**Iraqi National Journal of Earth Science**
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# Geomorphological Analysis of Duhok Dam Site Using Remote Sensing Data

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**Article information**

**Received:** 15- Apr -2023

**Revised:** 22- Oct -2023

**Accepted:** 16- Nov -2023

**Available online:** 01- Jan – 2024

**Keywords**:
Duhok dam
Germawa faults
gully Duhok fault
Bekhair anticline
seismotectonic situation

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## ABSTRACT

This study aims to analyze the geomorphological and geological features of Duhok Dam's sites and interpret the landforms and geological structures in this area. Field (observation) investigation, Satellite images and the data obtained from previous studies of this area have been facilitated in this study to make a compilation with each other to conclude a geological and geomorphological interpretation of landscapes. A Geomorphological map is prepared of the most dominant features. The Germawa strike-slip faults and their relation with the gully Duhok strike-slip fault are determined by their effect on the dam site. Sediments from erodible formations could decrease the dam reservoir capacity and flood waves during heavy rain and snow season could impact high pressure on the dam body so several sites were suggested to construct precautionary dams in anticipation of these risks. A seismotectonic situation for the dam area was also studied and determined, requiring officials to continuously monitor the dam body and its foundation.

DOI: 10.33899/earth.2023.139763.1073, ©Authors, 2024, College of Science, University of Mosul.

# التحليل الجيومورفولوجي لموقع سد دهوك باستخدام بيانات الاستشعار عن بعد

علاء نبيل حمدون [1] ، ربيع خلف زناد [2] ، عبدالرحمن رمزي قبع [3]* ، صباح حسين علي [4]*

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**معلومات الارشفة**

**تاريخ الاستلام:** 15– ابريل –2023

**تاريخ المراجعة:** 22– اكتوبر –2023

**تاريخ القبـول:** 16– نوفمبر –2023

**تاريخ النشر الالكتروني:** 01– يناير –2024

**الكلمات المفتاحية:**

سد دهوك

صدوع جرماوة

صدع دهوك

طية بيخير المحدبة

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**الملخص**

تهدف هذه الدراسة إلى تحليل الخصائص الجيومورفولوجية والجيولوجية لموقع سد دهوك وتفسير التضاريس والتراكيب الجيولوجية في هذه المنطقة. وقد تم في هذه الدراسة استخدام البحث الميداني (الملاحظة) والصور الفضائية والبيانات التي تم الحصول عليها من الدراسات السابقة لهذه المنطقة لتجميعها مع بعضها البعض للتوصل إلى تفسير جيولوجي وجيومورفولوجي لمنطقة الدراسة. وتم إعداد خريطة جيومورفولوجية لأهم المعالم المهيمنة. كما تم تحديد صدوع جرماوة ذات الازاحة المضربية وعلاقتها بصدع دهوك المضربي من خلال تأثيرها على موقع السد. أن الرواسب الناتجة عن التكوينات القابلة للتآكل يمكن ان تؤدي إلى تقليل سعة خزان السد وبالتالي فان هطول الأمطار الغزيرة وموجات الفيضانات أثناء وموسم الثلوج ستسبب ضغط عالي على جسم السد. لذلك تم في هذا البحث ايضا انتخاب واقتراح عدة مواقع لبناء سدود احترازية تحسبًا لهذه المخاطر . كما تم دراسة وتحديد حالة الزلزالية التكتونية لمنطقة السد تتطلب من المسؤلين مراقبة مستمرة لجسم السد وأساسه.

DOI: 10.33899/earth.2023.139763.1073, 

## Introduction

Many environmental factors can have an influence on the stability of any engineering project, either positively or negatively. The topographical, hydrological, and geological settings are critical for any dam project's success (Smith 1966). Human activities and events are usually concentrated in the areas where water sources exist, whether they are permanent or seasonal rivers, the environment and the shape of the land may control these events and activities, including the construction of precautionary dams on these rivers to make them as a source of water continuously, and these dams are considered as an essential benefit to the society, It may be considered as a negative source or a source of danger if the safety of these dams is neglected, even if they are small in size. In light of this, the human factor has been able to plan geological and engineering studies to try to understand and explain the stability and steadfastness of these dams before, during or after their construction. Therefore, the geological and morphotectonic characteristics of the dam site will be studied and analyzed, and the source of danger or the threat to the stability and safety of the dam will be identified. Integrating the results of the analysis which is deduced from the previous characterization of ground geological facts is a kind of attempt to develop applied studies in the field of disaster risk management to address the structural characteristics and the source of threat to dam safety (Lillesand and Kiefer, 1987).

The study area is situated between longitudes (42˚ 55 29) and (43˚ 00 34) east and latitudes (36˚ 48 32) and (36˚ 53 15) north. It is located in Duhok City-Northern of Iraq, (Fig. 1). The Duhok Dam was built in the Pila Spi Pila Spi and Avana formations (Middle to Late Eocene) near its contact with Gercus formation (Middle Eocene). The dam and reservoir have a height of 60.5 meters, a summit length of 740 meters, and a width of 9 meters. The dam was erected over the Duhok Canyon about two kilometers north of Duhok in 1988. The reservoir has a capacity of 52 million m3 and a total area ranging from 1,670,000 m2 to 2,800,000 m2 (Al-Talib, et al., 2021). The Duhok Dam is located in the southwestern limb of Bekhair Anticline, Data analysis found that the four segments of the Baikher Anticline are double plunging, asymmetrical, open to gentle, and cylindrical, with fold vergence and form varying from segment to segment. The first and third portions of the Baikher Anticline are oriented southwestwards, the second one northeastward, and the fourth one northward. According to the findings, the fold shape varies from chevron to box shape from one traversal to the next. There are two types of anticline-related faults. The first is a collection of strike-slip faults that impacted the fold trend, while the second is a collection of listric faults that influenced the fold vergence. Vertical fold type examinations were also conducted in the second and third traverses. The second traverse demonstrated the Middle Eocene reactivation of the foreland listric fault, whereas the third revealed unexpected vergences (Al-Azzawi, and Al-Hubiti, 2009).

The climate of the Duhok region is generally characterized by being hot to moderate in summer and cold and rainy in winter, accompanied by periods of snowfall and freezing with the presence of some climatic changes. One of the causes of this, is the presence of mountain ranges, which encouraged the construction of the Duhok Dam to store and harvest water in this region (Ossi, 1990).

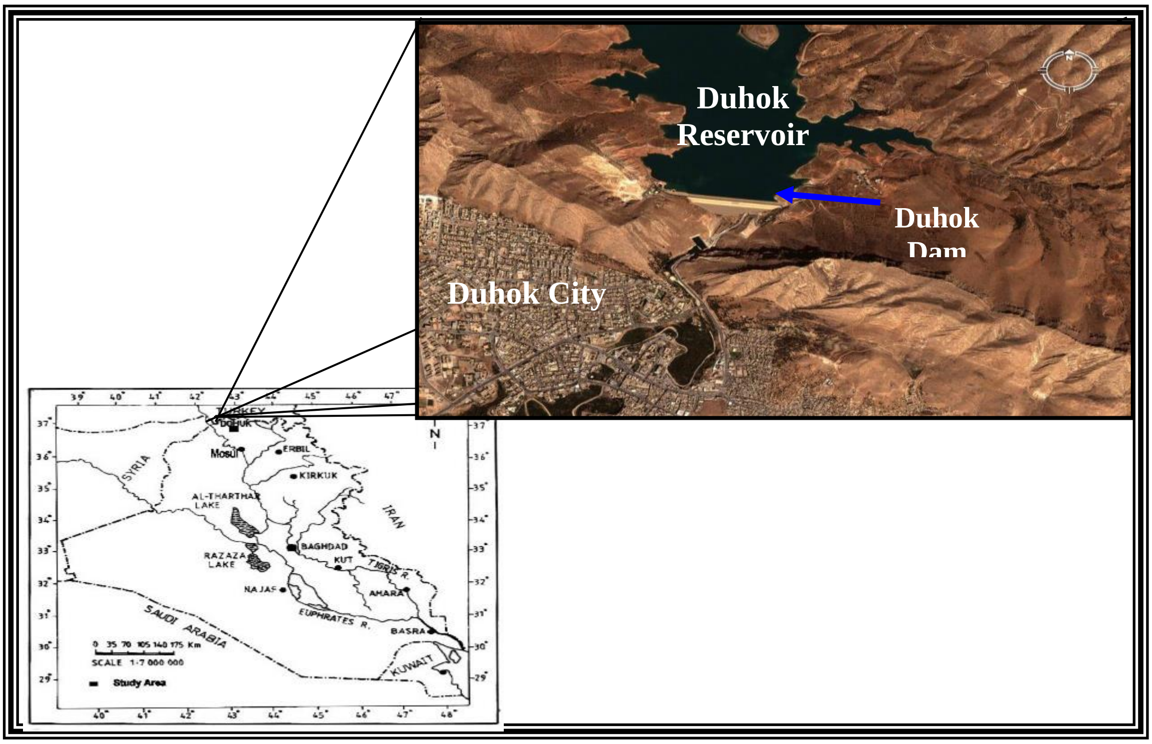



**Fig. 1. The location of the study area within the map of Iraq is illustrated by satellite data.**

## Materials and Methodology

This research relied on field observations, geological and geomorphological analyses, in addition to previous studies of the study area. Satellite images embedded in Google Earth were used to illustrate geological analyses and interpretations of the study area. The seismic record of Iraq from 1960 to 2022 (EMSC) was also used to discuss and illustrate potential risks to the study area. Fig 2 shows the work methodology and stages.

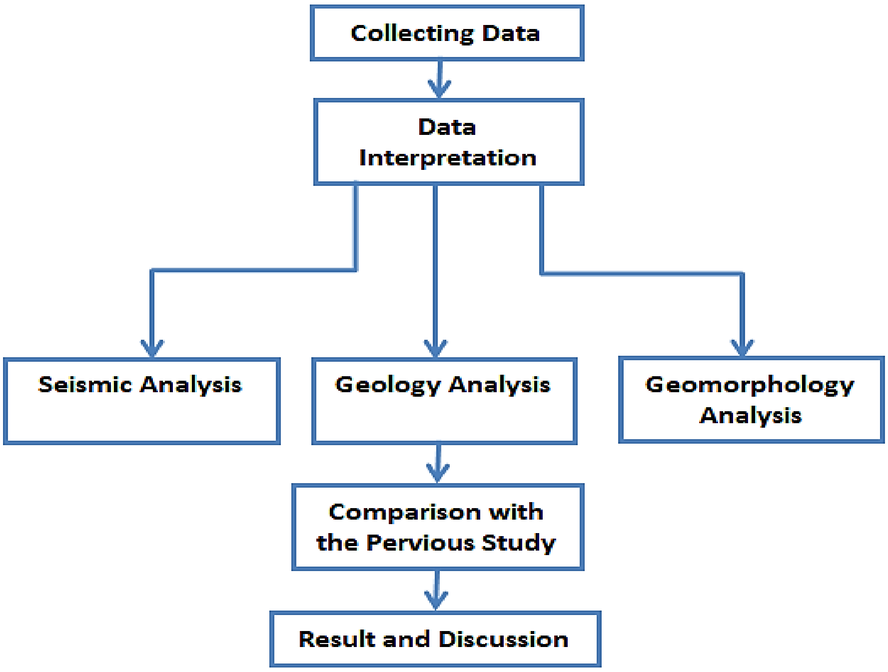



**Fig. 2. The Methodology and structure of the work.**

### 1. Geology of the Study Area

The study area is located in the southwestern limb of Bekhair Anticline, which is located within the High Folded Zone according to (Buday and Jassim 1987). The general trend (71 km.) of the anticlinal axis is northwest-southeast conceded with Zagros trend.

Through the filed measurement the vergency of the Bekhair anticline across the traverse is toward the SW i.e. the southwestern limb is steeper than the northeastern limb which is (45 and 21 degrees) respectively.

The Geological formation exposed in the study traverse according to (Alawi,1980; Al-Hubaiti,2008; Al-Brifkani,2012) are: (see Fig. 3)

Bekhme Fm. (Upper Campanian-Lower Maastrichtian)-Shiranish Fm. (Upper Campanian Maastrichtian)-Kolosh Fm. (Lower Paleocene-Lower Eocene)-Khourmala Fm. (Paleocene-Lower Eocene)-Gercus Fm. (Middle Eocene)-Avana Fm. (Middle Eocene)-Pil-Spi Fm. (Middle-Upper Eocene). The description of these formations from the oldest to the youngest is as follows:

1. Bekhme Fn.: It consists of a massive bed of limestone, yellowish to grey color and it constitutes the core of the anticline, and it is characterized by being of high hardness and prominent compared to the formations surrounding it.

2. Shiranish Fn.: the lower competent part is composed of marly limestone yellowish to bluish color, abundant in different types and sizes and the upper friable part is composed of marl with a dark gray color, the total thickness in the SW limb is 26 m.

3. Kolosh Fn.: It consists of dark-colored clastic materials due to its deposition in a reductive environment (sand, silt, and clay), which makes it a rapidly eroding formation. The thickness in the SW limb is about 234 m. including patches of Khourmala Formation about (4-9m.)

4. Gercus Fn.: It consists of clastic materials (sand, silt, and clay) with a red color because it contains iron oxides, and it is also fast eroding due to its fixable nature the thickness in the SW limb is about 626 m.

5. Avanah Fn.: It consists of a medium bedded limestone alternating with a thin layer of marl. This formation is in the form of a rocky excavation within the dam site. The total thickness in the SW limb is 12 m.

6. Pila Spi Fn.: It consists of thick to massive layers of limestone and dolomitic limestone, yellowish, and very hard, forming high ridges, extended parallel to the axis of the anticline. The total thickness in the SW limb is about 637 m.

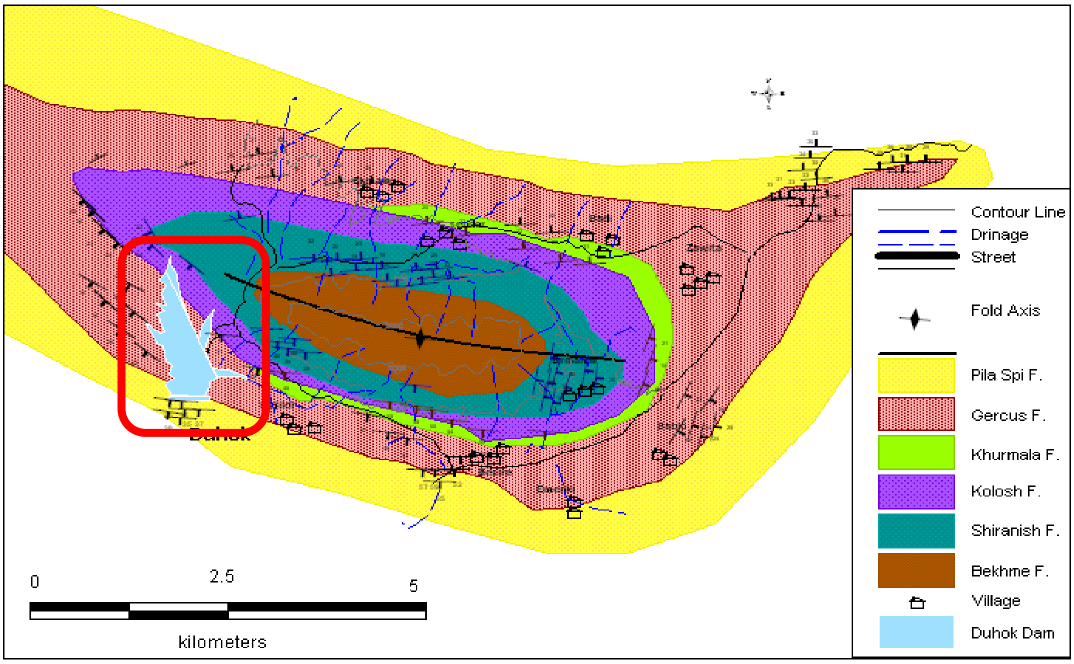



**Fig. 3. Geology of the study area (Al-Berifakani et al., 2012).**

## 2. Geomorphological Features in the Study Area.

According to the lithological characteristics of these geological formations, they can be classified into two groups: carbonate competent rocks which include (Bekhme, lower Shiranish, Khourmala and Pila Spi formations), and clastic incompetent rocks which include (Upper Shiranish, Kolosh and Gercus formations).

The main geomorphological features, (Fig. 4), arise due to the rock bed properties are:

- Major valley extent northeast southwest cut the whole geological formation called Gully Duhok, which the Duhok dam was built across it.

- Longitudinal valleys with hilly terrane developed in the clastic incompetent Kolosh and Gercus formations due to its friable and easily eroded, it is trend parallel to the anticlinal axis.

- The Central core of the anticline is occupied by hard competent Bekhme Formation which is named Spi Rise Anticline.

- Hogback ridge developed on dipping hard beds of Pila Spi Formation in the southwest limb of Bekhair Anticline, the side that coincided with the beds dipping is known as dip slop whereas the opposite side (including Avana Formation) is back slop formed acute cliffs toward the longitudinal valleys and filled by mobile regolith and different sizes blocks of weathered rocks.

-Patches ridges of Khourmala Formation within Kolosh Formation.

The dam site was built on the back slop side at the contact between Gercus and Avana Formations. The dam occupies the area of lowland within the longitudinal valley feature (Kolosh and Gercus formations).

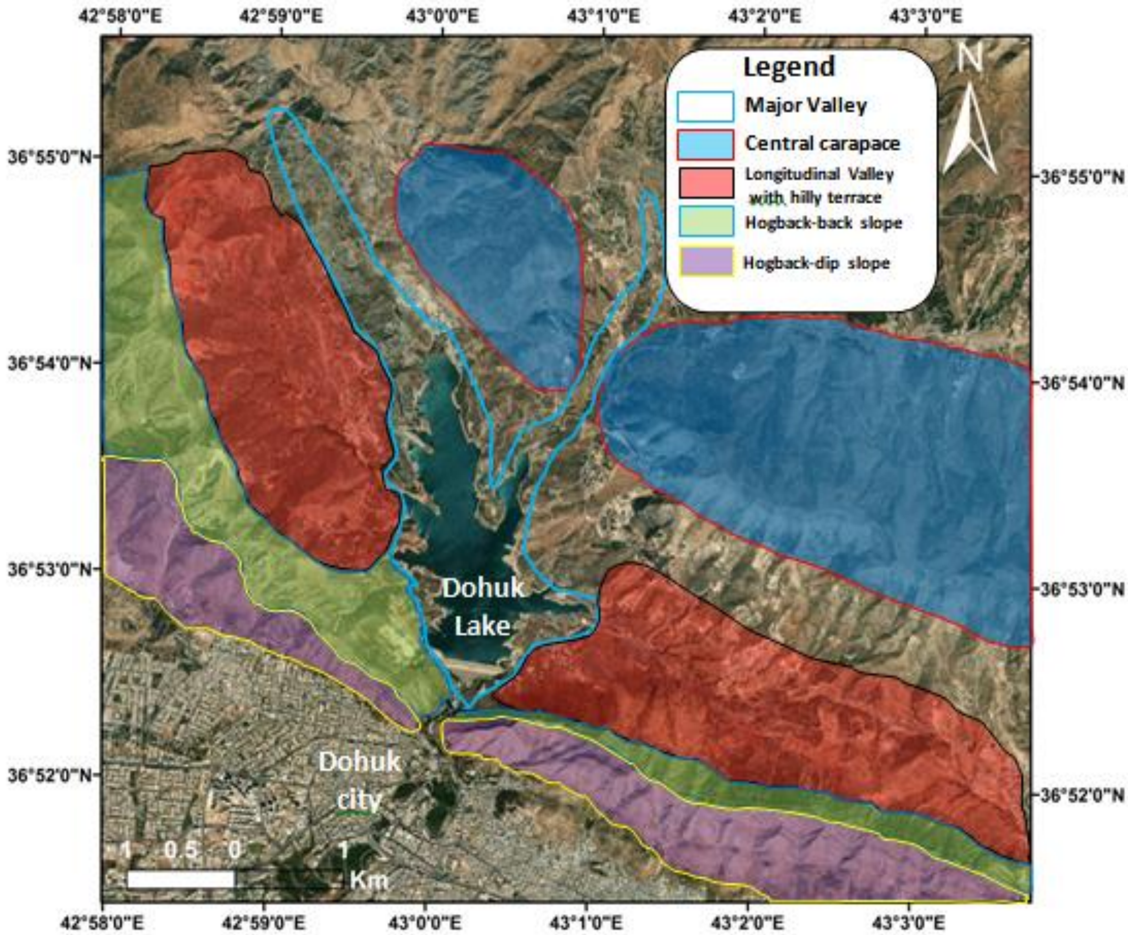



**Fig. 4. Geomorphological map of the study area.**

## 3. The Strike-Slip Faults in the Study Area.

The presence of strike-slip faults in the study area was determined by (Al-Hubaiti, 2008). It is called the Germawa fault group, (Fig. 5), and it consists of three striking faults, the first is Dextral (right-handed), offset towards north-south, and the second is right-handed, also offset, and in the direction of northeast-southwest. As for the third fault, it is the Sinistral (left-handed) offset and in a northeast-southwest direction. These faults greatly affected the morphology of the Bekhair Anticline.

Another major basement fault striking NE -SW, (Fig.5) is called Gully Duhok Dextral Strike Slip fault (Doski,2004), it extends about (5.5 km.) with horizontal and vertical displacement of about 200 m and 120 m respectively.

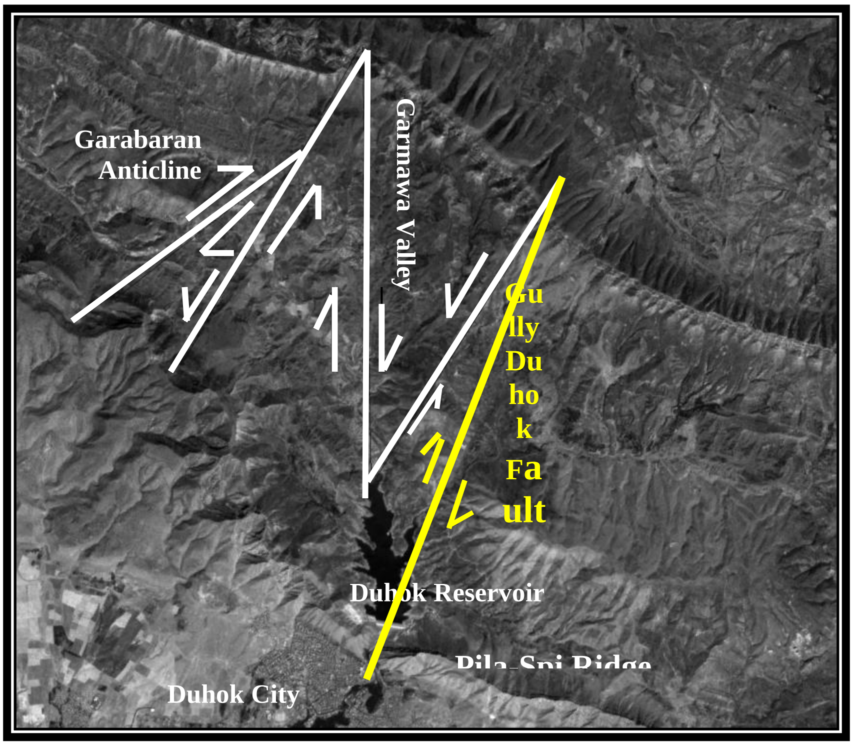
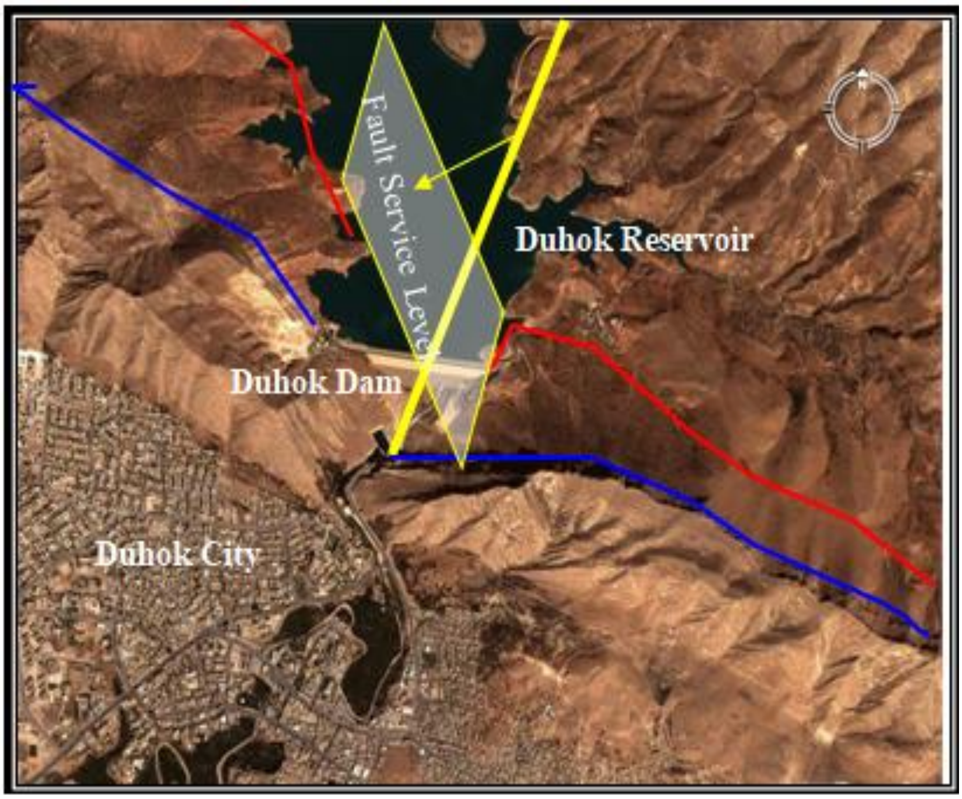



**Fig. 5. Strike- Slip Fault System in the Bekhair (Modified from Doski, 2004) (Al-Hubaiti, 2008).**

## 4. Morphotectonic Evidence of the Gully Duhok Fault under the Dam

The indications for the existence of a Dextral Strike-Slip Fault at this fault are the displacement of the Pil-Spi Formation and the dextral deviation of the axis of the anticline (Al-Hubaiti,2008). Also, the thickness of the Gercus Formation (450 m) to the east of the fault is less than the thickness of the same formation, about (700 m) to the west of this fault. The same case is concerning the Pila-Spi Formation as well, (Fig. 6).

The Gully Duhok Strike-Slip Fault extends northeastward to compete with the Germawa strike-slip faults system to divide the core of the Bekhair Anticline (Bekhme Formation) into two parts in right-hand echelon separated by saddle structure, these two parts called Spi-Rise Anticline and Garabarn Anticline, (Fig. 5).




**.Fig. 6. The displacement of the striking faults in the Bekhair Anticline (Al-Hubaiti, 2008)**

The transverse cross-section of Duhok reservoir near the dam according to the study conducted by (Abdulrahman, et. al., 2017), it is clear that the location of the fault corresponds to the cross-section of the reservoir, (Fig. 7).

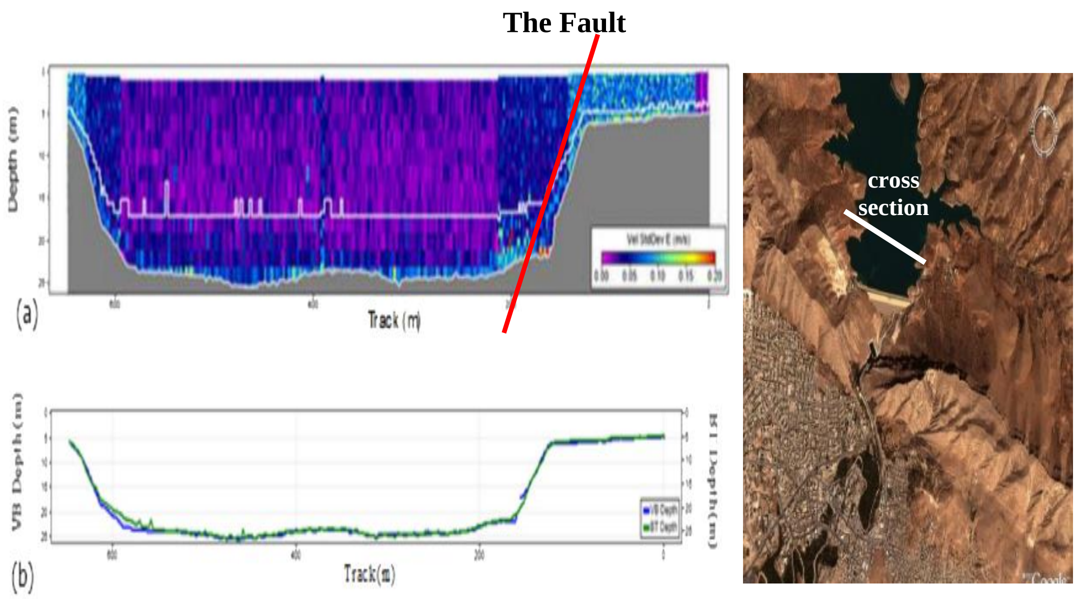



**Fig. 7. Cross-section of the bottom of the reservoir (Abdulrahman, et. al., 2017), showing the supposed fault location.**

This demonstrate that the dip direction of the fault is towards the west, apparently it is a normal fault (Fig. 8). Since it is already has been recognized as a strike-slip fault by (Doski, 2004), so must be identified as an oblique right lateral strike-slip fault. The superimposed fault with the Wadi Garmawa strike-slip fault system, therefore this may increase the possibility of reactivating the movement on the surface of this fault under the dam, given that the source of the forces or stress is perpendicular to the axis of the dam, or parallel to the axis of the fold, one of these two cracks will be affected by these forces.

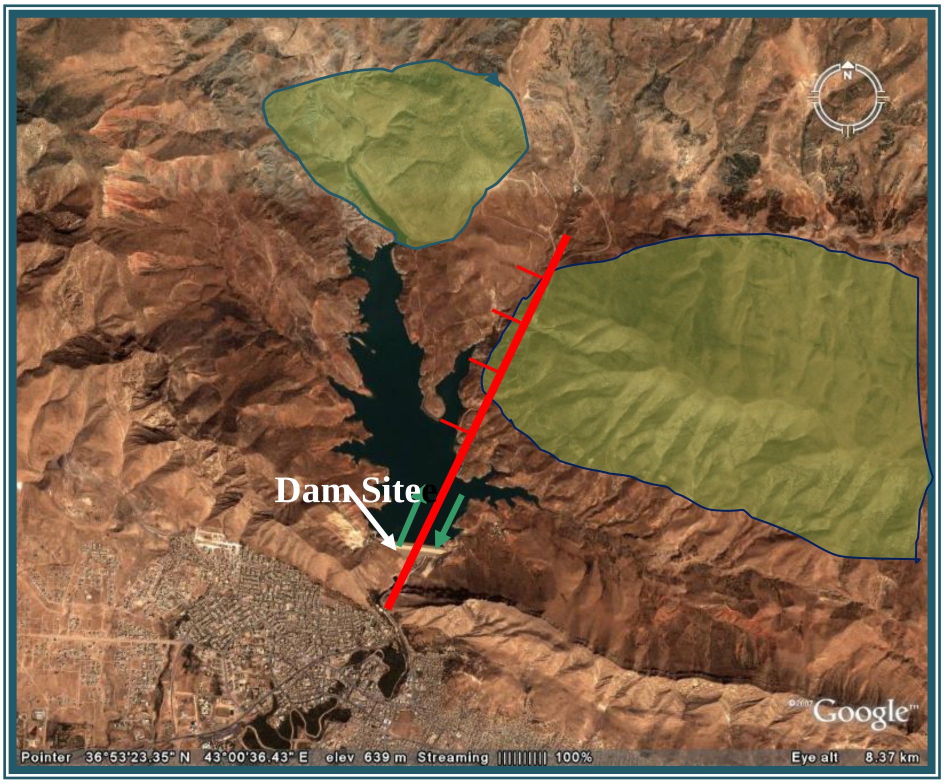



**Fig. 8. The position of the Gully Duhok Fault (red line) under the dam.**

**Green arrow= right lateral strike-slip fault**

**Hachures=dep direction of the fault**

## 5. Relationship of the Fault Position with the Dam: Geological Point of View.

The study area from the seismotectonic point of view lies within the range between the 4th and 5th seismic levels of the seismic levels divided according to the Richter scale (Johnson, 2018), in addition to being close to the seismic belt located in the northeastern part of Iraq (Buday and Jassim, 1987). This is what makes the possibility of earthquakes in that region very likely and possible at any time, and the first geological structures in response to earthquakes are the fractures (joints and faults) in that region if there is an accumulation of stresses on the surfaces of these faults so that these stresses are later released in the form of seismic energy. And that the fault under the Duhok Dam, which is in the direction (northeast-southwest), will respond to the impact of the earthquakes, as it is superimposed with other striking faults (Wadi Garmawa fault system) in the direction of northwest-southeast, and this will work to respond to any forces that come from any direction. And that the fault, if they exist as geological structures close to the site of the dam, then they will have a negative impact on the geological situation surrounding the site of the dam (Al-Dabbagh and Naqib 1999). As a final result, the Duhok Dam body will be affected by any seismic forces that strike that area, and then this works to break the components of the dam and make cracks, either large or small (Major or Minor Crack), and from an engineering point of view, these cracks constitute a source of danger if they are found in any dam (Fraser, 2001).

Since the direction of water flow is mainly on one of the shoulders of the dam, which is the left shoulder of the dam due to the nature of the land slope, in addition to the drainage basins of the study area passing through friable sedimentary formations that are subject to rapid erosion, this will work to collect large sediments in the reservoir dam (Al-Talib, etal.,2021) (Al-Abadi, 2002), and thus the percentage of these sediments will increase in the case of high rainfall and will be deposited at the bottom of the lake reservoir near the dam body, especially near the left shoulder of the body, (Fig. 9).

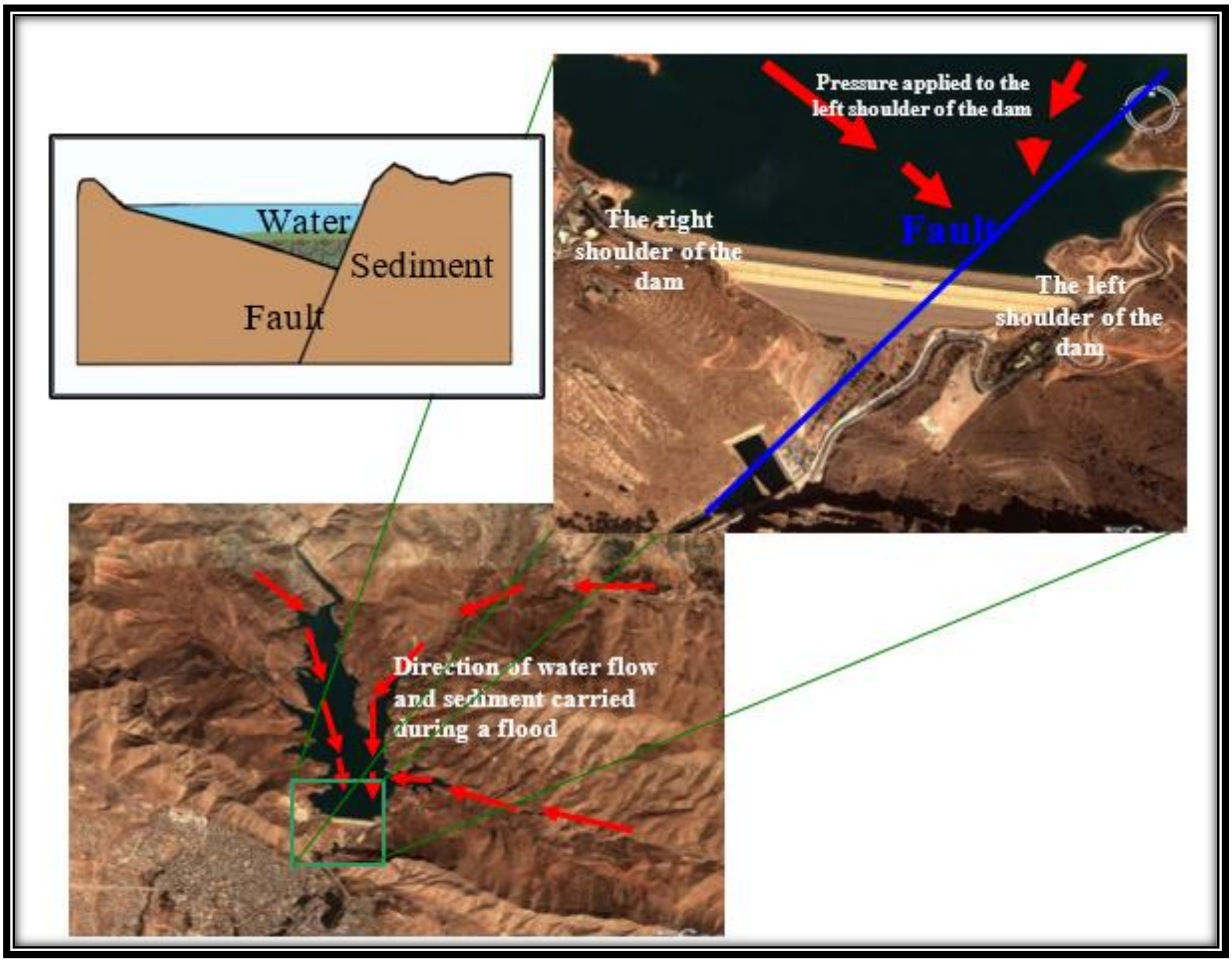



**Fig. 9. Direction of water flow toward the left shoulder of the dam during the flooding season.**

As a result, it is noted that the left shoulder of the dam is subjected to great pressure if a high rain falls, (Fig. 7), and that the left shoulder of the dam is located on the fault plane, and it works to shift it slightly, which increases the expansion of the cracks in the dam body, and so on, until it reaches a dangerous stage of disintegration of the dam body over time.

Accordingly, and to overcome the probable consequences (Fig. 10), several sites were suggested to construct precautionary dams in anticipation of these risks.

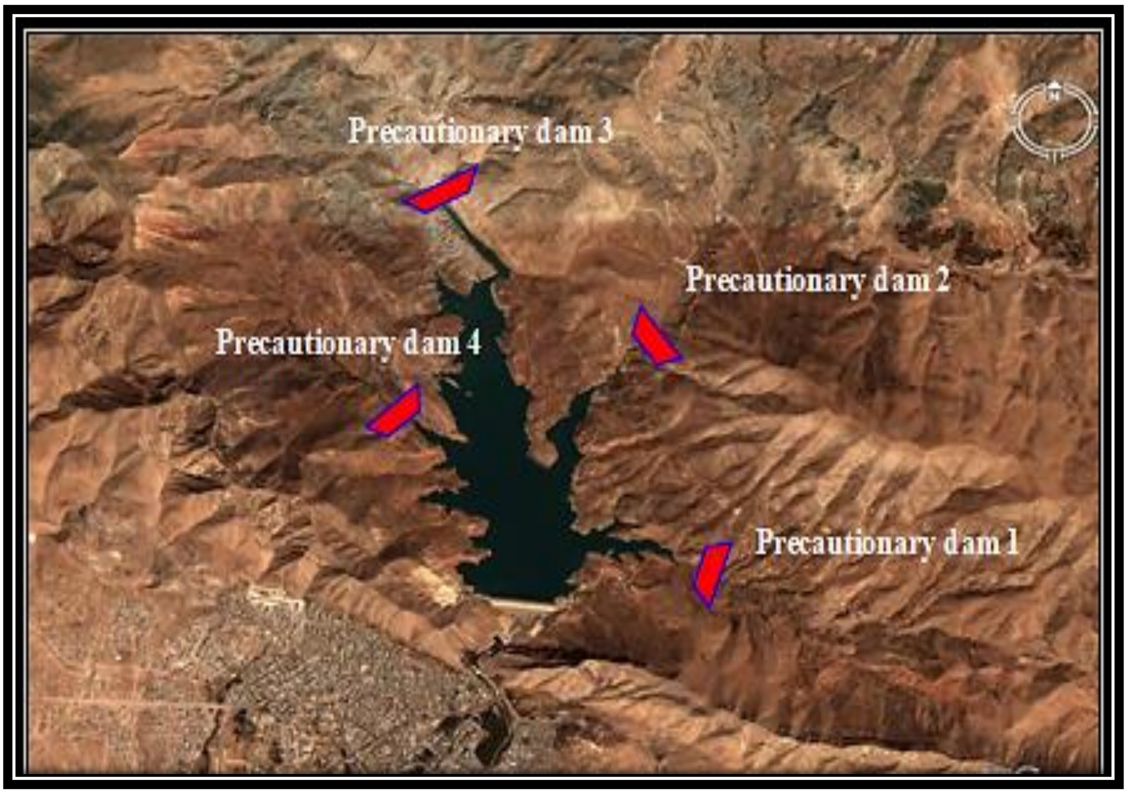



**Fig. 10. The places of construction of precautionary dams in the study area**

The study area is located within a seismically active range, which makes the occurrence of earthquakes highly likely, especially since the recorded history of earthquakes that occurred in the study area from 1960 to 2022 contained several foci of recorded earthquakes with intensity greater than 3 on the Moment Magnitude Scale (MM scale), (Fig. 11-a), also the study area was subjected to earthquakes close to the body of the dam, with a magnitude of 4.2 on the MM scale, with two earthquakes (Fig. 11-b) it works to break the dam body and collapse it (Bayraktar and Kartal, 2010).

Accordingly, must be conducting a weekly follow-up of the dam’s body accurately and observe whether there are small or large cracks in the dam’s body, and try to analyze and treat them quickly, in addition to examining the dam’s body and the geological formations adjacent to the dam after any earthquake, even if it was at intensities 2 and 3 on the MM scale. Also try to study the area completely and write down any geological observation that occurred in that area, even if it was on a very small scale in the area. It is better to set up a seismic monitoring station close to the dam body to observe any seismic surge in the daily seismic record of the region and specially to monitor any seismic activity due to oil extraction in the region.

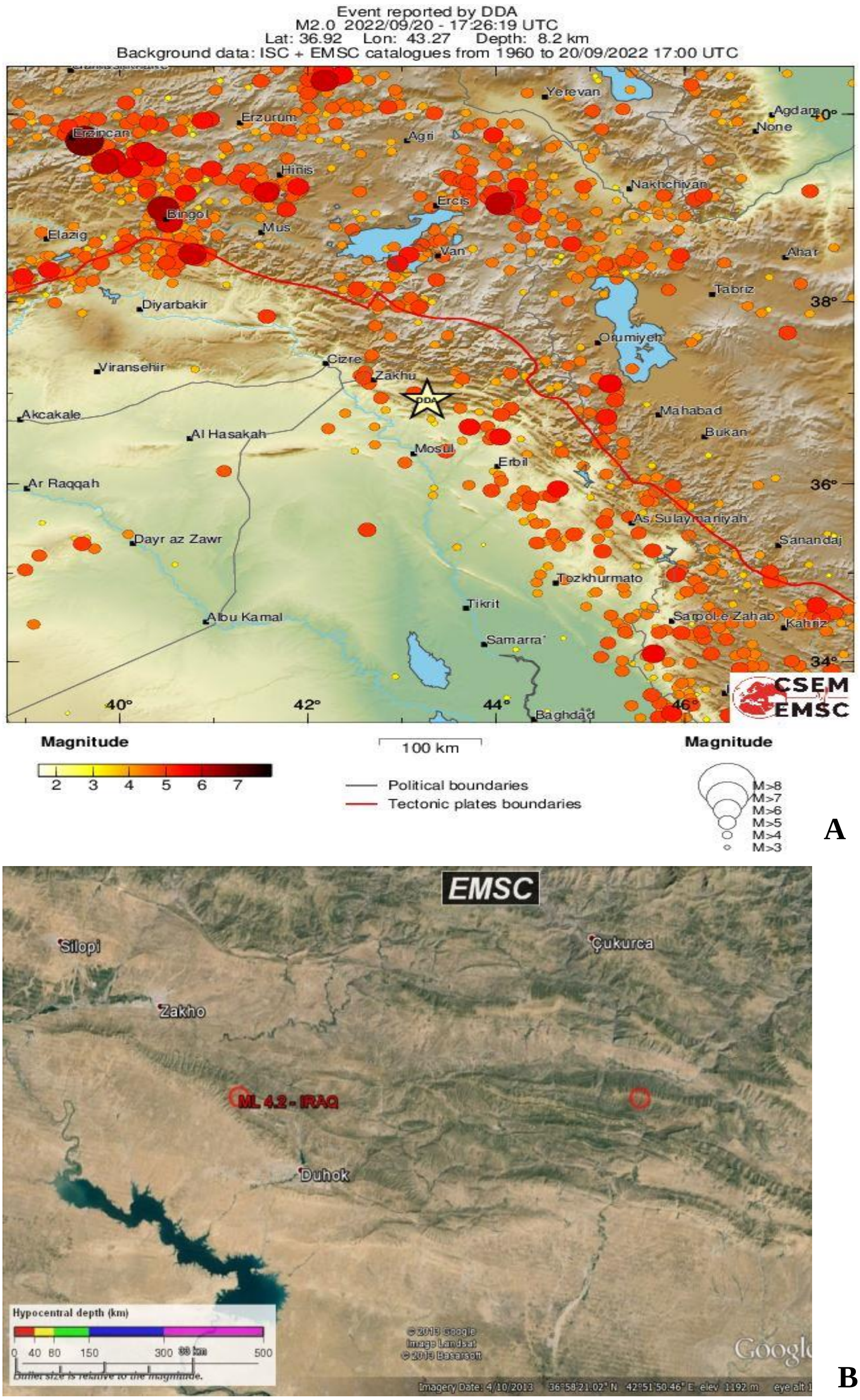



**Fig. 11. A- The seismic record of Iraq from 1960 to 2022 (EMSC). B- View of the earthquake that occurred near the study area.**

In addition, some information has been obtained about the commencement of the project of drilling an oil well in the Bekhair Anticline within the Spi-Rise anticline, which is mostly composed of the hard competent Bekhme formation, and therefore it will work to find the possibility of an induced earthquake. Usually, such a type of earthquake is formed through the withdrawal of high amounts of water, hydrocarbons or minerals, which will generate a disturbance in the pressure in the subsurface rocks and cause the release of energy through the occurrence of an earthquake. Since the site of the drilling well is not far from the location of the dam, this process might affect the safety or stability of the dam through some induced earthquakes.

## Conclusions

Many environmental factors have an impact on the stability of any engineering project, especially if it is a dam construction project, and the topographic, hydrological and geological settings are considered crucial to the success of such a project. In this study, geomorphological maps and geological structures (faults) of the study area were conducted and analyzed. It was concluded that the left shoulder of the dam is exposed to great pressure if heavy rain falls and that this shoulder is located at the level of the crack, and it is moved slightly, which increases the widening of the cracks in the dam body, and so on, until it reaches a dangerous stage of disintegration of the dam body with the passage of time. Therefore, to overcome the possible consequences, several sites were selected and proposed in this study for the construction of precautionary dams in anticipation of these risks.

The study also showed that the dam area is located within an active seismic zone, which makes the occurrence of earthquakes highly likely, especially since the recorded history of earthquakes that occurred in the study area from 1960 to 2022 contained several foci of recorded earthquakes with strengths ranging from (3 to 4.2) on the Moment Intensity Scale, which increases the risk of the dam body breaking and collapsing.

Therefore, the study recommended the necessity of continuing permanent seismic monitoring, which is considered vital for safety and reassurance. As a suggestion for future work, more geophysical surveys should be conducted using regular electrical or seismic surveying equipment on both sides of the dam and its downstream to reduce material and human risks and losses.

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