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# Submerged Surface Area and Water Storage Volume of Hamrin Dam Lake Using Contour Lines

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**Abstract**

The predictions and warnings from drying up lakes and rivers are increasing nowadays, especially in Iraq, due to climatic changes and water flow reduction from neighboring countries. Consequently, this paper deals with monitoring the changes in submerged surface areas and Hamrin dam lake storage volume from December 2011 to the end of 2022. Hamrin Lake supplies Diyala province, Iraq, with irrigation water. Multitemporal satellite images were acquired from google earth pro and Earth Observation (EO) browsers. Triangular Irregular Network (TIN) layers generated contour lines through the ArcGIS environment. Volumes were calculated using the end area method. The results show that the water storage volume reached 1.8 billion cubic meters (bcm) in December 2016 and decreased to 12 million cubic meters in December 2021. Hamrin Lake lost 99% and 98% of its capacity relative to the normal water storage volume in 2021 and 2022, respectively. At normal storage, the maximum water volume of Hamrin Lake is about 3 bcm. The scarcity of irrigation water from Hamrin Lake causes decreasing agricultural areas, desertification, and people migrating to other regions.
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**Keywords:** Contour Lines, Surface Area, Water Storage Volume, Triangular Irregular Network, End Areas.

# المساحة السطحية المغمورة بالماء وحجم الخزين المائي لبحيرة سد حمرين باستخدام الخطوط الكنتورية

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**الخلاصة**

تتزايد التنبؤات والتحذيرات من جفاف البحيرات والانهار في الوقت الحاضر خاصة بالعراق بسبب التغييرات المناخية وانخفاض تدفق المياه من البلدان المجاورة، لذا يتعلق البحث بمراقبة التغييرات في المساحات السطحية المغمورة بالماء وحجم الخزين لبحيرة سد حمرين خلال الفترة من كانون الاول عام 2011 الى نهاية عام 2022، حيث تجهز بحيرة حمرين محافظة ديالى بالعراق بمياه الري. تم الحصول على الصور الفضائية المتعددة الاوقات من google earth pro ومستعرض مراقبة الارض EO browser وتم استخدام طبقات شبكة المثلثات غير المنتظمة TIN لانتاج الخطوط الكنتورية من خلال بيئة ArcGIS وحساب حجم الخزين باستخدام طريقة المساحة النهائية. اظهرت النتائج ان حجم الخزين المائي وصل الى 1.8 مليار متر مكعب

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في كانون الاول عام 2016 ثم قل الخزين المائي الى 12 مليون متر مكعب في كانون الاول عام 2021، وعليه فقدت بحيرة حمرين 99% و 98% من سعتها الخزنية نسبة الى حجم الخزين المائي الاعتيادي في الاعوام 2021 و 2022 على التوالي، حيث يبلغ الحجم المائي الاقصى لبحيرة حمرين في الخزن الاعتيادي 3 مليار متر مكعب، وتسبب نقص مياه الري القادمة من بحيرة حمرين الى تقلص المناطق الزراعية والتصحر وهجرة السكان الى مناطق اخرى.

## 1. Introduction

Responsible water management offices, water allocation plans, and water release methods depend on their understanding of water volume changes in lakes and reservoirs. Water levels and volume data are rarely made public for legal, commercial, or political reasons [1]. At global and regional levels, lakes are the integrators of environmental issues [2]. The equilibrium between the inflow, like rainfall, and the outflow, such as evaporation and groundwater, determines the water storage volume. It is difficult to directly estimate the water amount stored in reservoirs and lakes [3]. The remote sensing process is suited for difficult access regions [4]. Interpolation of contour lines from remote sensing images is beneficial for water storage assessment.

Monitoring water resources requires regular satellite observations [5]. The multitemporal satellite images help detect the changes occurring in surface areas and water volumes of lakes and reservoirs. Google Earth and Earth Observation (EO) browser contain historical satellite images archive suitable for annual change studies. Images captured at different dates can be compared to find differences in the same areas. Multitemporal images need prior georeferencing or rectification so that the spatial data are common and referred to the same positions [6].

Observing water levels and surface areas at different times can show whether water bodies have shrunk or increased due to dryness or floods [7]. The surface area of a lake might shift in location over time while maintaining a fixed size [8]. The total lake volume must be determined to efficiently examine the lake water quantity [9]. A lake's water storage change due to climatic effects is more than a lake area change due to various topographic factors [10]. The water inflow and outflow in a lake reservoir can be managed by constructing a dam on the river [11]. The dam of Hamrin Lake is considered one of the essential dams in Iraq for water storage, irrigation, electric power generation, and tourism. Significant changes in shape were occurring in Hamrin Lake [12]. Rainfall, snowmelt, groundwater flow, and water releases from the Darbandikhan Dam reservoir all feed the reservoir of the Hamrin Dam [13]. Darbandikhan Dam is 155 km from Hamrin Dam, as indicated in google maps [14]. Alwand River, one of the Diyala River's tributaries, also provides water to Hamrin Lake [14].

A surface that represents terrain heights is known as Triangular Irregular Network (TIN). Triangular surfaces are created by TIN, linking existing points instead of interpolation between them [15]. The Digital Elevation Model (DEM) and the extrapolation of contour lines can estimate the water level. The levels and surface areas of a lake determine the water storage volumes. The end area method is widespread for reservoir volume computation. ArcGIS software can effectively be used for driving TIN surfaces and contour lines. Water volume studies are beneficial for engineering projects to avoid flooding and drought risks.

Many researchers use remote sensing techniques to study lake reservoirs' surface areas and water storage volumes. Ghazal et al. (2012) studied Al-Razaza Lake, Iraq, using Geographic Information System (GIS) and remote sensing imagery. The change detection of Al-Razaza Lake was done by applying image classification, TIN generation, interpolation, and contour line production. The results concluded that the water volume decreased in 2008 compared to 2002 [15].

Jumaah et al. (2022) observed surface areas and shoreline changes in Al-Razaza Lake using Landsat images and ArcGIS software in six different years between 1989 and 2020. Two image classifications were implemented: Support Vector Machine and Iso cluster. The study indicated that the water surface area and shoreline diminished by 84.1% and 63.4% in 2019 compared with 1989 [16].

Al-Obaidi and Al-Timimi (2022) detected the changes in Mosul dam lake, Iraq, utilizing remote sensing images and ArcGIS applications. Normalized Difference Water Index and image classification extracted surface areas and water bodies. Image differencing revealed changes in the lake surface areas through the selected twenty years. The study mentioned that the water surface areas of Mosul Lake oscillated in the period 2000-2020 [17].

Condeça et al. (2022) estimated water storage volumes and submerged surface areas of reservoirs from Google Earth images employing water indices and image processing. Depending on area indices and the comparison between estimated and absolute volumes, the results showed competence in volume estimation measurement and reliability [18].

Kale and Acarli (2019) processed satellite images to observe water surface area changes in the Atikhisar reservoir in Turkey between 1975 and 2017. The surface area variations of the Atikhisar reservoir are mainly due to climatic changes, natural factors, and man-made operations [19].

Sayl et al. (2017) generated DEM from Shuttle Radar Topography Mission (SRTM) with GIS, then developed Iraq's western-desert area, volume, and elevation curve. Three curves resulted for Horan-2, Al gara-2, and Al gara-4 dams. SRTM and GIS helped choose the most appropriate location for gathering the rainwater [20].

Sichangi and Makokha (2017) monitored the changes in surface areas and water volumes between 1993 and 2016 of Victoria Lake using remote sensing and bathymetry. During these twenty-three years, the water volume, surface area, and level of Victoria Lake had reduced [9].

## 2. Problem Statement and Study Objective

The drought and desertification phenomena of lakes and rivers are mainly caused by topographic, climatic, hydrological, and geological factors. In addition, the external factors, such as neighboring countries and their relation to the water flow of Iraqi rivers. The climate change factors, such as the increasing evaporation due to high temperatures and rainfall paucity, lead to decreased water levels, drought, desertification, and increasing dust storms. All these factors affect the shrinkage of agricultural areas and require good management of water resources.

Hamrin Lake is one of the essential water reservoirs in Iraq because it provides about three-quarters of water to areas in Diyala province. The lake was subjected to a nearly total drought in early 2022 due to climatic changes and the lack of rain. Estimating water storage capacity is a critical study of water scarcity in lakes and reservoirs. Interpreting contour lines surrounding the water border on the satellite images is beneficial for supplying the necessary data for water storage valuation.

**3. Study Area**

Hamrin Dam Lake was selected as a study area on the Diyala River, 120 km northeast of Baghdad in Iraq. It is an artificial reservoir extended from 34° 00′ 30″ to 34° 21′ 30″ north latitude and from 44° 52′ 00″ to 45° 12′ 00″ east longitude. Figure 1 shows the study area of Hamrin Lake, which is acquired from google maps. Hamrin Reservoir was formed by constructing the Hamrin Dam in June 1981 [21]. The dam is located on the southwest boundary of Hamrin Lake. The Hamrin Dam is 3360m long, 40m in height, 8m in width at the top, and elevation is 109.5m above sea level. The purpose of constructing the Hamrin Dam was to control the seasonal floods of the Diyala River. The dam is considered one of the irrigation sources used to provide electric power in Diyala province, Iraq. Alwand River meets the Sirwan River north of Jalawla to form the Diyala River. Diyala River flows into the Tigris River south of Baghdad [14].

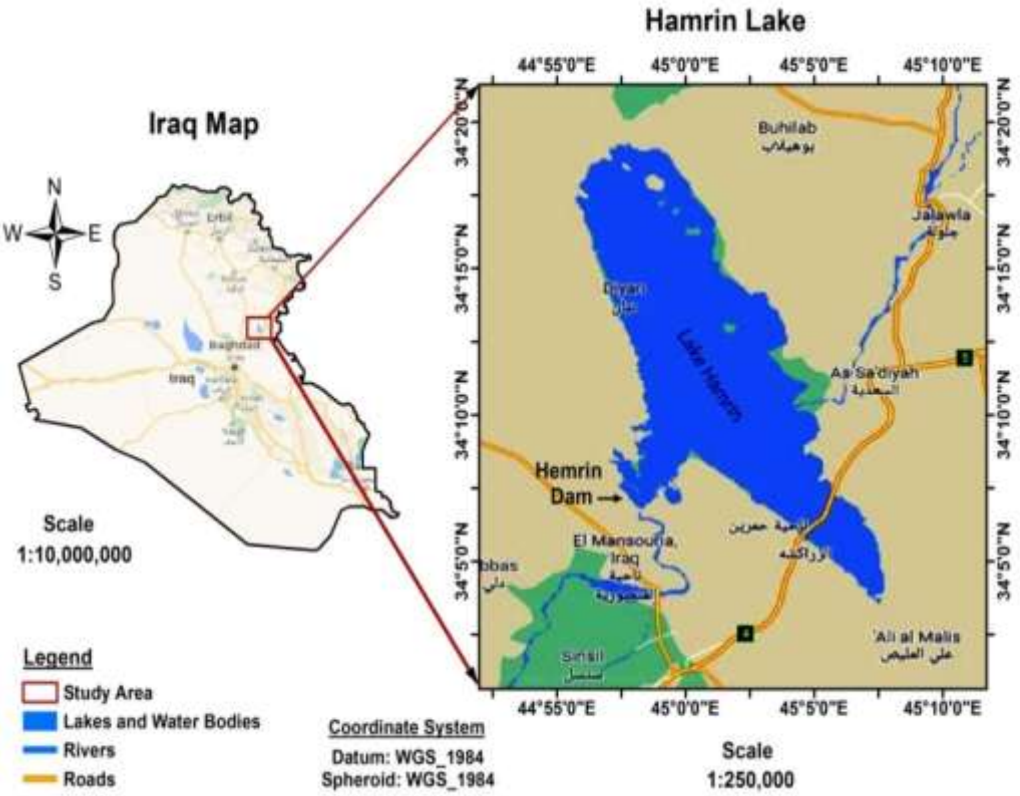


**Figure 1:** Hamrin Lake location map using ArcGIS software and Google maps

**4. Data Sources and Applications**

The satellite images of Hamrin Lake were collected between 2011 and 2022 from google earth pro version 7.1.8.3036 and the Sentinel Hub EO browser. Landsat satellite images from 31 December 2011 to 31 December 2020 were obtained from google earth pro. EO browser was used to download Landsat 8-9 level-2 images on 31 December 2021 and 3 July 2022. Also, the Sentinel-2 image on 29 December 2022 was downloaded from the Sentinel hub EO browser. Most frequently, the monthly water storage in Iraq is highest in May and lowest in September. In order to reflect the average between the highest and lowest water storage, the most satellite image dates were acquired in December. The total number of satellite images is thirteen covering the study area of Hamrin Lake.

On the other hand, the control point file, which includes latitudes and longitudes, was downloaded from google earth pro. Then, Global Positioning System (GPS) visualizer online utility was used to download altitudes for selected control points. The output was a GPS Exchange Format (GPX) file containing all control points' latitudes, longitudes, and altitudes. This GPX file was then converted to a shapefile using ArcGIS desktop version 10.8.

**5. Methodology**

The collected multitemporal satellite images were added to ArcMap and ArcGIS and georeferenced to the World Geodetic System (WGS) 1984 Universal Transverse Mercator (UTM) zone 38 north. Many control points were well distributed, covering the study area, and saved as (.kml) files. The elevations of these control points were extracted from GPS visualizer online utility by uploading the (.kml) file of control points. Then, the elevation data were converted and added as a GPX file. The output GPX file was converted to a shapefile using the ArcGIS application. The coordinate system resulting in the point shapefile was WGS 1984. The Project tool in ArcMap was used to project the geographic coordinates of the point shapefile to map coordinates according to WGS 1984 UTM zone 38 north, producing the digital elevation model.

After projection, TIN was created from the point shapefile. The TIN layer represents the elevation surface containing height values in the study area. The TIN layer is vector based converted to raster using the TIN to Raster tool. Contour lines were extracted from raster TIN using the contour tool. The contour lines produce a polygon around the water level boundary in Hamrin Lake. The selected contour interval was 0.5m. The surface areas of these polygons were obtained in the ArcGIS attribute table by calculating the geometry. The estimated surface areas depended on a satellite image's spatial resolution. Levels in the lake were observed from spot heights and contour lines concerning the year observed. The minimum water level in Hamrin Lake is 90m. The reservoir water heights were estimated from contours by subtracting the minimum level from the water surface level as illustrated in Eq. (1). The submerged surface area and the reservoir area at level 90m were evaluated by the ArcMap attribute table using the geometry tool. The end area method calculated the water storage volumes (Eq. (2)).

$$Reservoir\ Water\ Height\ (m) = Water\ Surface\ Level\ (m) - Minimum\ Level\ (90m) \quad (1)$$

$$Water\ Storage\ Volume\ (m^3) = Reservoir\ Water\ Height\ (m) \times [(Area1 + Area2)/2]\ m^2 \quad (2)$$

The end area equation was written in the attribute table field calculator using a Visual Basic (VB) script. The programmed VB script was executed multiple times for evaluating water storage volumes. The changes in surface areas of Hamrin Lake are shown in Figures (2-13). From the observation of multitemporal images, it is evident that Hamrin Lake shrunk in 2021 and 2022 despite the slight increment of water storage in the last two months of 2022 due to the rainfall. This situation was due to drought and climatic changes prevailing in Iraq.

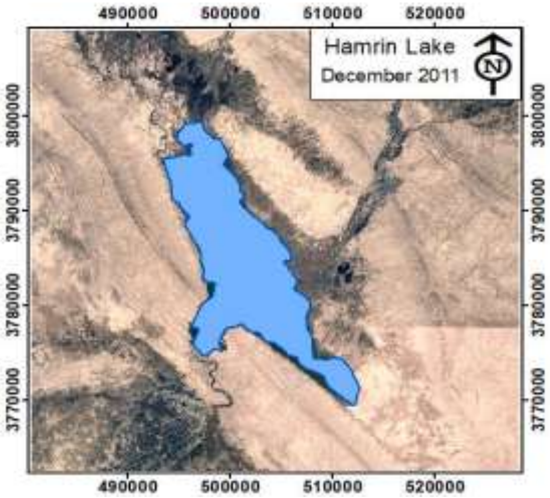


**Figure 2:** Hamrin Lake in December 2011

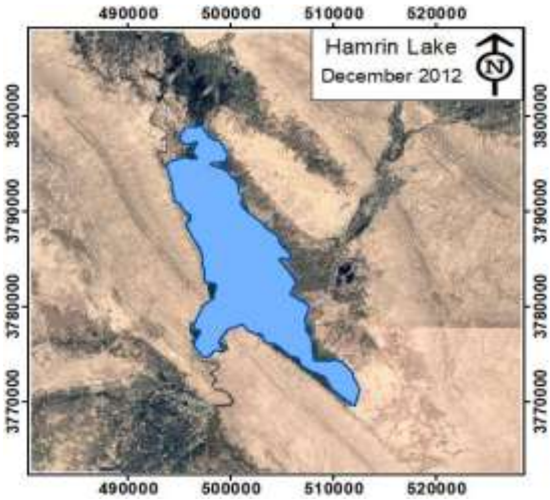


**Figure 3:** Hamrin Lake in December 2012

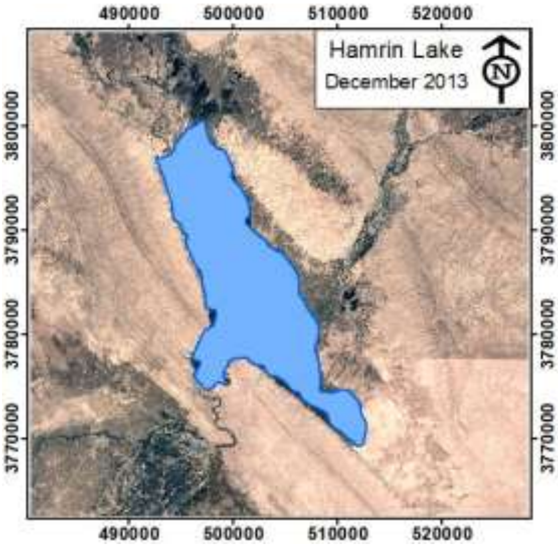


**Figure 4:** Hamrin Lake in December 2013

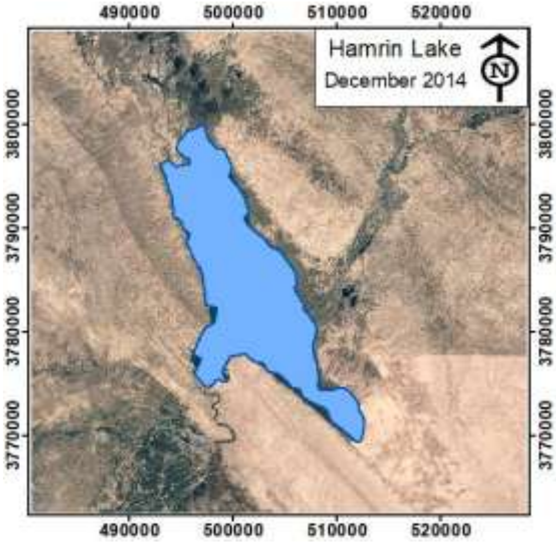


**Figure 5:** Hamrin Lake in December 2014

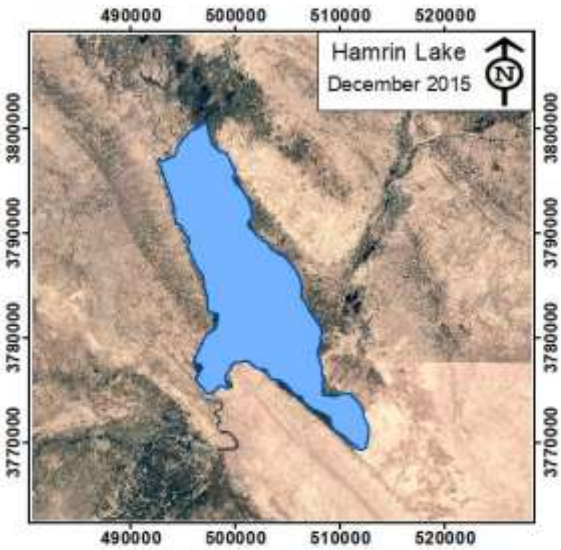


**Figure 6:** Hamrin Lake in December 2015

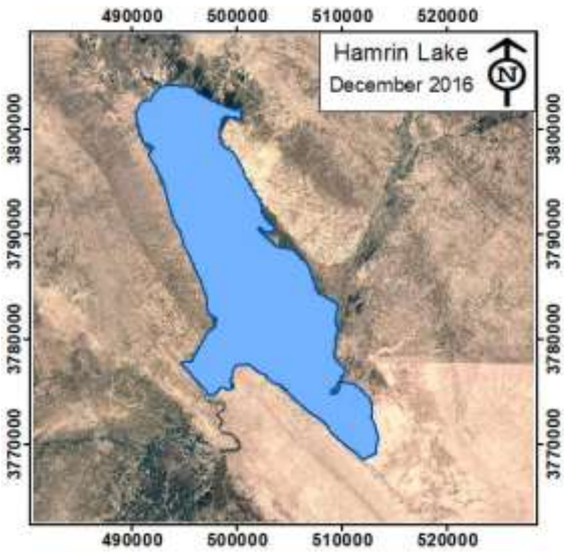


**Figure 7:** Hamrin Lake in December 2016

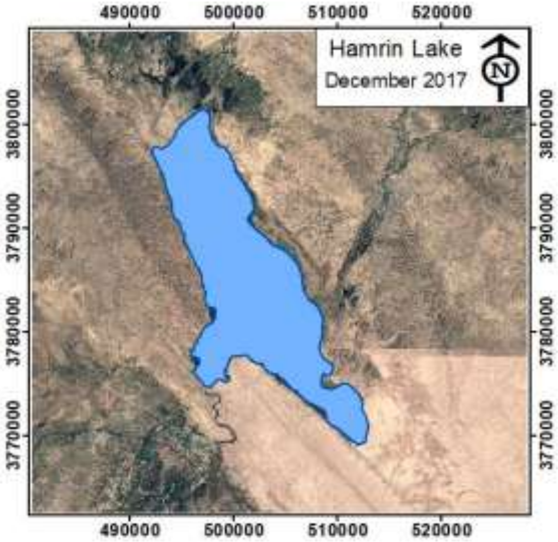


**Figure 8:** Hamrin Lake in December 2017

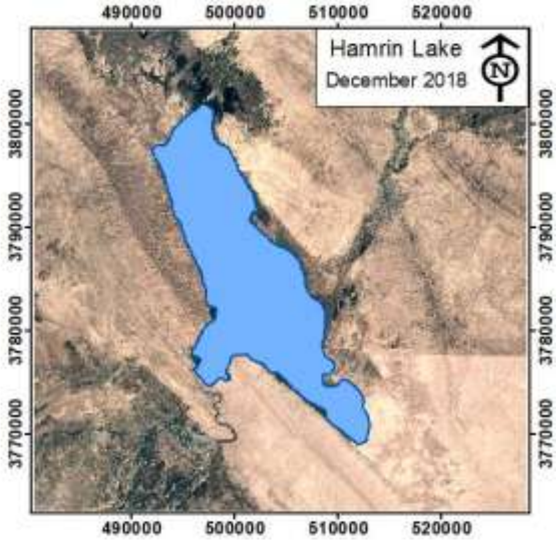


**Figure 9:** Hamrin Lake in December 2018

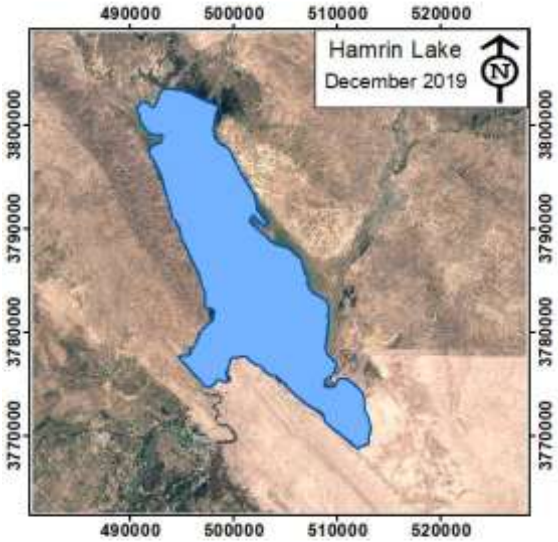


**Figure 10** Hamrin Lake in December 2019

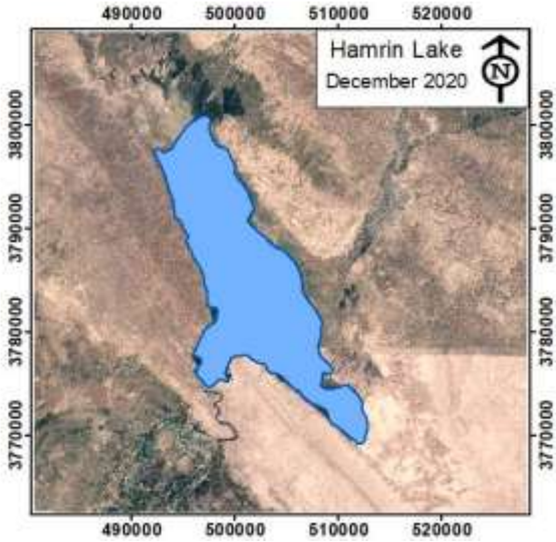


**Figure 11** Hamrin Lake in December 2020

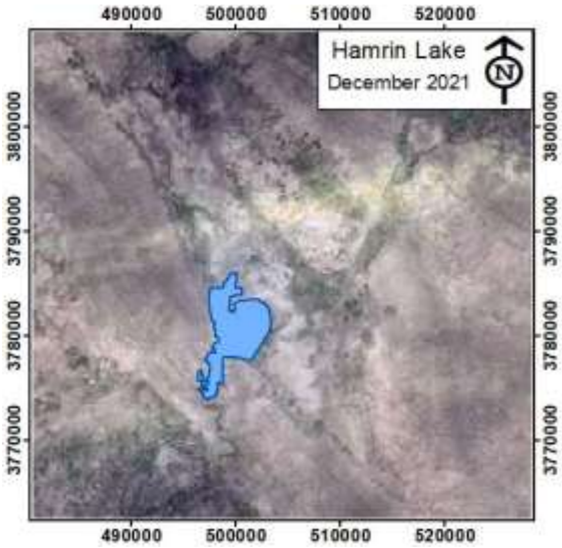


**Figure 12:** Hamrin Lake in December 2021

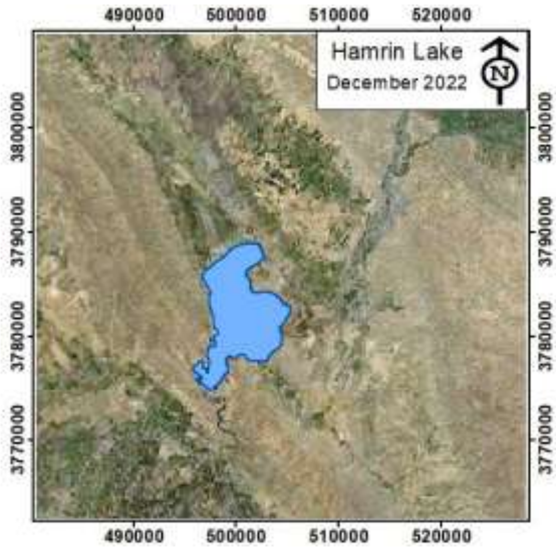


**Figure 13:** Hamrin Lake in December 2022

**6. Implementation and Results**

Different levels of Hamrin Lake were obtained from the extracted digital elevation model and contour lines. The maximum water level during the flood period is 107.5m, whereas the level at normal storage is 105m. ArcGIS calculator evaluated the surface areas. The water-submerged surface area of the reservoir bed at a level of 90m is 12.12 $km^2$. Water storage below the level of 90m was not considered because it is scarce. The water storage volumes were computed in the field calculator using the end area method (Figure 14). Table 1 shows water surface areas and storage volumes at normal and maximum levels. Lake water levels rise or fall over time. The contour line surrounding the water border forms the lake level. Levels range from 90m to 101m. The water level decreased in December 2021 to 90.5 m due to the lack of rainfall, and then it increased slightly in July and December 2022 to 91m and 91.5m, respectively. Table 2 shows the water surface areas and storage volumes observed over the years at different levels. The end area method is a volume calculation approximation, and its accuracy is adequate for estimating water storage volumes in the lake reservoirs from satellite images.

The water storage volume increases as the water level of the reservoir increases. Figure 15 illustrates the water storage volumes in billion cubic meters (bcm) of Hamrin Lake between 31 December 2011 and 29 December 2022. Maximum water storage was observed in December 2016. The water storage volume is gradually decreasing from 2019 to reach about 12 million cubic meters in December 2021. Then, this storage slightly increased to 59 million cubic meters in December 2022. The percentage of the water storage volume relative to the normal storage capacity is displayed in Figure 16. In December 2021 and 2022, Hamrin Lake lost 99.6% and 98.2% of its capacity from the normal storage volume. At the end of 2021, the water storage volume is the lowest since constructing the hamrin lake dam more than 42 years ago. It was expected that Hamrin Lake would disappear in the future case of continuous climatic effects, the lack of rain, and the rising temperature. The temperatures exceed 50 ºC in the summer season. Nevertheless, the last two months of 2022 witnessed torrents that partially revived Hamrin Lake.

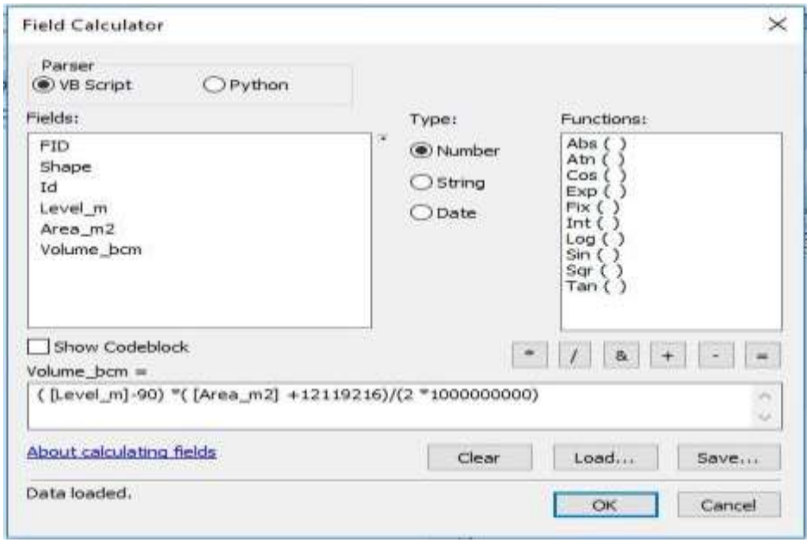

**Figure 14:** Visual Basic script for volume calculation using the end area method

**Table 1:** Water surface areas and water storage volumes at normal and maximum levels

| Case | Level (m) | Reservoir Water Height from Level 90 (m) | Water Surface Area ($m^2$) | Water Storage Volume (bcm) |
|---|---|---|---|---|
| *Normal Storage* | 105 | 15 | 426045645 | 3.286 |
| *Maximum Storage (Flood Season)* | 107.5 | 17.5 | 480750381 | 4.313 |

**Table 2:** Water surface areas and water storage volumes at different levels over the years

| Date | Level (m) | Reservoir Water Height from Level 90 (m) | Water Surface Area ($m^2$) | Water Storage Volume (bcm) |
|---|---|---|---|---|
| *31-12-2011* | 96.5 | 6.5 | 191065993 | 0.660 |
| *31-12-2012* | 96 | 6 | 178350686 | 0.571 |
| *31-12-2013* | 97.5 | 7.5 | 215656627 | 0.854 |
| *31-12-2014* | 97 | 7 | 203136077 | 0.753 |
| *31-12-2015* | 97.5 | 7.5 | 215656627 | 0.854 |
| *31-12-2016* | 101 | 11 | 311237712 | 1.778 |
| *31-12-2017* | 98.5 | 8.5 | 237967881 | 1.063 |
| *31-12-2018* | 99 | 9 | 248520228 | 1.173 |
| *31-12-2019* | 100 | 10 | 284827634 | 1.485 |
| *31-12-2020* | 98 | 8 | 227428560 | 0.958 |
| *31-12-2021* | 90.5 | 0.5 | 37510388 | 0.012 |
| *03-07-2022* | 91 | 1 | 56596924 | 0.034 |
| *29-12-2022* | 91.5 | 1.5 | 67125399 | 0.059 |

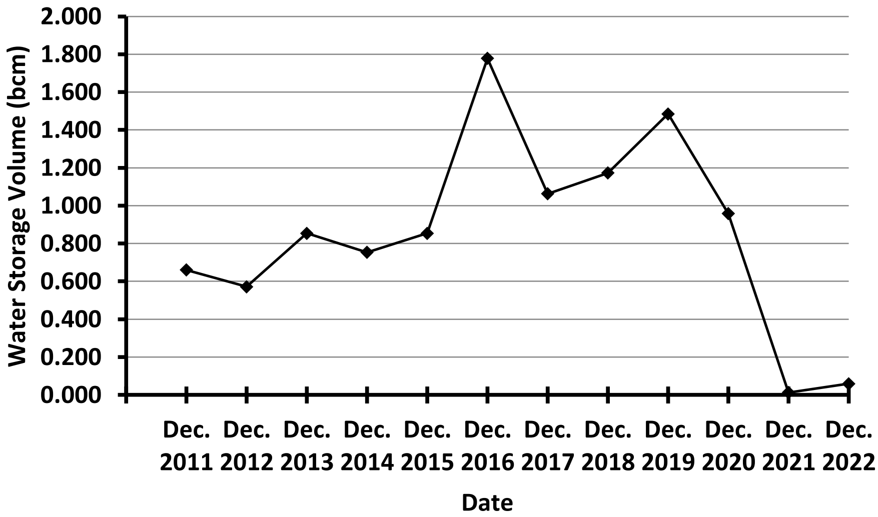


**Figure 15:** Annual variability of water storage volumes in Hamrin Lake

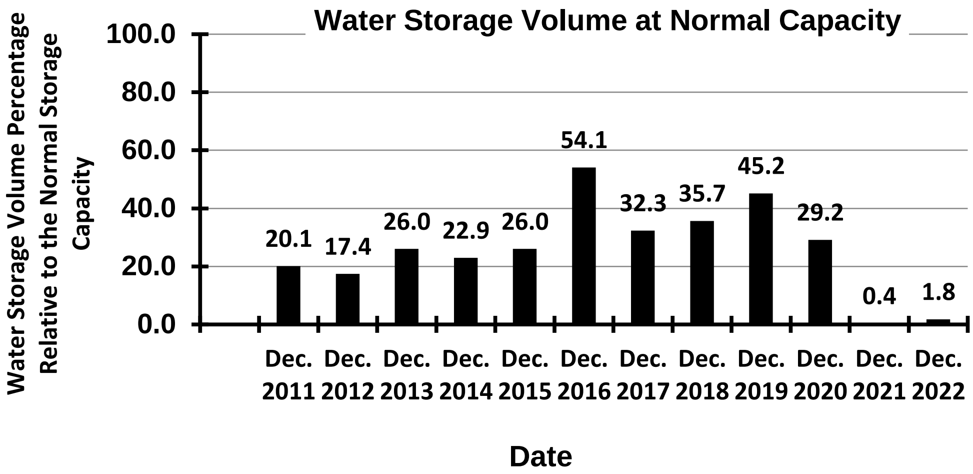


**Figure 16:** Water storage volume percentages relative to the normal storage capacity over the years

## 7. Conclusions

1. The water storage volume increases as the water level of the reservoir increases. At normal storage, the water storage volume of Hamrin Lake is about 3 bcm and may reach 4 bcm in the flood season. The maximum storage is 1.8 bcm, as observed in December 2016. This storage decreased to about 12 million cubic meters in December 2021. Hamrin Lake lost 99.6% and 98.2% of its capacity relative to the normal water storage volume in December 2021 and 2022, respectively. The storage capacity will have a little increment at the end of 2022.
2. Unfortunately, Hamrin Lake shrunk in December 2021, and it may be subject to drought in case the deficiency of water flows comes from Alwand and Sirwan Rivers, forming the Diyala River and flows from Darbandikhan Lake. In addition, the climatic change factors include the lack of rainfall, increasing evaporation rate due to temperature rising, frequently occurring dust storm phenomena, and underground water intrusion. Nevertheless, the last two months of 2022 witnessed some rains and torrents that partially revived Hamrin Lake.
3. The scarcity of irrigation water from Hamrin Lake leads to decreased agricultural areas and groves in Diyala province and the spread of desertification. All these cause the migration of people to other regions and the livestock destruction.
4. The accuracy of monitoring the submerged surface areas and water storage volumes using satellite imagery was restricted by spatial, spectral, radiometric, and temporal resolutions. ArcGIS software has a facility and reliability in data processing and calculating the geometry in the ArcMap attribute table. There are many methods for volume calculation. The end area method is a volume calculation approximation. Its accuracy is adequate for determining water storage volumes in the lake reservoir from satellite images.

## 8. Recommendations

1. Exploiting the drought period to improve riverbeds (Alwand, Sirwan, and Diyala Rivers) and maintain the shoulders of Hamrin Lake. These procedures will prepare the lake to receive water flows in rainy years.
2. The use of modern means for agriculture area irrigation to reduce the waste of water resources and preserve the environment of lakes from pollution.

## 9. Acknowledgements

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## 10. Disclosure and conflict of interest

The author declares that there are no conflicts of interest.

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