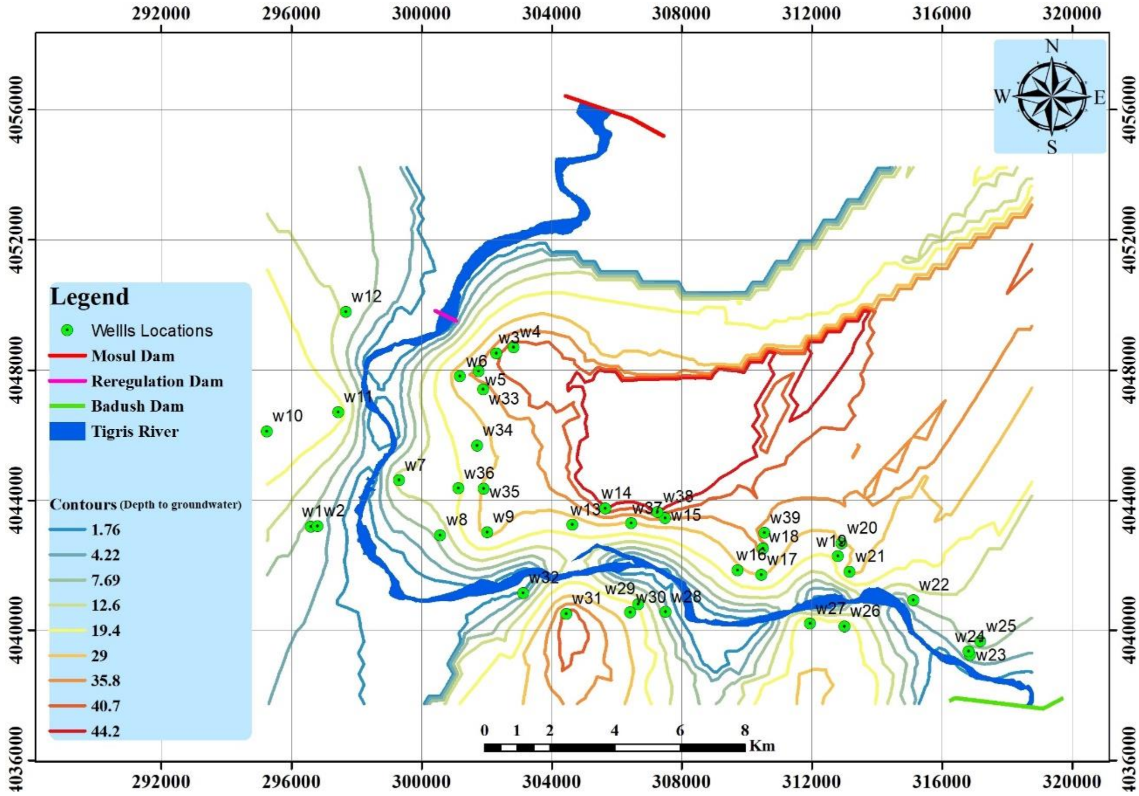

Figure 3: The spatial distribution of the groundwater depths in the study area between Mosul and Badush dams, which are less than (2 m) in the strip adjacent to Tigris River and then increase to reach more than (40 m) to the east and west of the study area

3.3. Groundwater and Flow Directions

The groundwater is one of the basic requirements in the groundwater studies and is the controlling factor in the groundwater movement. The fluctuation of the groundwater level is reflected in the pore water pressure, and thus in the effective pressure in the engineering facilities foundations, their geotechnical characteristics, the hydraulic characteristics of aquifer, the general direction of flow, hydraulic connection with other aquifers, and the interaction between the surface water and groundwater [6]. From this perspective, it became necessary to predict the behavior of groundwater fluctuation when filling the reservoir, at least in the adjacent strip area on both banks sides of Badush Dam reservoir. The data of groundwater monitored in (39) wells on both banks of the river reach between Mosul and Badush Dams was used to plot the spatial distribution map of groundwater. It is shown that these levels were less than (230) m (a.s.l) in the strip adjacent to Tigris River, then they increased to more than 284 m (a.s.l) to the northeast and south of the area surrounding the studied reach of the river (see figure 4).

According to the data of groundwater levels and behavior, the flow directions will be towards Tigris River reach between the two dams, meaning that the river will be a discharge area in the reach under study.

The rise in the water level in Badush Dam reservoir with the beginning of storage will lead to a rise in the groundwater level in the banks of the reservoir to the extent that the reservoir level balances with the groundwater level, and the groundwater continuous to flow in the same direction at the higher levels.

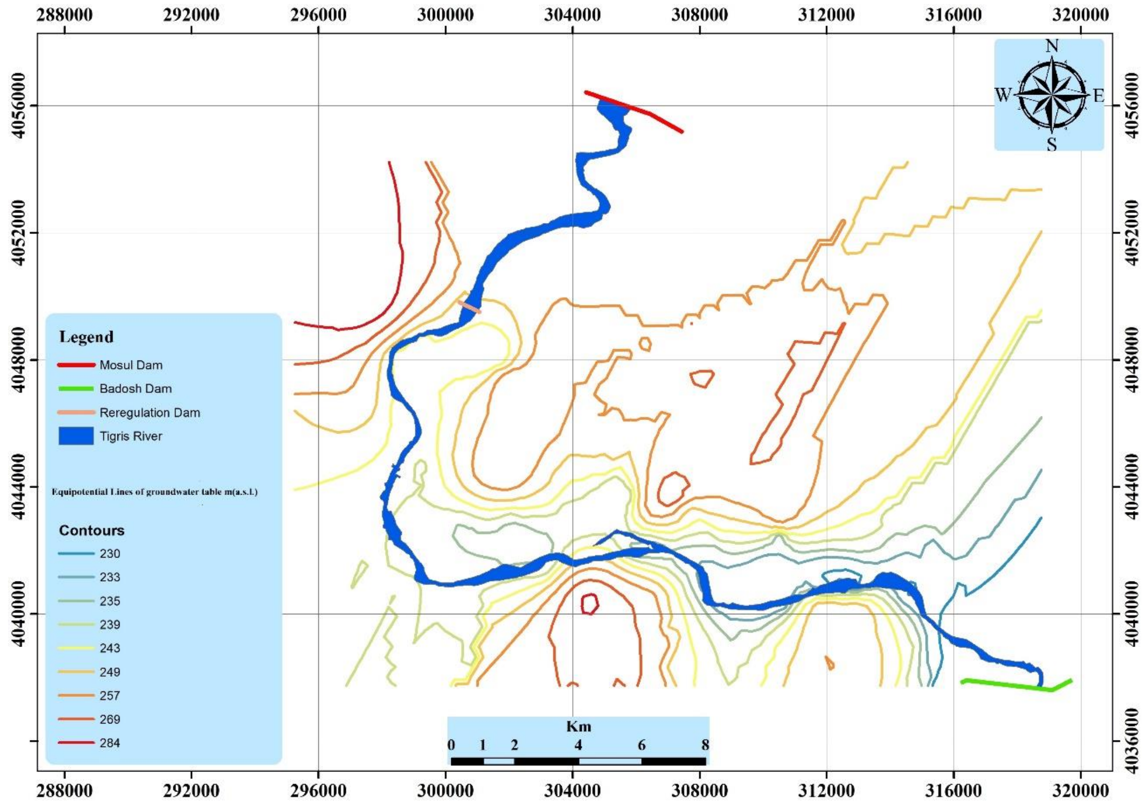

Figure 4: The spatial distribution of the groundwater in the study area between Mosul and Badush dams, which is less than (230) m (a.s.l) in the strip adjacent to Tigris River and then increases to more than (284) m (a.s.l) to the northeast and south of the studied reach of the river

3.4. The Expected Effect of Groundwater on the Banks During Filling

Predicting the future impact of groundwater during and after the beginning of the reservoir filling and the extension of the areas affected by the bank storage in the strip adjacent to the dam reservoir during normal operation (non-flooding) is very important for predicting the geotechnical problems that may occur in this region as a result of the influence of the pore water pressure and thus the change of effective stress in these areas as a result of saturation of the porous media with water at the selected operating level [7];[8];[9].

Thus, it became important to predict the extension of the bank storage areas on the sides of the reservoir at the normal operating levels, starting from the pre-operational level of the reservoir (228) m (a.s.l) to the operating level of the reservoir of (250) m (a.s.l), which exceeds the influence of the bank storage nearby the site of regulatory dam.

Raising the water level inside Badush Dam reservoir will generate a difference in the hydraulic head, which will cause a flow from the dam reservoir to the groundwater. This is attributed to that the recrystallized limestone and dolomite rocks, which represent the main aquifer in the study area, are hydraulically connected due to the presence of fractures, dissolution phenomena, sinkholes, caves, and karst, as confirmed by [10]; [11]. This flow continues until the hydraulic head stabilizes when the effect of the flow reaches the boundaries of the groundwater contour line corresponding to reservoir water level.

For this purpose, several hypothetical operational levels are elected including: 228, 235, 241.5, 245, 250 m. The area is determined between the assumed operational level of the reservoir and the corresponding contour line of the groundwater levels. The area between them is considered as an area of influence for the potential bank storage. Figures (5, 6, 7, 8, and 9) explain the extensions of the effect of bank storage for each of the selected levels, respectively.

Based on figure (5), it is noted that when the water level in the reservoir is (228) m (a.s.l) in the pre-storage stage, the area of influence of the groundwater bank storage is in a very limited area that does not exceed 2 km^2 on each side of the river at the area adjacent to the dam structure. This area very close to the dam will respond to the effect of bank storage at the beginning of reservoir storage directly. This is consistent with the similar conditions mentioned by [12] in a study on Bekhmeh Dam.

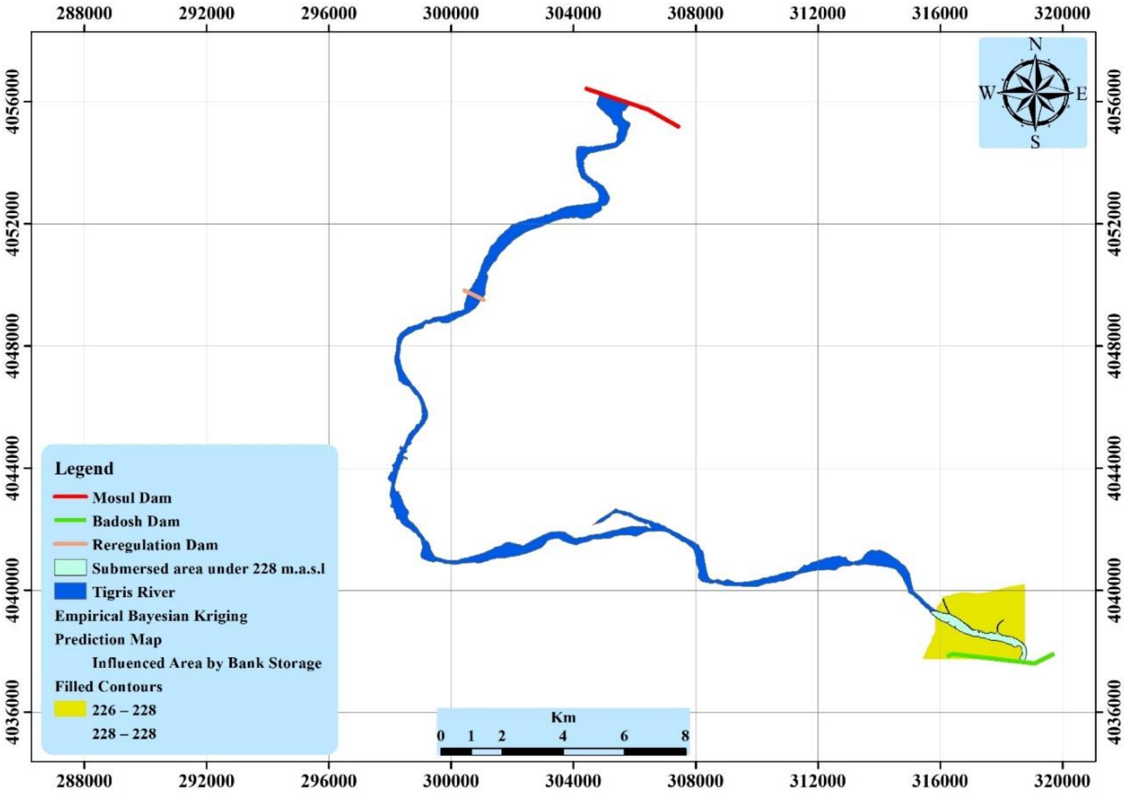

Figure 5: Scenario of the effect of bank storage when water level in the reservoir is (228) m (a.s.l)

As for figure 6, when the water level in the reservoir is (235) m (a.s.l) at the beginning of the storage, the area of influence of the groundwater bank storage will extend towards the upstream close to the main meander area. In addition, the effect on the eastern bank (left) will be more extensive compared to the situation in the western bank (right) where the impact is limited. The eastern side is characterized by the presence of a higher population density and more urban establishments; therefore, the foundations for these establishments will be more affected.

When the water level in the reservoir is (241.5) m (a.s.l) during the filling time, the area of influence of the bank storage of groundwater will extend further towards the upstream and cross the meandering area (Figure 7) until it reaches near the regulatory dam. Then, the effect on the eastern bank (left) is more extensive than that on the west bank (right), except in the meandering area, where the effect will be wide on the west bank and will be wider on the eastern side, which is characterized by the presence of a high population density and more urban facilities; therefore, the foundations of these facilities will be more affected.

Then, at subsequent levels (245) and (250) m (a.s.l) in the storage period, the area of influence of the bank storage of groundwater begins to almost stabilize and

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the expansion directs slightly towards the upstream until it reaches the regulatory dam and crosses it, as shown in figures (8 and 9). The effect on the foundations of regulatory dam requires attention to stop raising the level inside the reservoir.

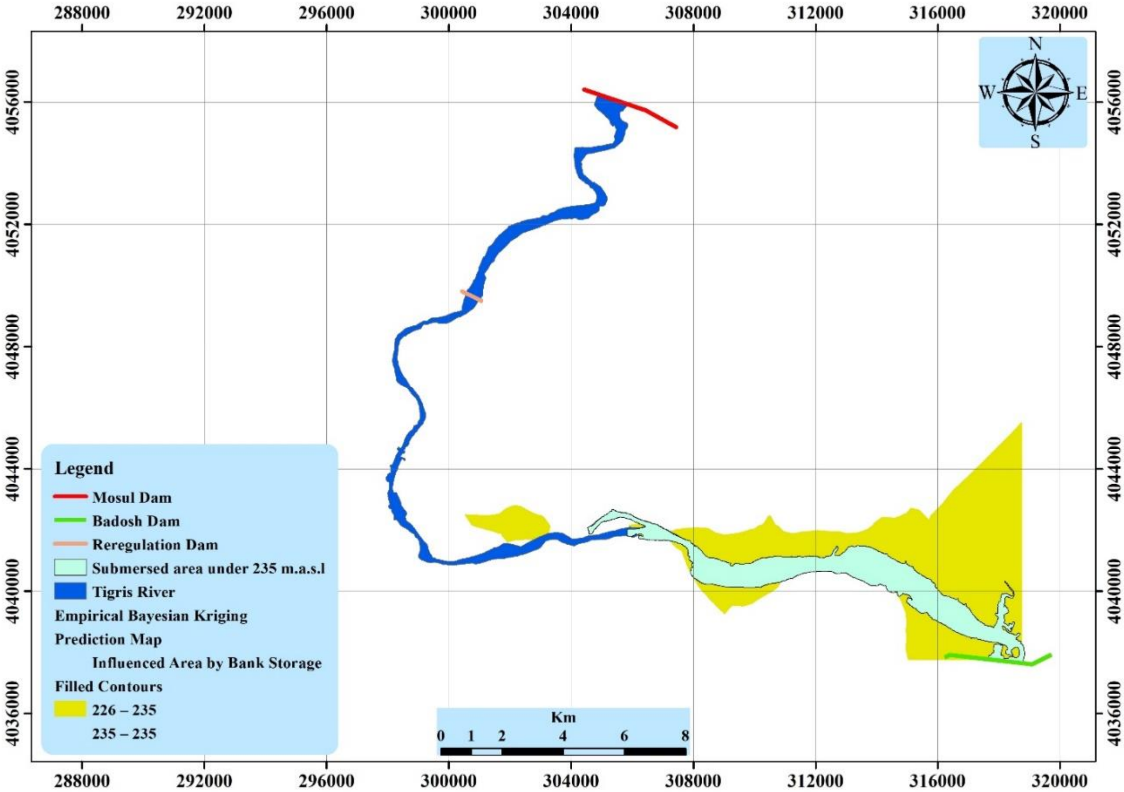

Figure 6: Scenario of the effect of bank storage when the water level in the reservoir is (235) m (a.s.l)

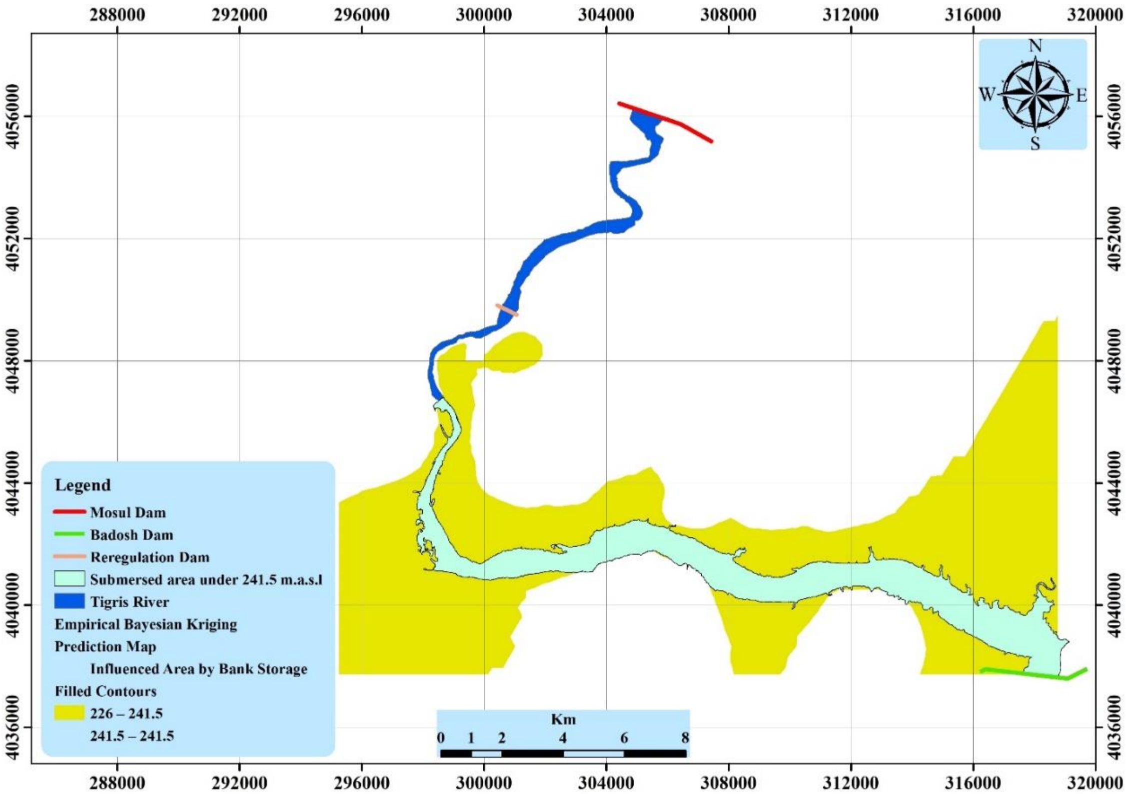

Figure 7: Scenario of the effect of bank storage when the water level in the reservoir is (241.5) m (a.s.l)

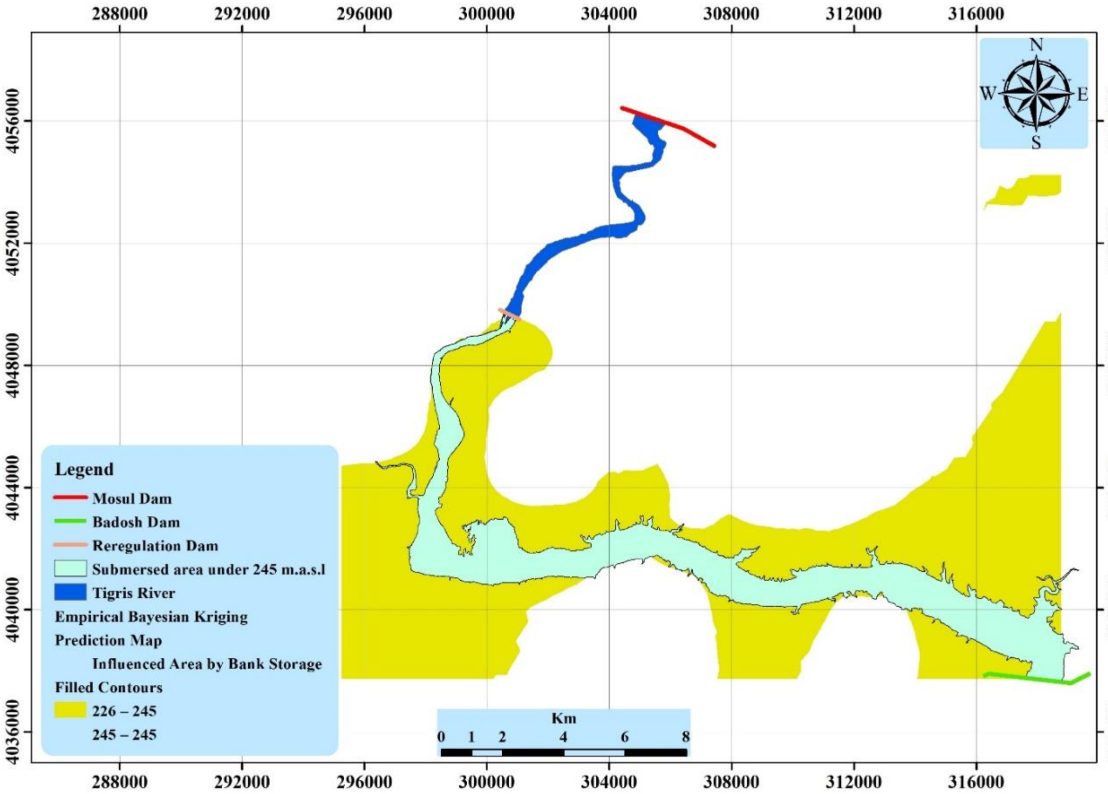

Figure 8: Scenario of the effect of bank storage when the water level in the reservoir is (245) m (a.s.l)

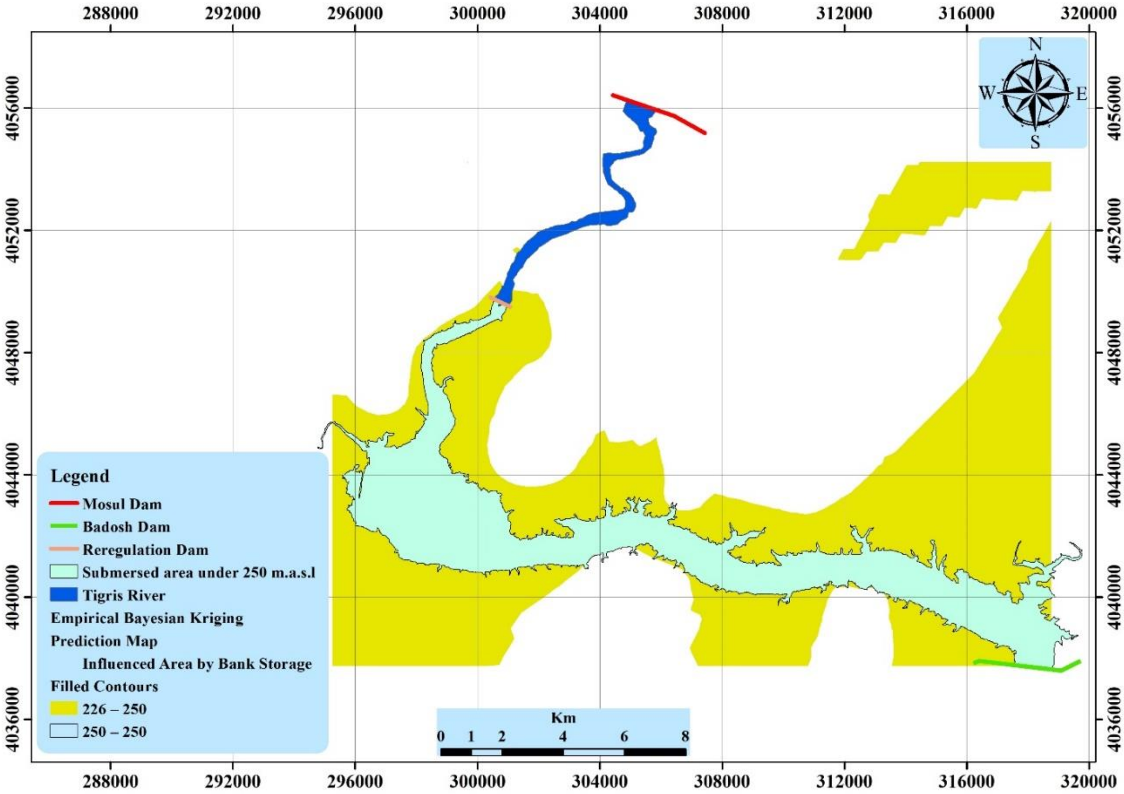

Figure 9: Scenario of the effect of bank storage when the level in the reservoir is (250) m (a.s.l)

Conclusion

The data of the groundwater depths and levels monitored in (39) wells on both sides of the river reach between Mosul and Badush dams were used to map their spatial distribution. The results showed that the depths and levels are as low as possible in the strip adjacent to Tigris River, and then increase to reach the maximum limit to the east and west of the study area, far from the original course of the river. The flow directions are towards the Tigris River reach between the two dams.

The rise in the water level in Badush Dam reservoir with the start of storage will lead to a rise in the groundwater level in the banks of the reservoir to the extent that the reservoir level balances with the groundwater level. This means that the river will be a discharge area in the reach under study. For several different levels of the reservoir, the low levels of reservoir at the pre-storage stages, the effect of the bank storage will be in a limited area near the structure and shoulders of the dam. Then, this area increases with the increase in the storage level until the effect reaches the acute river meander area in the original Tigris reach. At this stage, the effect of the meander reservoir on the eastern side of the river is more than on the western side. When the reservoir reaches the maximum operational level, the effect of the bank storage of groundwater reaches the foundations of regulatory dam, endangering the foundations of this dam.

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