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GIS and NDWI Based Assessment of Water Sustainability in Tharthar Lake, Iraq

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Abstract
The Tarthar Lake is an artificial lake that is among the largest in Iraq and that is very vital in controlling floods, water storage and water sustainability in the region dependent on arid climatic conditions. This paper evaluates spatiotemporal changes in surface water area and water sustainability on the basis of the Normalized Difference Water Index (NDWI) of three Sentinel-2 multispectral images taken during the years 2015, 2020 and 2025 on Tharthar Lake. The satellite data was preprocessed using a Geographic information systems GIS-based structure and NDWI was calculated using this structure and changes in water distribution and relative water volume were analyzed with reference to time. The findings indicate that there is a distinct temporal change in the NDWI values that show that there is a change in the lake water surface and internal hydrological processes. The comparison of the years 2015 and 2020 shows that NDWI is high, which is the characteristic of a comparatively stable and large body of water, and the year 2020 demonstrates that there were partial recessions of the shoreline and redistribution of water space. The NDWI map of 2025 indicates that the high-value zones of NDWI are noticeably reduced, which implies that the volume of water decreases and the hydrological pressure increases. These transformations are explained by the fluctuation in inflow, evaporation, and water management styles. All in all, the research illustrates the efficiency of Sentinel-2 image and GIS to track the lake water dynamics and offer meaningful information about the long-term sustainability of Tharthar Lake in the context of the changing environmental and climatic conditions.

Keywords: GIS, NDWI, Sentinel-2, Sustainability.

1. Introduction

The surface water resources are critical in maintaining the environmental sustainability, socio-economic development and water security especially in arid areas [1, 2]. Lakes and reservoirs are important elements of the hydrological systems as they control floods, store water to be used in agriculture and domestic purposes, and support aquatic systems [3]. Nevertheless, climate change, increased temperatures, extended droughts, and increased human activities are increasingly endangering these water bodies leading to considerable changes in water quantity and quality [4].

It is thus recommended that any water resource management and long-term sustainability planning should focus on the dynamics of surface water to effectively manage water resources and the environment particularly in areas where the climatic variability is quite high [5]. GIS and remote sensing have become an irreplaceable means of evaluating surface water resources at a large scale with respect to space and time [6-9]. The data on water extent and hydrologic conditions are continuously monitored using satellite-based observation, and it is consistent, repeatable, and cost-effective [10]. The index most commonly used in remote sensing has been the NDWI, which has been extensively used to identify open water bodies as it is highly sensitive to surface water as well as being able to reduce the effect of vegetation and soil backgrounds [8]. The water mapping has also been improved by the fact that the high-resolution multispectral satellite missions are now available including Sentinel-2 that are able to provide better spatial, spectral, and temporal resolution to analyse the lake on the finer detail [11]. With its multispectral capabilities and revisit time, Sentinel-2 imagery has been proved to be practicable in supervising inland water bodies in a variety of environmental conditions [12]. Having been combined with GIS practices, the spatial patterns, shoreline changes, and temporal changes of the lakes and reservoirs can be evaluated in detail using the indices of Sentinel-2, including but not limited to the NDWI [9].

This combined method has been of special benefit in arid areas, where in-situ hydrological data can be scarce or erratic, and where water management and evaporation are closely related to surface water supply.

The gap that will be filled by the study is the absence of long-term, constant monitoring of water extent and sustainability in Tharthar Lake due to the changing climatic and hydrological conditions. It is important to know the dynamics of the surface water of the lake across time to manage the water resources effectively. Hence, this study is significant in that it offers a valid assessment of water variability that is based on remote sensing and GIS analysis on Sentinel-2 images. The following are the key goals, (1) map the spatial distribution of surface water in Tharthar Lake by NDWI, (2) the temporal change in water extent and relative water volume between 2015, 2020, and 2025 and (3) implication of the same with regard to the long-term sustainability of the lake.

2. Study Area

One of the biggest artificial lakes in Iraq is the Tharthar Lake that is used as a strategic reservoir to control the flood and store water [13, 14]. The lake is situated in an area with a high temperature and annual rainfall which makes it very sensitive to climate changes and river control [15].

Over the last few decades, there has been an escalation in water scarcity in Iraq resulting in the questions of sustainability of the major surface water bodies including Tharthar Lake. Although it is essential, there is limited information on the spatiotemporal dynamics of water in the lake with modern satellite-generated data. Figure 1 is the study area Tharthar Lake.

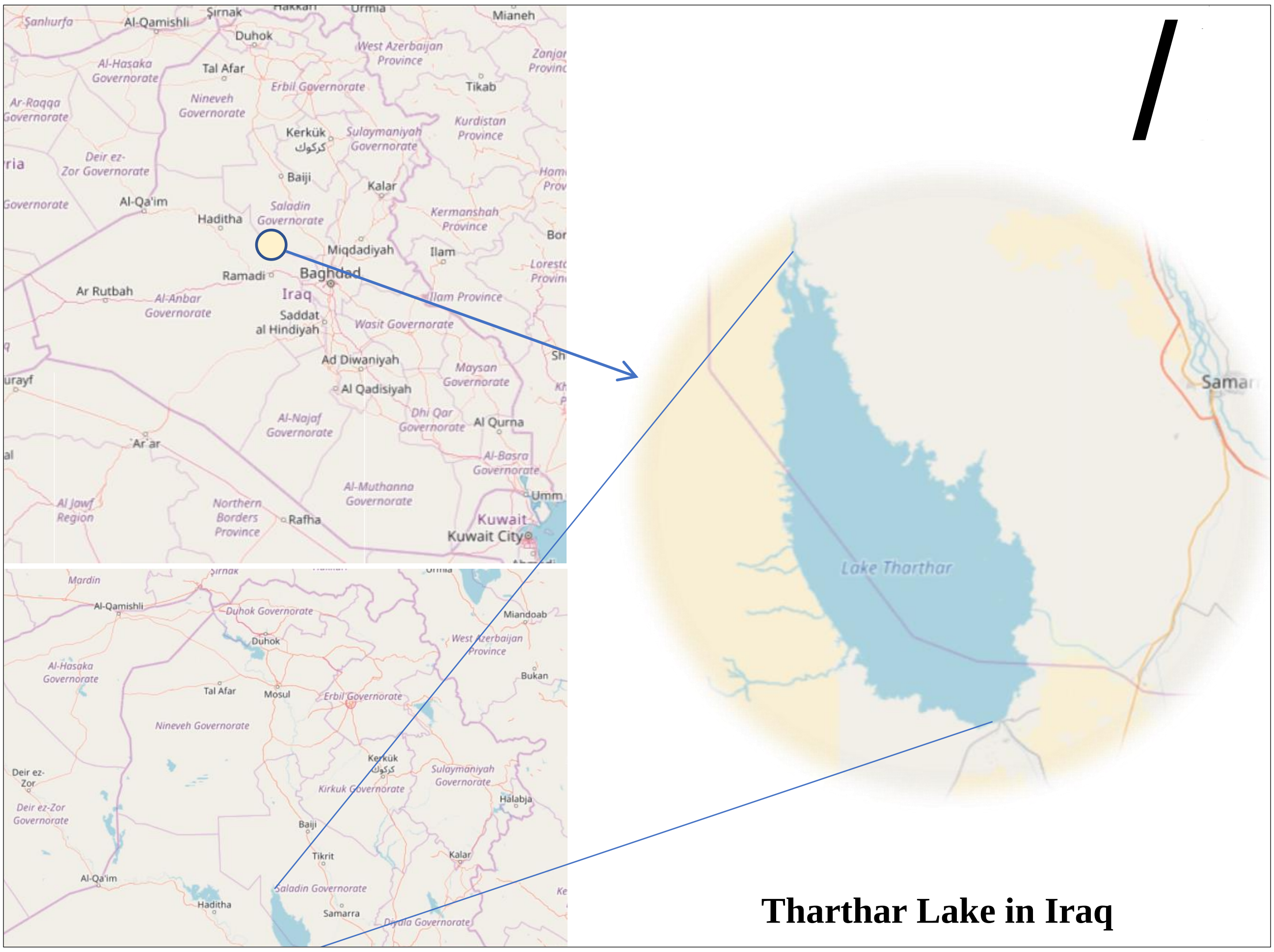


Fig 1: The study area Tharthar Lake in Iraq.

3. Methodology

This paper used a combination of GIS and remote sensing-based approach to determine spatiotemporal changes in water surface area and water sustainability in Tharthar Lake, Iraq, using the Normalized Difference Water Index (NDWI). To describe the various time conditions of the lake, three cloud-free Sentinel-2 Level-2A multispectral images in the year 21 August 2015, 14 August 2020, and 03 August 2025 were chosen (Table 1).

Table 1: Used Sentinel-2 images in NDWI assessment.

ID	Image	Date	Cloud Cover	Coordinate System
1	Sentinel-2 L2A	21-08-2015	0%	WGS 84
2	Sentinel-2 L2A	14-08-2020	0%	WGS 84
3	Sentinel-2 L2A	03-08-2025	0%	WGS 84

The Level-2A Sentinel-2 product offers atmospherically corrected surface reflectance, which is consistent and reliable in terms of multi-temporal analysis. All the images were given in TIFF format with 32-bit floating-point radiometric resolution, spatial resolution of 20 m and referenced to WGS 84 geographic coordinate system. Image preprocessing was done in a GIS setting to provide spatial and radiometric consistency of all the datasets. Preprocessing procedures involved subsetting of the image to the Tharthar Lake boundary, resampling of bands to ensure a constant spatial resolution, and manual verification of the image to ensure it contained very little cloud contamination. Bands that are needed to compute NDWI were removed, in particular, the green band and the near-infrared (NIR) band, which are well-established to detect surface water, as they have different reflectance properties over water and land surfaces. The standard formulation was used to compute the NDWI of each image with the difference between green and NIR products divided by the sum of the two.

The equation can be presented as [7];

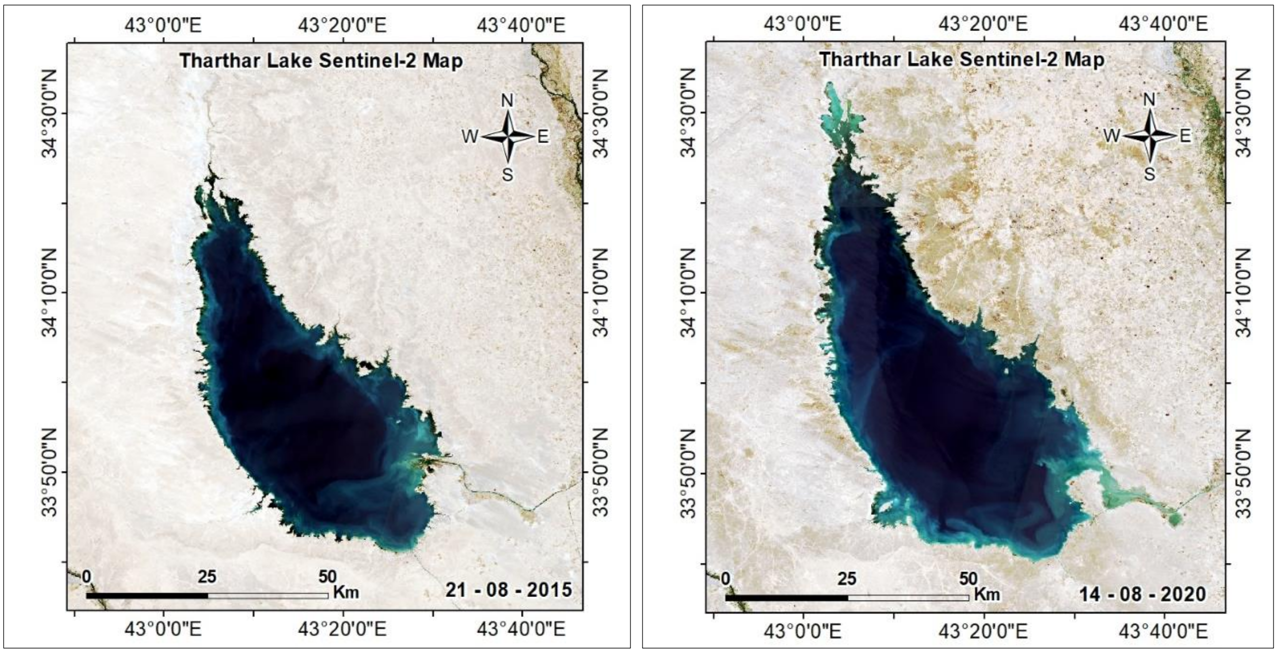
$$NDWI_{Sentinel-2} = \frac{BO3-BO8}{BO3+BO8} \quad (1)$$

Where BO3 is the green which is band 3, and B08 is the NIR which is band 8.

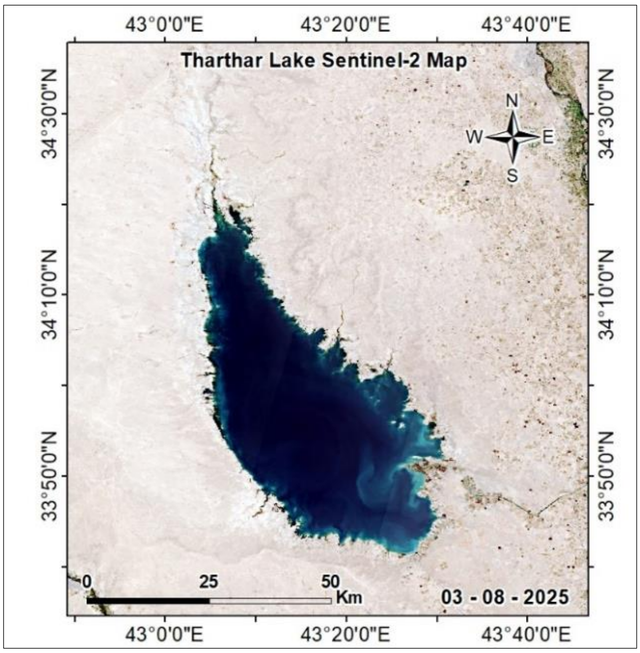
This index improves open water surface by giving the water bodies positive values and reducing vegetation and bare land surfaces. These maps of NDWI were subsequently categorized into water and non-water areas using thresholding which enabled the lake area to be clearly defined in each study year. Patterns of spatial distributions of NDWI values were evaluated to determine the changes in surface water cover, internal lake processes and relative water volume across a period of time. Comparison of water sustainability across the three periods was done through comparative spatial analysis.

The alterations in the magnitude and spatial areas of NDWI were interpreted as watershed changes in terms of water volume changes and shoreline recession or expansion, as well as, hydrological stress.

Moreover Figure 2 shows the used three Sentinel-2 images for mapping.



(a) (b)



(c)

Fig 2: Tharthar Lake Sentinel-2 maps of the years; (a) 2015, (b) 2020, (c) 2025.

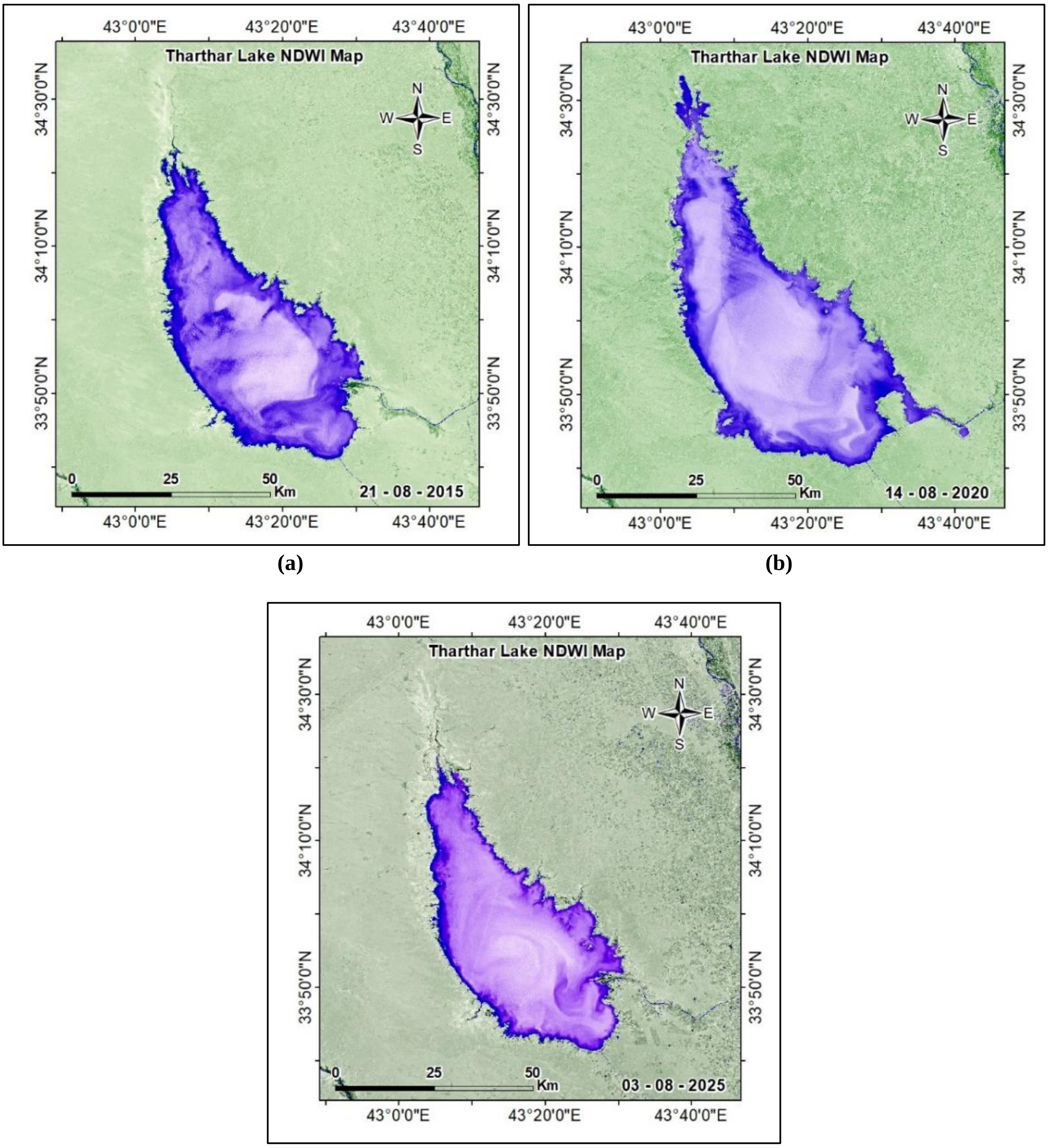
The GIS setting made it easy to carry out overlay analysis and visually compare the results, and thus be able to identify stable and susceptible areas in the lake. Though there was no direct data on the volume of water, spatial trends derived through NDWI offered a good proxy that can be used to determine what happens to water storage conditions when there are comparative changes. Altogether, the given methodology proves the ability of the Sentinel-2 images used with the GIS analysis to monitor the water processes in lakes in the arid and semi-arid areas on a long-term basis. The methodology provides a sustainable, reusable and scalable framework, which can be used to facilitate management of water resources in the region in addition to hydrological future tests of Tharthar Lake and other inland water bodies.

4. Results and Discussion

Figure 3 shows Tharthar Lake NDWI maps of the years 2015, 2020, and 2025 respectively.

The 2015 NDWI map of the Tharthar Lake in Figure 3(a) shows that there is a comparatively large and continuous water body with high values of the NDWI mostly prevailing in the central and southern regions of the lake. These high NDWI values indicate good presence of surface water implying that the lake was experiencing large amount of water at this period of time. Spatial distribution of NDWI reveals a gradual attenuate to the lake margins where lower values reflect the shallow water bodies, or bare sediments or mixed pixels of water bodies in contact with the surrounding lands. This is common in semi-arid reservoirs in which seasonal inflow and evaporation place a strong dominance on shoreline flows. High NDWI values have a large spatial scale, which suggests that the inflows of the upstream sources and flood diversion systems were adequate to maintain the storage capacity of the lake in 2015. Hydrologically, this situation indicates a fairly balanced water, where inflows must offset the evaporation losses normally very high in central Iraq. The 2015 NDWI trend indicates good sustainability concerning the ecological processes, such as the habitat provision of aquatic and semi-aquatic organisms and protection against the occurrence of extreme drought events. Nevertheless, the moderate NDWI values at the edges point to susceptibility to the changes in water level, as well as the lake is sensitive to the hydrological regulation and fluctuations in climate. The situation of the year 2015 could then be regarded as a reference condition, which is a relatively healthy hydrological condition of Tharthar Lake. This background shows the significance of regulated inflows in maintaining the volume of lake water and emphasizes the lake as a strategic system of water storage to facilitate flood management and long-term water security in Iraq.

The 2020 NDWI outcomes in Figure 3(b) show that there are significant differences in the percentage change of the surface water spatial distribution and intensity between 2015 and 2020. The lake is also distinct but deviations in the values of NDWI show that there is a change in water volume and internal water dynamics. The core basin is still of high positive NDWI values, which indicates the presence of open water but an increase in the lower NDWI areas at the edges indicates that parts of the water have receded and the shallow areas have been exposed. This trend can be explained by inter-annual change in inflow, a high evaporation rate, and water management activities during the given time.



(a) (b)

(c)

Fig 3: Tharthar Lake NDWI maps of the years; (a) 2015, (b) 2020, (c) 2025.

The NDWI distribution was heterogeneous, meaning that overall storage was preserved, but there was redistribution of water mass in the lake, perhaps associated with regulated releases or less upstream contribution. The 2020 NDWI map is indicative of a transitional hydrology condition in terms of sustainability. The shrinking of the high NDWI bands towards the shoreline indicates the growing pressure on the lake system, which can influence the processes of sediment resuspension, water quality and ecological stability. However, the fact that a deep continuous body of water exists shows that Tharthar Lake was still a functioning reservoir where a significant percentage of water remained. These results underscore the strength of the lake in changing hydrological conditions, and at the same time provide a sharp focus on the need to employ adaptive water management techniques to reduce the effects of climate variability and competing water demands. The 2020 NDWI pattern, therefore, indicates a middle point between stability and stress, which indicates the criticality of the continued monitoring of water resources to ensure the sustainability of the water resources in the long run.

The NDWI prediction in Figure 3(c) at 2025 indicates further development of the hydrological situation of Tharthar Lake, and water volumes and sustainability have obvious implications. Although the lake still exists as a discrete body of water, the spatial coverage of the high values of NDWI seems to be smaller than in previous years especially on the northern and peripheral areas. This shrinkage indicates that the total amount of water will decrease, perhaps due to long periods of dry weather, greater evaporation, and perhaps controlled inflows will fall. Dominating moderate to low NDWI values in big portions of the water body show that the water is less deep and more of the sediments forming the lakebed are exposed. These are typical of water stressed lakes in arid and semi-arid areas and could indicate a transition of a less stable hydrological regime. In terms of sustainability, the 2025 NDWI pattern creates issues related to the sustainability of Tharthar Lake as a strategic water storage facility. The decreased amount of water may impact adversely on the flood control, buffering of water supply and the sustainability of the lake environment. Moreover, the long-term low-water scenarios might provoke the salinity increase and worsen the quality of water, which will additionally reduce the functionality of the lake. Although these are the challenges, the fact that positive NDWI values persisted in the central basin means that the lake has not fully desiccated and this shows a level of resilience. The trend that has been observed, however, gives special emphasis on the pressing necessity of the integrated water resource management, such as streamlined management of inflows and climate-responsive planning, to make Tharthar Lake remain sustainable under future hydrological and climatic stresses.

5. Conclusion

This experiment revealed that a combination of GIS and Sentinel-2 multispectral sensor in measuring surface water dynamics and water sustainability in the Tharthar Lake in Iraq by the use of the Normalized Difference Water Index (NDWI). The comparison of three Sentinel-2 images in 2015, 2020, 2025 demonstrated evident changes in the spatiotemporal distribution of surface water because of changes in water volume and hydrology. The 2015 NDWI findings showed a balance state between lake conditions whereby the open water areas were vast to form a favorable baseline state of water storage and sustainability. Conversely, the 2020 analysis demonstrated that the spatial heterogeneity was higher with the partial shoreline recession and water redistribution implying the effect of inter-annual variability of inflows and evaporation. The NDWI map of 2025 showed an additional decrease in high NDWI values and shrinkage of the surface water area, which points to the augmentation of hydrological strain and the drop in water volume. The witnessed trends indicate the susceptibility of Tharthar Lake to climatic variations, high rate of evaporation, and water management in an arid and semi-arid setting. Even though the lake still maintains a central body of water, the gradual shrinkage of the surface water makes one have questions about the future role of the lake in flood control, water supply buffer and ecological sustainability.

The results underscore the need to have continuous monitoring based on remote sensing to aid in informed water resource management and adaptive planning strategies. In general, this research proves the hypothesis that Sentinel-2-derived NDWI and GIS analysis is a reliable, cost-effective, and repeatable method of assessing dynamics and sustainability of lake waters. These strategies are critical towards sustainable water management policy and resilience to future climatic and hydrological stresses in Iraq and other arid lands.

It is suggested that Tharthar Lake should be constantly monitored by means of multi-temporal Sentinel-2 and other water indices to enhance the realization of early warning indicators of reduced water level and hydrological stress. The NDWI results in the future should be combined with in-situ hydrological data, such as water level, discharge, and evaporation, to improve the accuracy of the water volume estimation. This would be complemented with the performance of climate variables and hydrological modeling to allow understanding of the effects of climate change and water management conditions on the sustainability of lakes. It is suggested to use high-resolution temporal analysis based on the seasonal and monthly satellite images that could reveal the short-term changes in water extent and the shoreline dynamics. Developing the methodology to cover water quality indices and machine learning is a potential to offer a more holistic approach to the ecological and environmental sustainability of Tharthar Lake.

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