Assessment of the Water Level Changes Based on Optical Satellite Images Analysis

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Abstract

The combination of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies has drastically increased the efficiency of mapping and evaluating changes in water bodies. Surface water areas confront significant challenges due to changing environmental conditions and declining water levels, which are further aggravated by human activities and climate change. The decreasing water surface area of Lake Hamrin, one of the largest lakes in Diyala Province, Iraq, is a major issue locally and regionally. This study examines changes in Land Use and Land Cover (LULC), lake area, water-holding capacity, and levels using ESA Sentinel-2 imagery and a deep-learning AI land classification model. The categorical change detection method was applied to the classified LULC maps to detect the changes in the lake area over five years. The extracted changes depending on time series datasets from 2018 to 2022 were quantified and analysed by developing a new strategy. The results showed changes in Lake Hamrin by 1.88% in 2018, 35.9% in 2019, 25.8% in 2020, 81.17% in 2021, and 84.58% in 2022. Comparing the lake's change values with the actual measured values yielded an overall accuracy of around 94.85%, indicating the promise of our enhanced change detection technique. The findings of this research can help promote sustainable water management techniques in the area and provide insightful information about the dynamics of Lake Hamrin. Also, our study will help the area's sustainable water management techniques.

1. Introduction

Lakes and other bodies of water are vital for biodiversity, ecological balance, and the provision of resources needed for human activity. For the purpose of managing water resources efficiently and protecting the environment, it is essential to track and comprehend how these bodies of water have changed over time. One such important body of water, Lake Hamrin, is located in the Iraqi province of Diyala. Both natural and man-made influences have significantly altered the lake's surface area and water levels.

Over vast geographic areas, remote sensing technology has shown to be an effective tool for tracking changes in land use and cover. The European Space Agency (ESA) launched the Sentinel-2 satellites, which offer high-resolution multispectral photography that is especially useful for change detection and environmental monitoring. Sentinel-2 Level-2A products are essential for collecting critical-grained temporal and spatial fluctuations in land cover because they provide 10-meter spatial resolution imagery (Drusch et al., 2012).

One popular technique in remote sensing to detect and measure changes in land cover categories over time is called "categorical change detection." Using this method, one can identify changes between different types of land cover by comparing categorised photos taken at different times. Robust Geographic Information System (GIS) software, ArcGIS Pro, offers sophisticated tools and features for analysing spatial data and detecting categorical change (Esri, 2020).

In this study, we identify and examine changes in Lake Hamrin during five years using ArcGIS Pro's categorical change detection approach. The worldwide classified Land Use Land Cover (LULC) maps, which are produced using Sentinel-2 Level-2A imagery and offer high-resolution and temporally consistent observations, serve as the main source of data for this investigation. Our goal is to measure the changes in the lake's surface area and identify the underlying reasons that are causing these changes by adopting a new strategy.

With its emphasis on Lake Hamrin, this study, therefore, adds to the expanding corpus of information regarding the use of GIS and remote sensing for water resource management in dryish and semi-dryish areas. The results of this study will be immensely beneficial to scholars, environmental decision-makers, and policymakers who are trying to manage water resources sustainably in Iraq and similar regions.

This article is organised as follows for the remainder of it. Section 2 reviews prior research on change detection using GIS and remote sensing data. Section 3 details our methodology and the Lake Hamrin detection procedure. Section 4 discusses the experimental results; Section 5 offers a thorough discussion; and Section 6 offers closing thoughts and suggestions for further research.

2. Previous work

Improved clarity in land use and land cover (LULC) data is necessary for precise studies of change detection. Global LULC datasets of 10m resolution have been developed as a result of recent advances. One example of this is the Sentinel-1 and Sentinel-2 imaging ESA WorldCover, which is given by the European Space Agency (ESA). These remote sensing databases provide accurate monitoring of environmental changes by providing updated and comprehensive information on a variety of land cover types. Research has confirmed that these high-resolution LULC maps are dependable and reliable, emphasising that they are useful for tracking period changes in a variety of environments (Kadhim et al., 2016). The accessibility of such data is essential for conducting thorough evaluations of the dynamics of land cover over short time periods, especially for regions with rapid environmental changes like Lake Hamrin. LULC maps, which track changes in water bodies through the use of Geographic Information Systems (GIS) analysis and Sentinel-2A data, have been utilised in various research. Therefore, many studies have shown how effective these technologies are at identifying changes in land cover, especially in water bodies, over a wide range of regional and temporal scales. Mishra and Rai's (2016) study, which used remote sensing methods to track the temporal and spatial patterns of water bodies in Varanasi, India, is one of the profound works in

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this field. The study emphasised the significance of high-resolution imaging in precisely registering alterations in aquatic bodies and showcased the capability of satellite imaging for environmental surveillance. The influence of changing climates on lake surface regions in China's Tibetan Plateau was also evaluated by Du et al. (2016) using Landsat imagery, highlighting the importance of temporal analysis in comprehending environmental changes.

With Sentinel-2 imagery's good level of spatial resolution and 10-day revisit durations, it has been used in more recent investigations. For example, Wang et al. (2020) mapped and tracked above-ground water bodies in the Yangtze River Basin using Sentinel-2 data. The benefits of Sentinel-2's 10-meter resolution in identifying small and medium-sized water bodies—which are frequently overlooked by coarser-resolution sensors—were illustrated by their research. Sentinel-2 Level-2A products, which offer atmospherically corrected images and improve the performance of change detection analyses, were also demonstrated to be useful in this investigation.

In order to increase change detection, recent research has also looked into integrating machine learning methods with data from remote sensing. Li et al. (2021), for instance, used machine learning methods to classify land cover and detect changes in metropolitan areas using Sentinel-2 data. Their results highlight the potential for improving the precision and effectiveness of change detection assessments by fusing conventional GIS approaches with cutting-edge computational methodologies. In another new study (Abd El-sadek, E., Elbeih, S., and Negm, A., 2022), the second-largest lake in the northern Mediterranean region of Egypt, Buullus Lake, is being monitored for changes in land use and land cover using remote sensing and GIS techniques. According to the study, the lake's floating vegetation area and water bodies shrank by 52% and 16%, respectively, between 1984 and 2019. Furthermore, there was a 290 km^2 rise in fish farms and 648 km^2 growth in agricultural fields. In order to achieve sustainable development goals, the findings assist decision-makers in taking the required actions to lessen anthropogenic activity and restore the lake. A further recent study, Dong, Zhen, et al. (2023), the Bitemporal Image Transformer (BiT) was employed remote sensing data to map Lake Poyang's inundation extents and evolution in 2020. A water change detection dataset was generated using Sentinel-1 images from Poyang Lake and seasonal variations analysis. According to the study, the amount of water surface covered rose from May to July before stabilising before November. A flood distribution map indicated that almost 600 km^2 of agricultural land was submerged. In a fresh research, Zhao, Desong, et al. (2024), the authors developed a Chlorophyll-a (Chl-a) retrieval algorithm using Sentinel-2 satellite images and in-situ data to monitor and trace the spatial distributions of Lake Chl-a in 3067 global lakes. The average concentration was 16.95 ± 5.95 mg/m3 from 2019 to 2021, with low concentrations mainly in high-latitude, high-elevation, or economically underdeveloped areas. In an additional recent study, Belayhun, M., & Mekuriaw, A. (2024) used four machine-learning models to estimate the spatial distribution of water hyacinths in Lake Tana, Ethiopia. Eleven variables from Sentinel-1 SAR bands, Sentinel-2A bands, and bioclimate data sources were incorporated into the models. AUC, ROC, TSS, COR, sensitivity, specificity, and kappa coefficient were used to assess the models. When it comes to water hyacinth spatiotemporal conditions prediction, the random forest model performs better than other models. Because of increased rainfall, water levels, and nutrient runoff during wet seasons, water hyacinths have a larger geographic distribution. It is imperative to integrate machine learning models with Sentinel image indices.

Although these studies on various techniques for detecting changes in water bodies are encouraging, resolving these potential flaws is essential to enhancing the validity and relevance of the results. Ensuring high-quality data, using the right approach, and thoroughly validating the results will improve the accuracy of the change mapping and offer insightful information for controlling lake and similar water body levels. Additionally, the change detection techniques should also be simple to use and straightforward. This was one of the reasons we carried out this investigation.

The research's relevance is seen in its application to Lake Hamrin, a vital water source in Iraq's Diyala province. The water level of Lake Hamrin has fluctuated significantly as a result of human and natural forces. For the region's environmental preservation and efficient use of water resources, it is imperative to comprehend these changes. This study intends to provide a detailed examination of land cover changes in and around Lake Hamrin over a five-year period by utilising the high-resolution capabilities of Sentinel-2 Level-2A imagery and categorical change detection algorithms in ArcGIS Pro. The utilisation of remote sensing and GIS techniques in this region is unprecedented, and as such, the change detection maps produced will be far superior to those produced by standard field survey methods, which are labour-intensive, time-consuming, and expensive. Monitoring Lake Hamrin's changes is crucial to preserving its natural equilibrium, guaranteeing long-term economic activity, safeguarding public health, and advancing scientific understanding. By facilitating strategic management and restoration initiatives, it guarantees that the lake will always offer significant ecosystem services and advantages to the surrounding community and the wider environment.

3. The Method

When comparing categorical rasters, the Categorical Change Detection approach works especially well at identifying areas that have changed from one class to another. In order to detect changes in certain land cover classes, the categorical change detection approach compares two or more raster datasets. This method is essential for identifying changes in land use patterns, such as shrinking water bodies, urbanisation, or agricultural expansion. Our method offers a thorough way to find and examine changes in Lake Hamrin. We devised a reliable approach to measure the alterations in the lake. This work intends to promote sustainable water management techniques in the area and offer important insights into the dynamics of Lake Hamrin by utilising robust classification algorithms and high-resolution Sentinel-2 data represented by the global LULC maps.

3.1 The study area

The study is centred on Lake Hamrin, which is found in Iraq's Diyala province in Figure 1. In eastern Iraq's Diyala Province sits Lake Hamrin, sometimes referred to as Hemrin Dam Lake. It is roughly 50 km northeast of Diyala's provincial capital, Baqubah. This lake, one of the largest bodies of water in Diyala Province, has seen considerable changes in recent years in both its surface area and water levels. Lake Hamrin's approximate coordinates are 34.1100° N latitude and 45.0300° E longitude. The Hamrin Dam on the Diyala River was built to produce Lake Hamrin, an artificial reservoir. The lake's surface area is around

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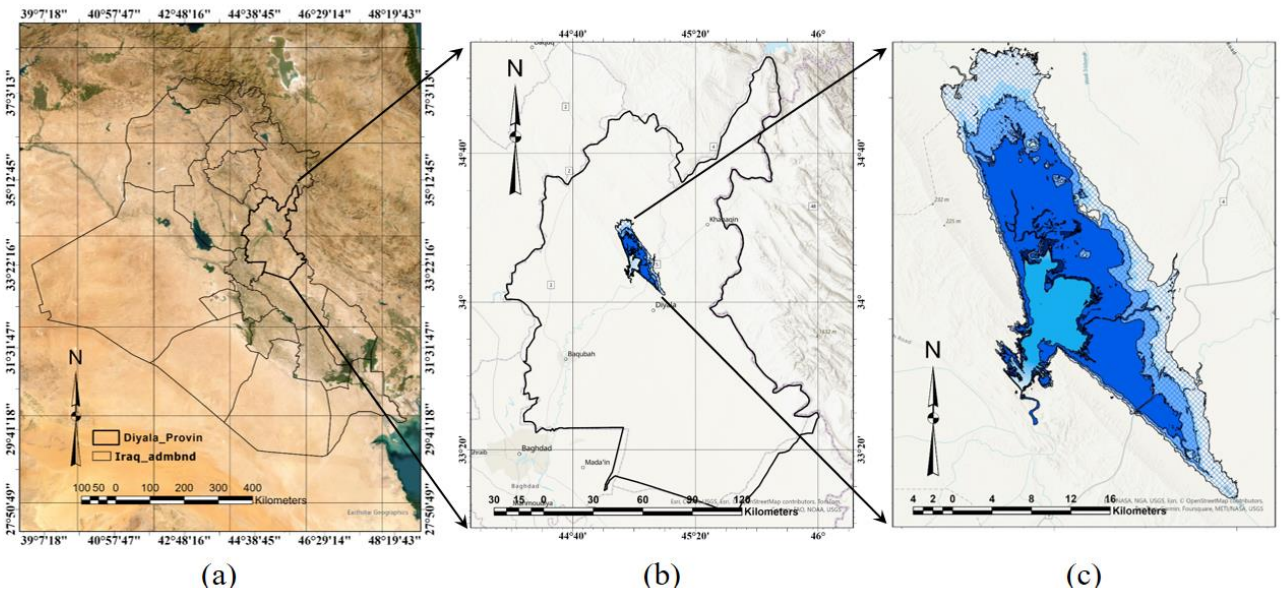

Figure 1. The study area of our research.

340 km^2, and its size varies seasonally and yearly based on water management techniques and rainfall. The main source of water in Lake Hamrin is the Diyala River, which rises in the country's Zagros Mountains. In addition to providing irrigation for the nearby agricultural areas, the lake is essential for flood control and water storage. The area has moderate, rainy winters and hot, dry summers due to its semi-arid environment. The majority of the rainfall falls between November and April, making for a comparatively low annual precipitation total. Because of its varied contributions to agriculture, ecology, water management, and socioeconomic development, Lake Hamrin is an important research region. Sustainable management and development in the area depend on an understanding of this lake's dynamics, and one of their requirements is monitoring and measuring lake changes.

3.2 Data Collection

This study's main source of data is a worldwide map of land use/land cover (LULC) created with 10 m spatial resolution using European Space Agency (ESA) Sentinel-2 imagery. Each year of this global map is produced annually by Impact Observatory's deep learning artificial intelligence (AI) land categorisation model, which was trained on billions of National Geographic Society image pixels that have been human-labeled. In current research, five years of the global Land Use and Land Cover (LULC) of our study region were downloaded from Sentinel-2 global 10m land cover/land use time series produced by Esri and Impact Observatory. The timeframe covered by the data was from [Oct 2017-Sep 2018] to [Oct 2021-Sep 2022], as shown in Figure 2. For the sake of comparison and validation in this study, these five years were chosen based on the data about the Hamrin Dam Lake that we were able to obtain from the dam administration. Excel sheets displaying the reservoir level, capacity, inflow and outflow, etc. are the type of data that was gathered from the dam administration.

3.3 Categorical Change Detection

Raster data that contains values assigned to each pixel that correspond to a class or category is known as categorical raster data. It is most frequently used in GIS to represent land cover, land use, or other zonal information like risk level. It is also occasionally referred to as discrete, thematic, or discontinuous data. Comparing category rasters is meant to help us find areas that have changed over time between different classes.

In this regard, ArcGIS Pro was used to import the classed LULC rasters and perform a categorical change detection analysis. To find and measure changes in the land cover categories throughout the five years, a change detection matrix was built. This entailed identifying changes between various land cover categories by comparing each classed image with the image from the next year, Figure 2.

By adding together all of the pixels in the LULC maps that were designated as water, the area of Lake Hamrin was determined on an annual basis. The yearly classed maps were compared in order to quantify changes in surface area and water levels. Every year's percentage change in the water's surface area was computed, as shown in the following Equation:

$$\text{Year's percentage change} = [V_n - V_o/V_o] \times 100 \qquad (1)$$

Where, V_n is the next year of the classified LULC map within the specific time series of the current study, and the original year with normal surface area and water levels at Lake Hamrin is denoted by V_o. This process was achieved after creating vector versions of the classified LULC rasters of all selected maps. Thereafter, the area of Lake Hamrin in each specific year was extracted in these vector maps by eliminating all other vector features, such as lines (e.g. streams and rivers etc.), polygons (e.g. some fields) and any point feature. The five extracted lake regions' attributes tables were constructed to show the real area in kilometres every year. Therefore, we obtained the exact shape files of the boundaries of the lake to accomplish the comparison. This step helps us to perform the comparison between the areas of the lake in each year only. In addition, to identify trends and patterns in the variations in Lake Hamrin's water surface area and levels over the course of five years, a time series analysis was carried out. To see the variations and spot any noteworthy trends or anomalies, the annual percentage change in the water area was plotted. Variations in temperature, precipitation, and human activity in the area were shown to be connected with variations in Lake Hamrin. For this, additional data had to be gathered from the lake dam stations and other pertinent sources. The final maps of the change detection displayed the actual lake area for each year

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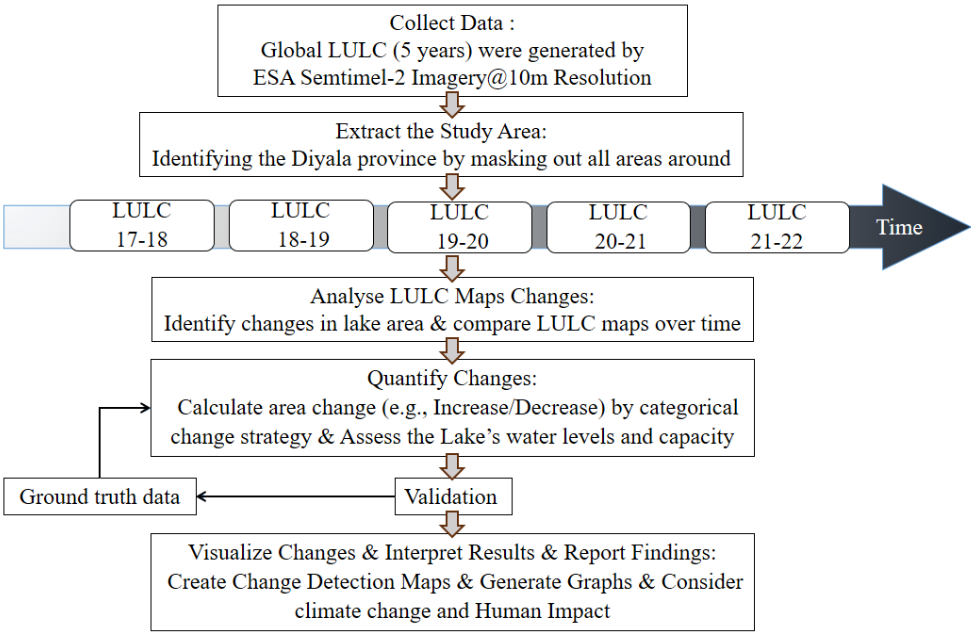


Figure 2. The flowchart of the applied method.

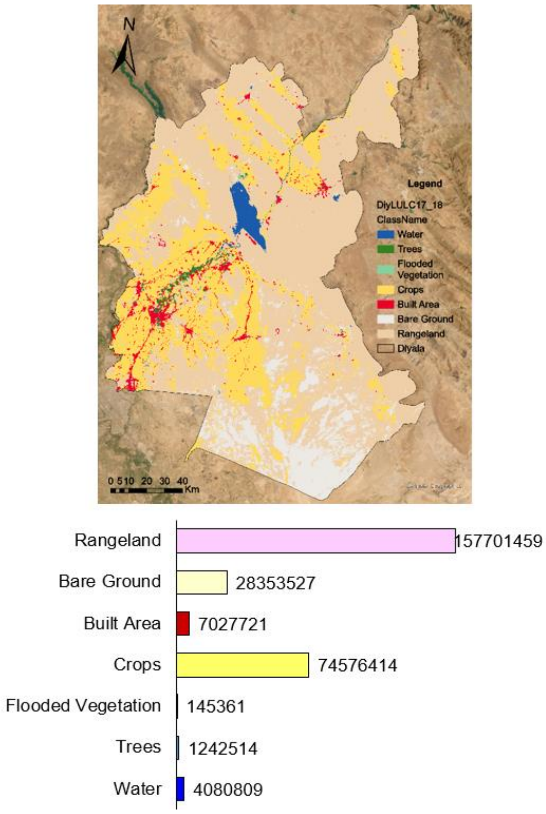
as well as the changes that were found in the Lake Hamrin area. To give an understandable and succinct depiction of the results, tables were made that summarised the annual variations in water surface area and levels. In addition, statistical analyses were conducted to evaluate the importance of the noted alterations. The above-discussed methodology offers a thorough strategy for utilising ArcGIS Pro's categorical change detection tools to find and analyse changes in Lake Hamrin. This work intends to promote sustainable water management techniques in the area and offer important insights into the dynamics of Lake Hamrin by utilising robust classification algorithms and high-resolution Sentinel-2 data.

4. Results

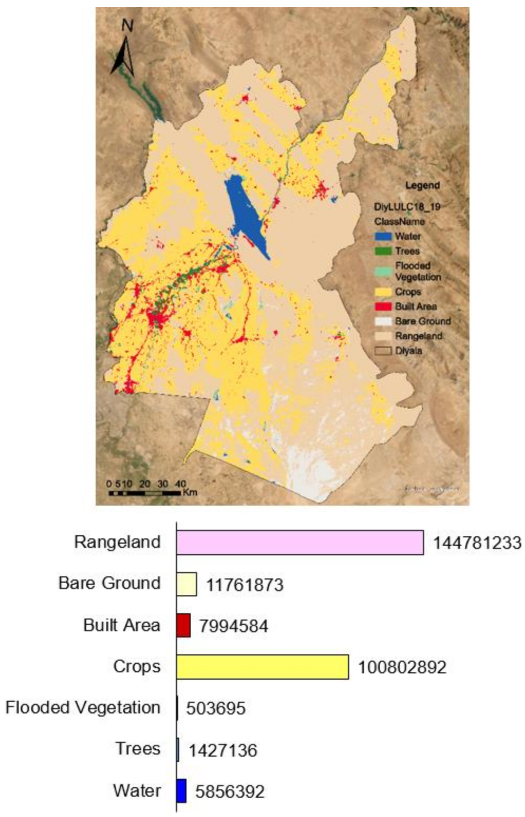
This section presents the key findings of the water surface area change detection analysis for Lake Hamrin from 2018 to 2022. It concentrates on the quantitative results that effectively address our research inquiries.

The water levels and surface areas of Lake Hamrin under study had notable variations during the assigned period, as demonstrated by the ArcGIS Pro analysis of the categorical maps derived by satellite imagery. Our analysis findings offer insightful information for tracking and comprehending the dynamics of water systems. We made use of the 10m resolution global land use/land cover (LULC) data obtained from ESA Sentinel-2 Level-2A imagery. The deep learning AI land classification model developed by Impact Observatory, which was trained using enormous sums of National Geographic Society (NGS) image pixels that have been human-labeled, is used to construct each of the five most recent years that we selected. Lake Hamrin area was compared in the five LU/LC datasets by employing the Change Detection Wizard in ArcGIS Pro version 3.2.2. Comparing category rasters is meant to help us find areas that have changed over time between different classes, as shown in Figure 3. The purpose of comparing categorical rasters is to identify areas that have changed from one class to another class over a period of time. As seen in Figure 4, Lake Hamrin's water surface area significantly decreased during the time frame of the five-year period. From 2018 to 2022, the lake's surface area dropped by almost 83%, approximately 325.68 km², on the average yearly decline. The period of greatest contraction took place in 2019 and 2021, at the same time as a severe drought in the Diyala province. Even though there was a brief period of sustained improvement in 2019, there was generally a steady downward trend, as shown in Figure 5. Moreover, Figures 3 and 4 show that the areas of the lake that were closest to freshly constructed rangelands and croplands—the north, east, and south—saw the largest losses in water surface area. On the other hand, the western portion of the lake had the majority of the water surface abundance areas, which correlate to locations with significant rates of erosion and steep topography.

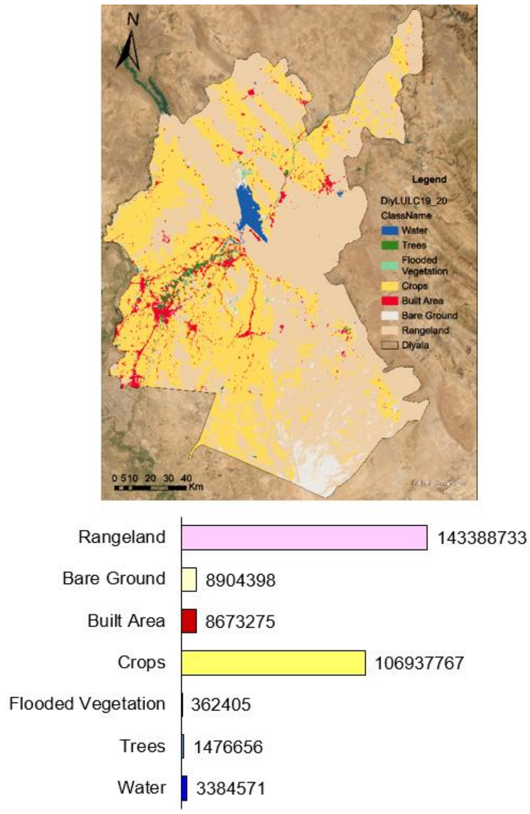
In Figure 6, similar to what was reported by the dam administration data itself, Lake Hamrin's rate of water surface decline was present. For instance, data analysis has shown that lake water levels, reservoir capacity, and surface water area are all impacted by the same rate of lake water reduction in the data gathered from the Hamrin reservoir data centre. The Table 1 displays the average values of the reservoir over a period of five years, including water surface area, capacity, and reservoir level. Over time, there is a notable variation in surface area. It reached its highest point in 2018–2019 at 391.646 km2, and by 2021–2022, it had drastically dropped to 50.6 km2. Similar to the surface area, the volume capacity peaks in 2018–2019 at 2.001 ml and subsequently declines to 0.166 ml by 2021–2022. This implies a significant decrease in the volume of water at that time. The reservoir level gradually decreases, going from 101.84 M.A.S.L. in 2017–2018 to 91.91 M.A.S.L. in 2021–2022. This gradual decline is consistent with surface area and capacity trends. The validation findings show that our improved method's average values for the variables collected by the dam administration match the change detection of the water surface area during a five-year period. The accuracy of extracting and measuring the changed areas is outstanding, as indicated by Table 2, with an extremely low error percentage for each year comparison. In this context, the total error was 5.51% with the overall accuracy of checking water surface area in Kilometers



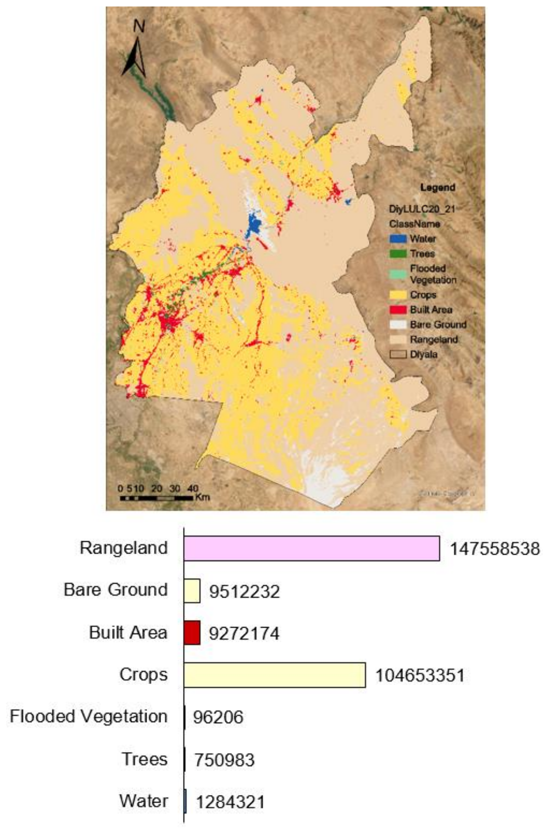
(a) Year: 2017 - 2018



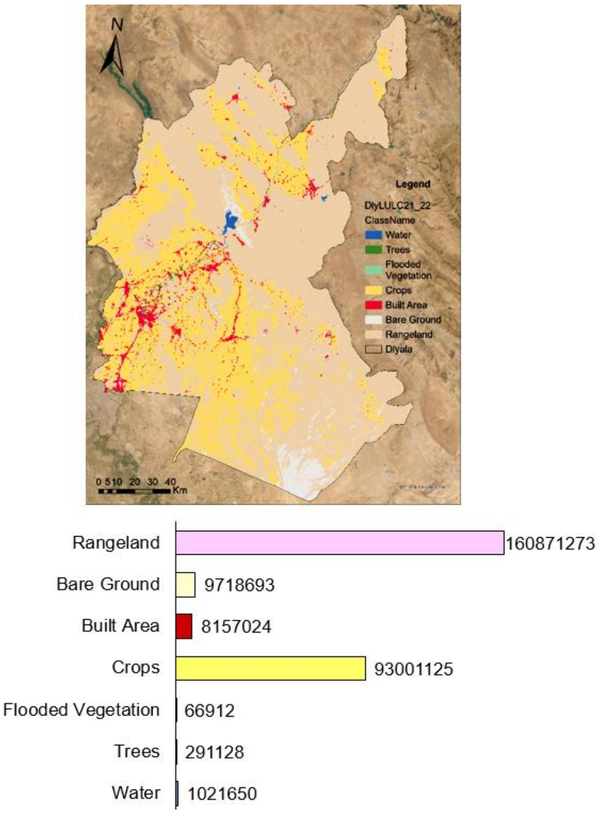
(b) Year: 2018 – 2019



(c) Year: 2019 – 2020



(d) Year: 2020-2021



(e) Year: 2021 – 2020

Figure 3. LULC maps of Diyala Province showing the number of changed pixels in each class

was 94.85%. Furthermore, field investigations were carried out to confirm that all changes detected were actually located in the designated area; Table 2 shows that the majority of these investigations were accurate.

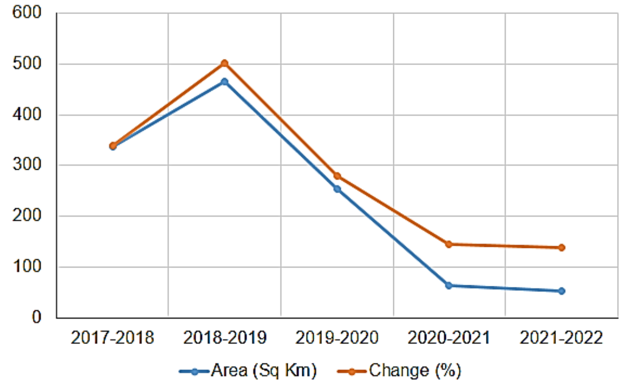


Figure 5. The comparison of surface area changes of lake water over five years

Despite the astounding outcomes, some methodological issues might exist. Sentinel-2's high spatial resolution may not accurately distinguish subtle variations in water quality and surface materials, leading to potential misclassification. Temporal resolution may not capture all significant changes, and atmospheric interference can affect the quality of imagery. Misclassification can occur due to similar spectral signatures between different land cover types and seasonal changes in water levels and vegetation.

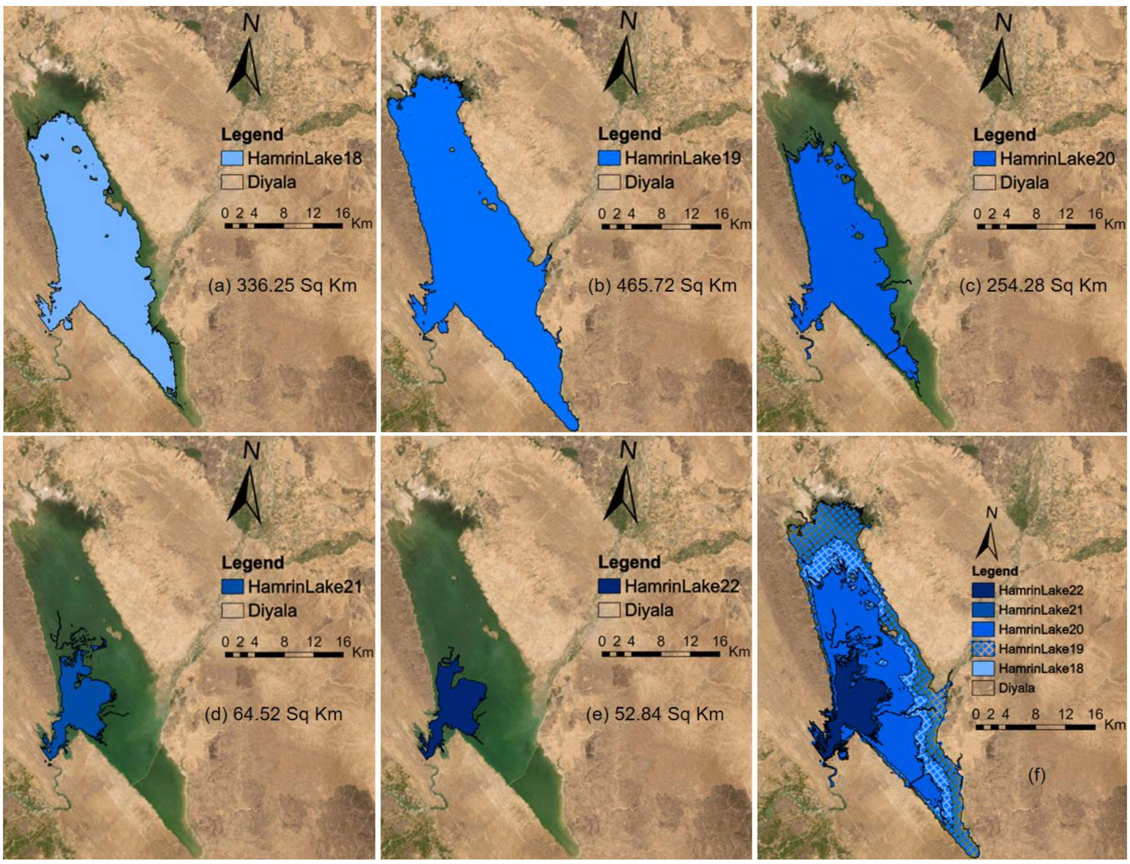


Figure 4. The change detection maps of Hamrin Lake over five years from 2018 to 2022: (a), (b), (c), (d) and (e), and (f) the overlaying change map of the five surface change areas of Hamrin Lake

Years (range) / Variables (average)	2017 - 2018	2018 - 2019	2019 - 2020	2020 - 2021	2021 - 2022
Surface Area (Sqr KM)	374.90	391.65	232.60	65.61	50.60
Capacity (ml)	1.188	2.001	1.229	0.458	0.166
Reservoir Level (M.A.S.L)	101.84	105.51	100.29	95.58	91.91

Table 1. The average values of Lake Hamrin main variables including: water surface area, capacity, and reservoir level.

The comparison results	2017 - 2018	2018 - 2019	2019 - 2020	2020 - 2021	2021 - 2022
Water surface area (reservoir data)	374.90	391.65	232.60	65.61	50.60
Water surface area (our method)	336.25	465.72	254.28	64.52	52.84
Error percentage	10.31%	0.04%	9.32%	1.65%	4.43%
Our method accuracy	89.69%	99.96%	90.68%	98.35%	95.57%
Over all accuracy	94.85%		Total error		5.15%

Table 2. Over all accuracy and the error percentage.

5. Discussion

The decline in water levels, which is made worse by climate change and human activity, is one of the most urgent problems surface water areas are currently experiencing. The stability of regional economies, local communities, and ecosystems are all seriously threatened by these changes. An affecting example is the situation in Lake Hamrin, which is located in Iraq's Diyala Province. Being one of the biggest lakes in the area, its decreasing water surface area emphasises how urgently efficient management and monitoring techniques are needed.

The examination of time series datasets spanning from 2018 to 2022 indicates notable variations in the bodies of water. Changes of 1.88% in 2018, 35.9% in 2019, 25.8% in 2020, 81.17% in 2021, and 84.58% in 2022 are shown in the findings. These differences highlight the water bodies' dynamic character as well as the impact of both natural and man-made elements. Nevertheless, the accuracy of LULC classification depends on several factors, including spatial resolution, classification accuracy, edge effects, algorithm dependence, data processing and calibration, human and environmental factors, and temporal consistency. While 10 m resolution is high, it may not detect small-scale changes or features. Edge effects and algorithm dependencies can also affect the accuracy of change detection. Therefore, selecting the most appropriate algorithm is crucial for accurate detection. However, GIS technology combined with machine learning techniques and data from remote sensing and comparing their findings with ground truth data provides a potent arsenal for evaluating and monitoring water bodies. The situation involving Lake Hamrin serves as an example of how vitally important these technologies are to solving the intricate problems brought on by anthropogenic environmental change. We can enhance the safeguarding of our precious water resources and guarantee their sustainability for upcoming generations by rationalising water consumption and implementing these developed technologies. Furthermore, our results illustrated that our developed framework for tracking environmental changes in Lake Hamrin based on utilising the Categorical Change Detection method in ArcGIS Pro and high-resolution global LULC data was accurate. Accurate datasets and cutting-edge GIS technologies guarantee the validity and applicability of the results, which are consistent with current developments in environmental monitoring and remote sensing.

6. Conclusions

The ultimate objective of this research is to support the Sustainable Development Goals (SDGs) by offering practical insights that help improve Lake Hamrin management strategies. The environmental balance of the lake can be preserved and restored more successfully if stakeholders and policymakers comprehend the complex dynamics of shifting land cover and water levels. Over the course of the five years, the results show a distinct and alarming trend of declining surface area, capacity, and reservoir level. This may be a sign of a number of things, like less rainfall, more water being extracted, or environmental changes that are harming the reservoir or lake. As a result, our research offers a method for lake monitoring, which is essential for planning any required interventions to prevent more loss and managing water resources. The results of this study will also be helpful to researchers, environmental managers, and legislators who are trying to manage water resources sustainably in Iraq and other similar regions. Furthermore, an effective set of tools for evaluating and controlling water bodies is provided by the combination of GIS technology with machine learning techniques and data from remote sensing. The situation involving Lake Hamrin serves as an example of how vitally important these technologies are to solving the intricate problems brought on by anthropogenic environmental change. We can enhance the safeguarding of our precious water resources and guarantee their sustainability for upcoming generations by means of persistent invention and implementation of these technologies. Although this research would help comprehend the dynamics of the land cover in the region, the tedious procedure of extracting only the lake area took a long time because the process of eliminating the rest unwanted features was accomplished manually. As a result, to save time and effort in our future work, we will employ AI technology to detect and extract the lake's boundaries and areas automatically.

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