Libyan Journal of Ecological & Environmental Sciences and Technology
(LJEEST)

LJEEST
ISSN: 2710-5237
www.srcest.org.ly/jou

http://aif-doi.org/LJEEST/060102

Estimate Changes in the Surface Area and Water Volume of the Wadi Ka'am and Al-Mjeneen Dams, 2017-2021

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ARTICLE INFO

Vol. 6 No. 1 June, 2024
Pages (6- 11)

Article history:
Revised form 07 May 2024
Accepted 30 May 2024

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Keywords:
Open-source data, water storage, geographic information system, Wadi Ka'am, Al-Mjeneen Dams.

ABSTRACT

The aim of this study was to identify and determine the extent of changes in both the surface and water capacity of the Wadi Ka'am and Al-Mjeneen dams in NW Libya between 2017 and 2021. Open-source ESA data with a spatial resolution of 10 m were used to create LULC thematic maps. The data were processed using geographic information systems (GIS) to estimate changes in the surface area and water volume in both dams. The results showed that, during each rainy season from 2017 to 2021, the volume of water reserved in front of each dam varied. The storage capacities of the two dams peaked at the end of 2018 and then decreased to drought by 2021. The changes in the water storage capacity of the two dams and their decrease are due to a sharp decrease in rainfall during 2019, 2020, and 2021, with high annual evaporation rates and increased pressure on the use of water from the two dams for agricultural purposes. Thus, this study highlights the importance of using open-source data and geographic information systems to monitor and manage water resources in dams.

تقدير التغيرات في المساحة السطحية وحجم المياه في سدي وادي كعام والمنيين، 2017–2021

عبد العاطى احمد محمد الحداد

الهدف من الدراسة هو معرفة وتحديد مدى التغيرات في كل من السعة السطحية والمائية لسدي وادي كعام والمجنين بشمالي غربي ليبيا ما بين عامي 2017 و2021. استخدمت بيانات وكالة الفضاء الأوروبية (ESA) مفتوحة المصدر لإنشاء خرائط مواضيعية من فئة استخدام الأراضي والغطاء الأرضي (LULC) بدقة مكانية تبلغ 10 أمتار. تمت معالجة البيانات باستخدام نظم المعلومات الجغرافية (GISs) لتقدير التغيرات في مساحة السطح وحجم المياه في كلا السدين. أظهرت النتائج أنه خلال كل موسم ممطر من 2017 إلى 2021، يختلف حجم المياه المحجوزة أمام كل سد. وصلت سعة تخزين السدين إلى ذروتها في نهاية عام 2018 ثم انخفضت إلى حالة الجفاف في عام 2021. ترجع التغيرات في سعة تخزين مياه السدين وانخفاضها إلى تناقص حاد في هطول الأمطار خلال الاعوام 2019 و2020 و2021، مع ارتفاع معدلات التبخر السنوية، وزيادة الضغط على استخدام مياه السدين للأغراض الزراعية. بذلك سلطت هذه الدراسة الضوء على أهمية استخدام البيانات مفتوحة المصدر ونظم المعلومات الجغرافية لرصد وإدارة الموارد المائية في السدود.

INTRODUCTION

The lakes and reservoirs created by dams play a crucial role in the natural water cycle by contributing to the availability of water resources. These bodies of water also serve as indicators of climatic conditions and changes due to modifications in their physical, chemical, and biological properties (Mustafa & Noori, 2013). Dams provide several benefits, including regulating river and stream flows, mitigating flood intensities

, recharging groundwater, and serving as significant sources of water for various applications (Khojiakbar et al., 2019). Conversely, water reserved by dams is essential for the planning and management of water resources, given the increased demand for water resources and the urgent need to construct dams in anticipation of the impacts of climate change on water resources, particularly in the Middle East and Mediterranean region, which results in observable fluctuations in the water cycle (Shumba et al., 2018).

The storage capacity of a dam refers to the amount of water that can be stored in front of the dam, which is determined by the volume of water flowing into and out of the dam and the volume of the dam itself. Dams are classified according to their size, with small dams having storage capacities of a few million cubic meters and large dams having storage capacities of tens or hundreds of millions of cubic meters (Khojiakbar et al., 2019; rvem, n.d.; Shumba et al., 2018). Typically, a direct method involving field surveys and gauge readings is employed to manage the water resources associated with dams. This method aims to determine the changes in water levels in the reservoir to identify and quantify changes in the surface area and water storage volume between each period. However, this technique is expensive, requires measurement devices, is time-consuming, and requires many users (Khojiakbar et al., 2019). Alternatively, modern geospatial methods, such as remote sensing (RS) and geographic information systems (GIS), can be used to indirectly determine changes in surface area and water storage volume in dam reservoirs (Sisipho Ngebe, 2022).

Remote sensing technology has emerged as a valuable tool for providing users with multitemporal data in the form of high spatial- and temporal-resolution multispectral satellite images, enabling the detection of changes in the surface area and water volume of dam reservoirs. By analyzing satellite images acquired at different time periods, information on changes in the Earth's surface can be extracted. Geographic Information Systems (GIS) are widely used in hydrological studies because of their ability to process, analyze, and interpret spatial data(Bhagwat et al., 2019). GIS can represent spatial data in various formats such as maps, tables, graphs, and charts, providing a powerful tool for visualizing and testing spatial relationships. Through the integration of mathematics, information technology, and geography or location, GIS can collect, operate, analyze, model, and visualize spatial geographic data, enabling the creation of graphical representations of the surface area and water storage volume of a dam reservoir during different periods(Hagos et al., 2022). By linking the satellite image processing outputs with digital elevation models (DEM) within the GIS software environment, these spatial techniques can provide long-term and cost-effective solutions for monitoring changes in the surface area and volume of water storage of dams (Bhat et al., 2015).

The availability of open-source data provided by the official websites of the European Space Agency (ESA) and NASA has proven to be an important resource for obtaining reliable spatial data. These data sources can be used to produce objective land cover maps and land use classifications using deep learning techniques (ESA, 2022). Consequently, this study aims to identify and determine the extent of changes in both the surface and water capacity of the Wadi Ka'am and Al-Mjeneen dams NW of Libya between 2017 and 2021 using land cover maps provided by the official website of the European Space Agency (ESA), which were extracted using Sentinel 2 satellite imagery classification procedures.

in the surface area and water storage volume of the Wadi Ka'am and Wadi Al-Mjeneen dams during the period– 2017-2021 using spatial analysis tools available within the GIS software environment. The objective of this study was to achieve reliable results that allow for a better understanding of the extent of the impact of climate change and rainfall variability on the volume of water stored by dams in the region. Furthermore, this study demonstrates the usefulness of remote sensing and GIS techniques in obtaining valuable information that can be employed in the field of surface water resource management.

The study area of this research is defined as the region encompassing the Wadi Ka'am and Wadi Al-Mjeneen dams, both located in northwest Libya (Figure 1). The Wadi Ka'am dam is situated between the cities of the Al-Khums and Zliten, approximately 7 km from the Mediterranean coast and 144 km east of Tripoli. It was completed in the late 1970s and has a storage capacity of approximately 40 million cubic meters. The Wadi Al-Mjeneen dam, located 64 km south of Tripoli, was constructed in 1972 to protect the city from floods and has a storage capacity of approximately 10 million cubic meter. The geographic coordinates and location map of the study area are shown in Figure 1. *(Aqneber, 2014; Al-Ghryani, 2018; Abdullah, 2021).*

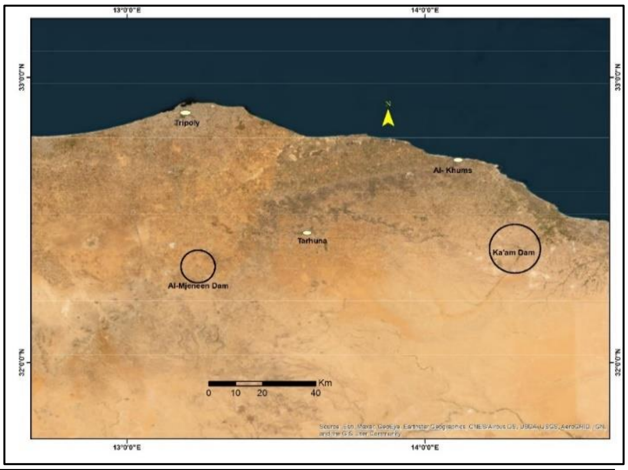

Figure (1): Map showing the locations of the Wadi Ka'am and Wadi Al-Mjeneen dams.

Materials and Methods

The current study utilized free and thematic maps as the primary data source, which was available on the official website of the European Space Agency (ESA) in the GeoTIFF format (Figure 2). These maps provide land cover classifications and land use maps (LULCs) from 2017 to 2021, with a spatial resolution of 10 m *(https://esa-worldcover.org/en)*. These maps were produced by the American Environmental Systems Research Institute (ESRI) and Microsoft using advanced deep learning techniques based on artificial intelligence (ESA, 2022). It should be noted that the classification maps utilized a massive dataset that contained billions of pixels from Sentinel-2 European satellite imagery, which covers the entire world.

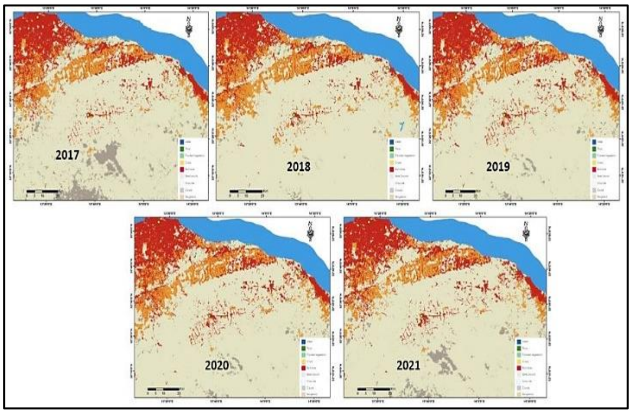

Figure (2): shows the land cover classification maps for the study area during the period 2017-2021, obtained from the official website of (ESA).

Furthermore, a Digital Elevation Model (DEM) with a resolution of 12.5 meters was used to generate contour lines and elevation points above sea level for both the Wadi Ka'am and Wadi Al-Mjeneen dams (Figure 3). These data were used to provide additional information on the topography of the study area.

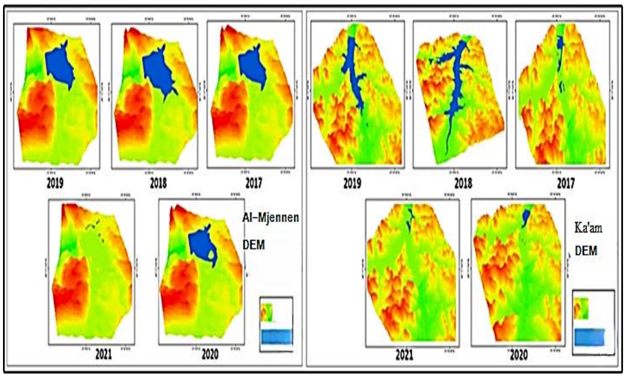

Figure (3): shows a Digital Elevation Model (DEM) of the study area with a spatial resolution of 12.5 meters. DEM data were obtained from the United States Geological Survey (USGS) website.

The data were processed using Geographic Information Systems (GIS) software tools to execute the following operations:

1. The class of water bodies, represented by each dam lake during a specific year within the study period, was converted from raster format to vector format using the conversion tools available in the GIS Processing, Calculation, and Analysis ArcToolBox. This process resulted in a polygonal shape representing the surface area of each dam lake.

2. The polygon shape of the dam lake was utilized as a mask to clip the Digital Elevation Model (DEM) for the lake area during each year of the study period.

3. The Spatial Analyst Supplemental Tools produced by ESRI within the additional ArcToolBox tools were utilized for various spatial analysis operations (Figure 4). A storage capacity tool was used to calculate the surface area and volume of the water in the dam lake.

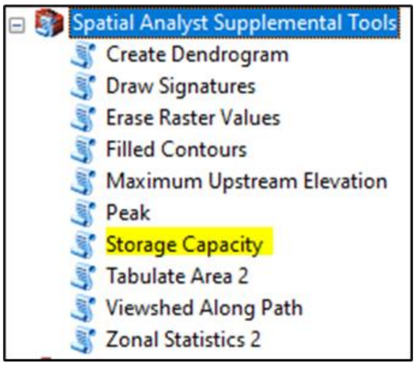

Figure (4): Spatial Analyst Supplemental Tools.

Notably, this tool generates a table of water surface elevations and corresponding storage capacities for a Digital Elevation Model (DEM) representing a reservoir or any other terrain surface. The storage capacity is defined as the net accumulated volume, surface area, and specific water surface elevation. Using this tool, storage capacity tables can be easily created for any elevation raster data and the results can be presented in graphical form. Table (1) outlines the measurement requirements for the supplemental spatial analysis tools.

Table (1): summarizes the essential requirements of the Storage Capacity tool.

Parameter	Explanation	Data Type
Input DEM	The input raster representing a continuous surface	Raster Layer
Input boundary polygon (optional)	The feature used to clip the input features	Feature Layer
Maximum elevation (optional)	The maximum water free surface elevation to use while assessing storage capacity. A default value equal to the minimum elevation value of the raster is populated when the Input DEM file path is specified.	Double
Minimum elevation (optional)	The minimum water free surface elevation to use while assessing storage capacity. A default value equal to the minimum elevation value of the raster is populated when the Input DEM file path is specified.	Double

RESULTS AND DISCUSSION

The study findings were obtained following these steps, resulting in maps depicting the lake surface area for each year between 2017 and 2021 for the two dams. Additionally, tables were generated that indicate the contour-based area and volume of water stored in each dam lake. These outcomes were utilized to create graphical representations that demonstrated the correlation between the elevation above sea level in meters for each contour line, the surface area in square meters, and the stored water volume in cubic meters.

Specifically, the results revealed a discernible fluctuation in the surface area and water volume of the Wadi Ka'am dam lake between 2017 and 2021. Figure 5 and 6 and Table 2 illustrate the changes in the lake surface area, which peaked in 2018 at approximately 3 km², indicating an 86% increase from 2017, along with an 88% increase in water volume. However, the lake surface area and water volume declined by 48% in 2019 compared to 2018. This decline continues until the end of 2021, resulting in a substantial reduction of 96% in the surface area and 99% in the water volume of the lake, compared to their levels in 2018.

Table (2): Water Storage Quantity during the years 2017-2021

Dam Name	Year	Lake Surface Area (m²)	Water Volume (m³)
Ka'am	2017	3998750	3464840
	2018	29462344	30635238
	2019	15048906	15805070
	2020	4170938	2941382
	2021	1160781	55564
Al- Mjeneen	2017	3617031	3478445
	2018	3889061	4508854
	2019	3689063	3880924
	2020	3350625	3457917
	2021	72500	6953

Figure (5): Change in surface area and water storage volume 2017-2021

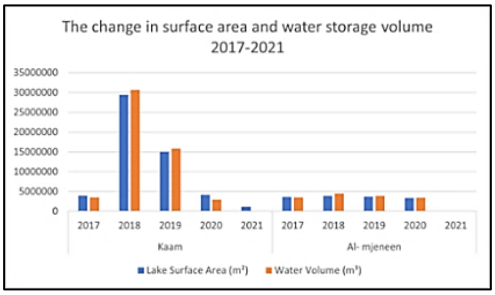

Figure (5): Change in surface area and water storage volume 2017-2021

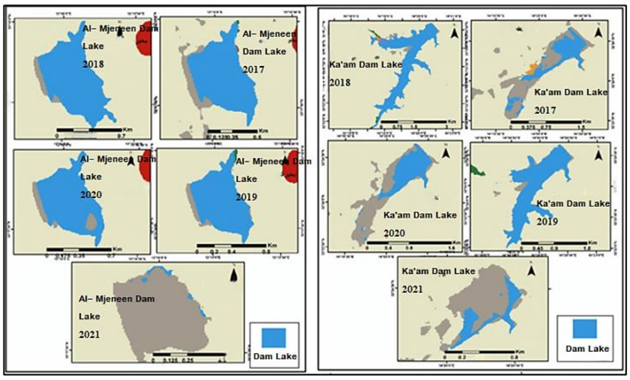

Figure (6): shows the variations in the surface area and water volume of the Wadi Ka'am and Wadi Al-Mjeneen Dams.

The analysis of archival images provided by Google Earth revealed that the lake's longitudinal extension in front of the dam exceeded 4.5 km in December of that year (see Figure 7). In addition, the water volume in the dam lake exceeded 30,000,000 m³ by the end of the year, which was close to the maximum storage capacity of the dam. This suggests that the Wadi Ka'am Dam was filled during the year in question.

To corroborate these findings, it is worth noting that the administrative boundaries of the Tarhuna and Mislatah regions encompass the Targlaat Ka'am Basin, where the dam was constructed at the estuary's outset. In 2018, these regions experienced above-average rainfall of over 300 mm, which further supported the conclusion that the dam was filled to its maximum capacity during that year.

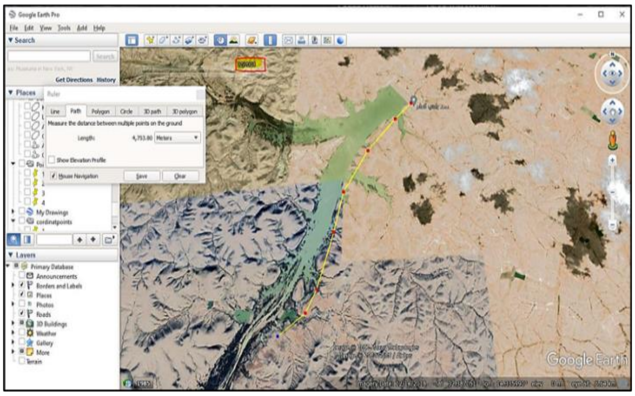

Figure (7): illustrates the maximum length of the Wadi Ka'am dam lake in 2018, which was derived from archival images from Google Earth.

Furthermore, as shown in Figures 5 and 6 and Table 2, the water storage volume for the surface area of Wadi Ka'am Dam Lake experienced a significant decline in 2020 and 2021. The curve representing the water storage volume, as shown in Figure 8, shows a steep decline due to reduced precipitation rates during these years, leading to the complete drying of the dam lake in August 2021. This unprecedented event has not occurred since the dam was built 40 years ago, as confirmed by the relevant institutions responsible for dam management in Libya through reports and surveys published on their official websites. This finding is supported by a study conducted by Abdullah (2021), which attributed the drying up of the Wadi Ka'am dam lake to low rainfall during the winter of 2020/2021 in northwestern Libya, combined with high temperatures and increased rates of evaporation during the summer of 2021. The study reported that the precipitation rate was 33% lower in 2021 than in previous years, with only 118 mm recorded during the year. Additionally, the evaporation rate reached 158 mm in June and 160 mm in July 2021, according to data from the Ministry of Water Resources, ultimately resulting in complete drying of the dam lake in August 2021.

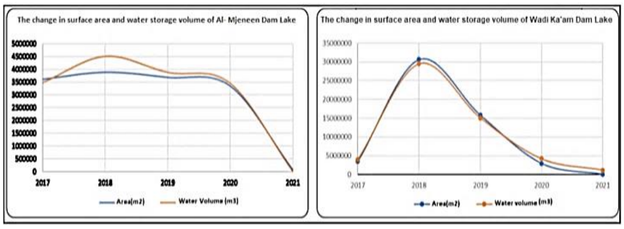

Figure (8): shows the variations in the surface area and volume of water storage of the Wadi Al-Mjeneen dam lake during the period 2017-2021.

The findings revealed that the surface area and volume of the dam lake did not experience a significant decline, except in 2021, as shown in Figure 5 and Table 2. During this year, the dam lake approached a state of complete desiccation, with reductions of 98% and 99% in its surface area and water storage volume, respectively, in comparison to the end of 2018. This rapid decline is attributed to a substantial drop in precipitation rates throughout the year, accompanied by increased evaporation rates and increased pressure on the use of dam lake water for agricultural purposes by residents residing around the dam. However, during the years 2017-2019, the dam lake surface area and water storage volume did not undergo significant changes owing to the consistent inflow and outflow of water from the dam.

CONCLUSIONS

This study aims to estimate changes in the surface area and water volume of the Wadi Ka'am and Al-Mjeneen Dams in Libya using open-source data from the European Space Agency. Data were obtained in the form of thematic maps with a spatial resolution of ten metres for land use and land cover classes for the period 2017–2021. The study used a Geographic Information System to analyse the data and found clear fluctuations in the reserve water volume in front of each dam at the end of each rainy season during the years 2017-2021. The storage capacity of dams peaked at the end of 2018 and then decreased to a state of drought by 2021. The fluctuations and decreases in the annual water storage capacity of the dams were attributed to a decrease in the amount of annual precipitation in 2019, 2020, and 2021, an increase in annual evaporation rates, and an increase in the pressure on the use of dam water for agricultural purposes.

Climate change is known to have a significant impact on dam storage capacity because changes in temperature and precipitation patterns can alter the amount of water available for storage. The study found clear fluctuations in the reserved water volume in front of each dam at the end of each rainy season.

RECOMMENDATIONS

1. Research efforts should prioritize studies investigating the impact of climate change on water resources, particularly in regions vulnerable to water scarcity, such as Libya.

2. Institutions responsible for managing dams in Libya should ensure the provision of sequential and regular geohydrological data related to changes that occur in the surface area and depth of the dam reservoirs. This information is vital for the proper monitoring and management of water resources and can help mitigate the effects of climate change.

3. Efforts should be made to establish training courses that focus on programming and artificial intelligence operations using the open-source Google Earth Engine program. This program has the potential to conduct studies that monitor spatial changes using the time-series data processes contained in satellite images. Such courses can enhance the capacity of researchers and decision makers, allowing for better management of water resources in Libya.

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