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Drought Monitoring and Water Depletion of Haditha Lake, Iraq Using Sentinel-2 Data and GIS

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Abstract
This research examines the dynamics of drought and water depletion in Haditha Lake, Iraq, through satellite imagery of Sentinel-2 and GIS-based analysis in 2021-2026. The evaluation is a combination of the Normalized Difference Water Index (NDWI) and the Normalized Difference Vegetation Index (NDVI) to measure the spatiotemporal variations of the surface water and vegetation response. The findings indicate significant interannual variability, with an initial decrease in water-related indicators (−12%), and a further more drastic decrease (−30%), suggesting the aggravation of drought and significant water loss. There is a partial recovery period in the following years (+12% and +8%), indicating temporary positive changes in hydrological conditions, probably associated with seasonal rainfall variability. Nevertheless, there is a steep fall in the last year (−35%), as the drought stress is extreme, and water sources are highly depleted. The NDWI analysis shows distinct contraction and expansion trends of water extent and NDVI findings indicate that vegetation health is largely dependent on water supply. Low water levels are linked with vegetation stress, fragmentation, and low greenness, and enhanced water conditions are linked to vegetation recovery. Remote sensing indices coupled with GIS is useful in tracking the effects of droughts and identifying any changes in the environment. In general, the results demonstrate the susceptibility of Haditha Lake to climatic variability and water deficit, and the necessity of sustainable water resource management and constant monitoring to reduce the effects of droughts in the future.

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Keywords: GIS, Haditha Lake, NDVI, NDWI, Remote Sensing

1. Introduction

Drought is among the most complicated and repetitive natural hazards that impacts arid and semi-arid areas, and has significant effects on water resources, ecosystems and human livelihoods [1]. Drought differs in that it is not an instant disaster, and most of the time it is hard to notice at the onset and therefore a continuous monitoring is a key factor in managing it [2]. In places like Iraq where the water resources are already strained by the variability in climate and upstream control, drought has become a more pressing concern. Lakes and reservoirs, which constitute a major source of freshwater, are especially susceptible to extended dry periods, resulting in a considerable drop in water levels and related ecological decline [3]. Aggressive means of observing drought and water resources are frequently based on the ground, which might be both spatially restricted and infrequent. Alternatively, remote sensing methods are also a potent option, as they can be used to make large scale and repeatable measurements of the environment [4]. Satellite images, especially those of Sentinel-2, provide high-resolution images that are quite appropriate in tracking the dynamics of surface water and vegetation over time [5]. Multispectral data can be used to compute different indices that are commonly employed in the environmental sciences [6].

Two of the most widely used indicators used in the evaluation of hydrological and ecological conditions are the Normalized Difference Water Index (NDWI) and the Normalized Difference Vegetation Index (NDVI) [7]. NDWI is uniquely crafted to better identify water bodies by increasing the difference between water and land features, which enables it to be very useful when mapping surface water changes [8]. On the other hand, NDVI is generally used for evaluating vegetation health [9]. These indices are complementary, and thus when used together, researchers can study the relationship between water availability and vegetation response. Integration of NDWI and NDVI into a Geographic Information System (GIS) improves capability of analysis of spatial and temporal distributions of environmental data [10]. GIS helps to process, visualize and analyze indices obtained by satellites and provide a more in-depth understanding of the effects of drought [11]. The synergies between these tools allow tracking the slightest variations, stress levels and the general state of ecosystems [12]. Recent research has found that use of remote sensing indices in monitoring droughts and in evaluation of water resources has proved effective in different regions of the world [13]. These articles indicate a close connection between vegetation dynamics and the water availability, and the necessity of combined analysis [14]. Even slight variations in the water levels in arid surroundings, where water is a limiting factor, may lead to great consequences on vegetation cover and productivity [15]. Thus, tracking water and vegetation will give a better understanding of the change in the environment [16]. When it comes to Haditha Lake, NDWI and NDVI analysis could help to gain a deeper insight into the dynamics of water loss and the reactions of vegetation to this occurrence. The time aspect of the satellite data facilitates the determination of trends, variations and possible periods of recovery. Decision-makers and resource managers find such information essential as it aids in the formulation of strategies to reduce the effects of drought and make water use sustainable. Furthermore, the knowledge of the interaction between hydrological and ecological elements can assist in anticipating the changes in the future and designing the adaptive strategies [17]. The second key feature of this method is that it will give a steady and objective data [18]. However, in contrast to the conventional techniques that might be affected by the constraints of measurement or variation, the satellite-based analysis provides uniform observations over time. This regularity is needed in long term observations and comparisons especially in areas where the environment is changing rapidly [19]. Moreover, the temporal resolution of Sentinel-2 images is quite high, so it can change rather frequently, and thus, it is also possible to monitor the changes as they are taking place [20].

Irrespective of these benefits, there are still difficulties in the correct interpretation of remote sensing data, especially in complicated conditions when other factors affect spectral responses. To illustrate, the accuracy of NDWI and NDVI is subject to changes due to variations in soil type, atmospheric conditions and land use. Hence, preprocessing and validation should be done carefully to guarantee quality results. However, in the right hands, such indices can give us great information about the processes occurring in the environment and are generally considered to be a necessity in the contemporary geospatial analysis. Haditha Lake has been characterized by apparent water level changes over the past few years which have prompted concerns regarding escalating levels of drought and depletion of water resources. These alterations not only pose a threat to water availability, but also to the vegetation around and the stability of the ecosystems. It is hard to completely comprehend the scale and effects of these changes due to the absence of large-scale and continuous monitoring. Thus, it is in urgent need of effective and efficient means of measuring water and vegetation dynamics. Remote sensing and GIS are effective solutions, offering a way to monitor in time and maintain water sustainably in the midst of increasing environmental challenges. This research will follow up the drought conditions and evaluate the water depletion in Haditha Lake with the help of the Sentinel-2 data and the GIS, examining the changes in NDWI and NDVI over time and determining the correlation between the water availability and vegetation reaction.

2. Methods

2.1. Study Area

One of the largest artificial lakes in Iraq is Haditha Lake, created by the Dam of the Euphrates River, which is an important source of water storage, irrigation, and hydropower generation. The lake sustains the agricultural activity of the surrounding and plays a role in the ecological balance of the region. Nevertheless, the changes in the water levels in the recent years have cast doubts on the sustainability of this valuable resource. The shrinkage of river flows, growth in the rate of evaporation because of the rising temperatures, and human activities are some of the factors that have led to observable changes in the extent and state of the lake. Such alterations do not only impact the availability of water but also other vegetation around, which relies heavily on the availability of moisture. Figure 1. is the map of Haditha Lake in Iraq.

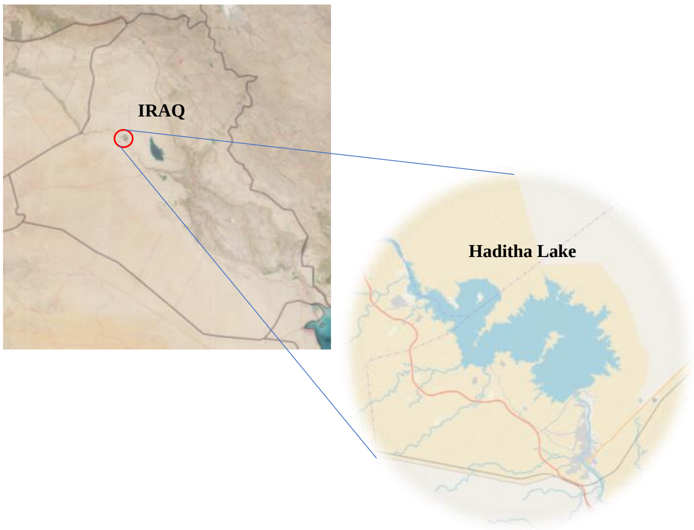


Fig 1: Map of Haditha Lake in Iraq.

3. Data

The data used in this study were downloaded from Copernicus an online Sentinel-2 data provider, where six images have been obtained represent 2021, 2022, 2023, 2024, 2025, and 2026 years. The images properties were cloudless, high resolution, and WGS-1984 coordinate Systems. Furthermore, the used Sentinel images of Haditha Lake of each date were mapped in Figure 2. Moreover, climatic data of Haditha Lake area have been downloaded from NASA POWER application and charted in Figure 3.

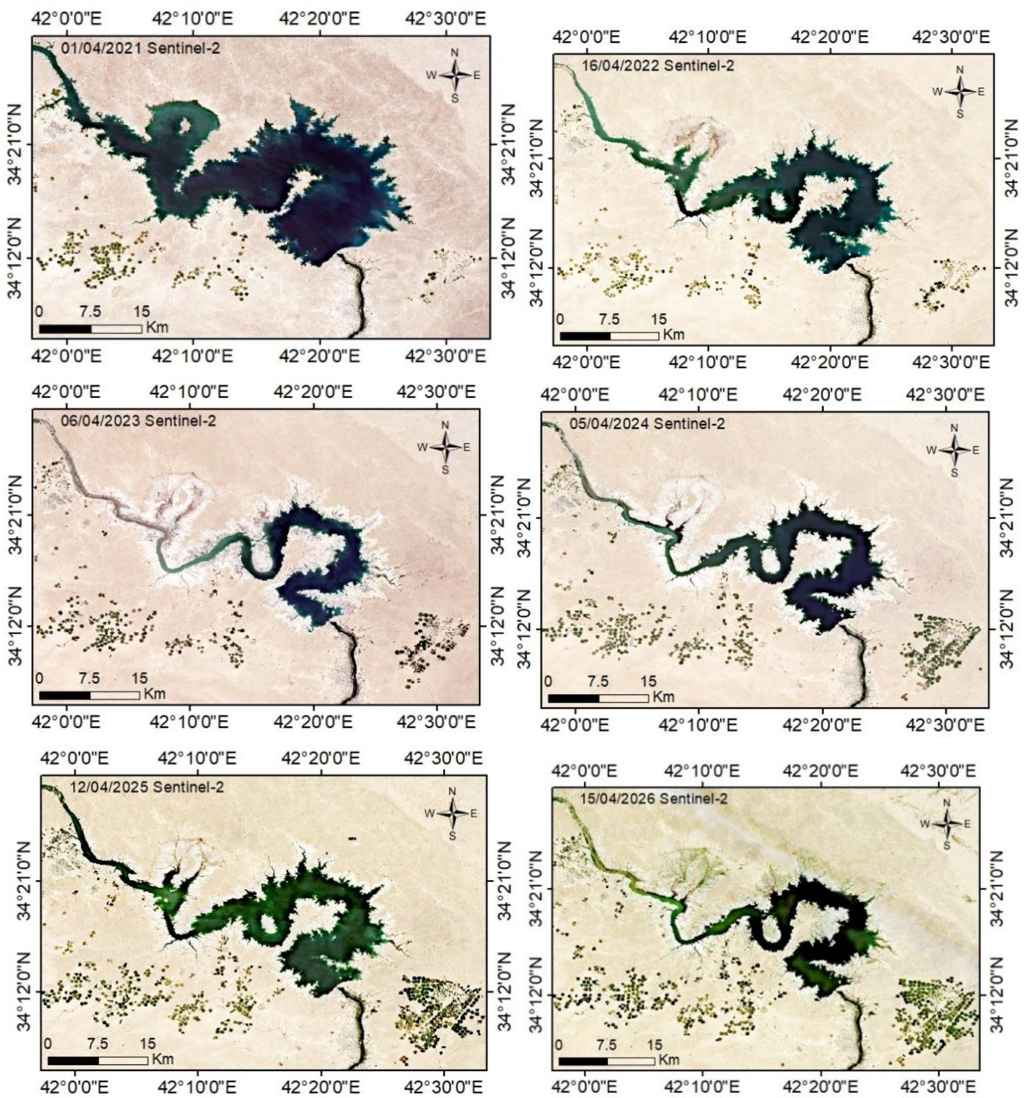
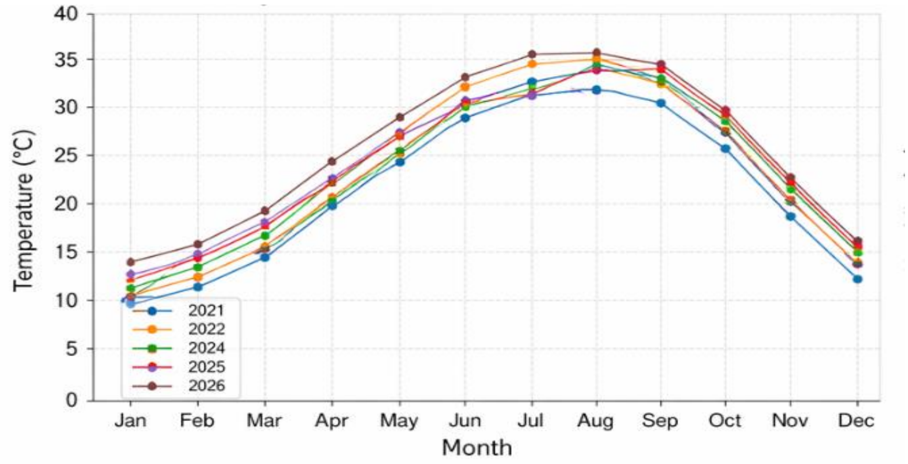
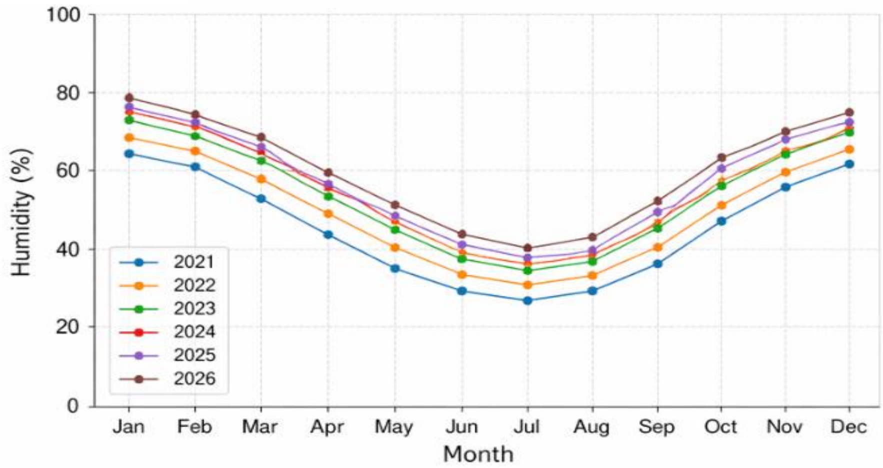


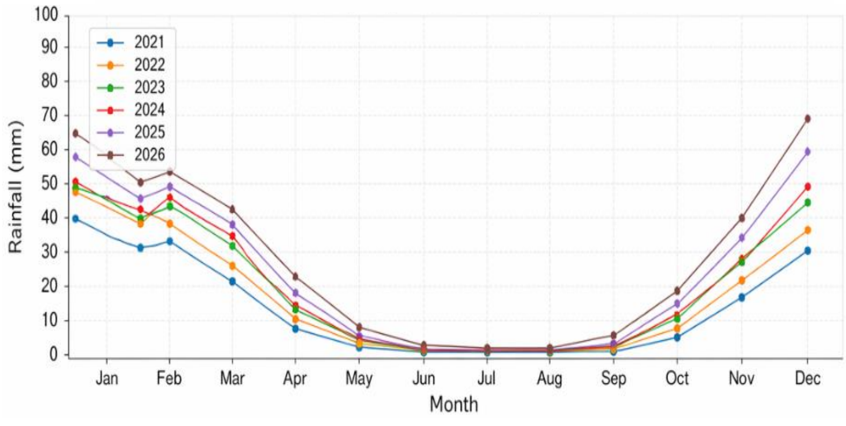
Fig 2: Sentinel-2 images of the years 2021-2026.



(a)



(b)



(c)

Fig 3: Climatic data of Haditha Lake area since 2021-2026; (a) Temperature, (b) Humidity, (c) Rainfall.

The number shows monthly climatic variations of Haditha Lake between 2021 and 2026, such as temperature, relative humidity, and rainfall. These data obtained from NASA POWER application on Haditha Lake for the years 2021-2026. There is a consistent seasonal pattern in temperature, with maximum values in summer (July and August) (above 30 C) and minimum values in winter. The humidity is inversely related, with greater amounts in winter and less during summer. The rainfall is gathered during winter (December–March) and almost absent during summer due to semi-arid climate of the region. The variations are interannual, with a little more rain and humidity in later years, suggesting that they vary, which affects the water levels in the lake and drought periods.

4. GIS and Water Indices

GIS procedures to compute water area using NDWI and NDVI by Sentinel-2 images can be applied after downloading Sentinel-2 Images and calculating each index by its Formula. The formula of each index can be set as [21];

$$NDWI = (B03 - B08)/(B03 + B08) \qquad (1)$$

where, B03 represents band three, and B08 represents band eight.

$$NDVI = (B08 - B04)/(B08 + B04) \qquad (2)$$

where, B08 represents band eight, and B04 represents band four.

In ArcGIS using Raster Calculator of the equations, we can get NDWI and NDVI raster. In order to extract water area, we applied GIS-based Reclassify Tool. Raster to Polygon will also applied to get water bodies of vectors.

Its important to clean data by eliminating small polygons (noise reduction). So, we kept only lake area by removing polygons less than 0.5 km^2. Final step is to calculate each year area by Calculate Geometry. Then total area per year statistically can be obtained.

In NDWI thresholding for extracting water bodies, the values more than zero were classified as water. The binary raster was then transferred into a vector format and the overall water surface area was determined in square kilometers. This technique is extensively used in remote sensing research in mapping surface water, where NDWI can maximize water bodies, but minimizes the influence of vegetation and soil, and is therefore an effective tool to precisely detect water bodies, especially during droughts.

While, the extraction of water bodies that done through NDVI thresholding, whereby values below zero were considered water. The resulting binary raster was turned into a vector format and the total area of water surface was computed in square kilometers. This technique has been common in remote sensing research in the mapping of surface water in the study because it is an easy and efficient technique.

5. Results

5.1. NDWI Results

Figure 4 represents NDWI maps of Haditha Lake since 2021-2026. While Table 1 shows the reported resulted areas and water levels interpertations.

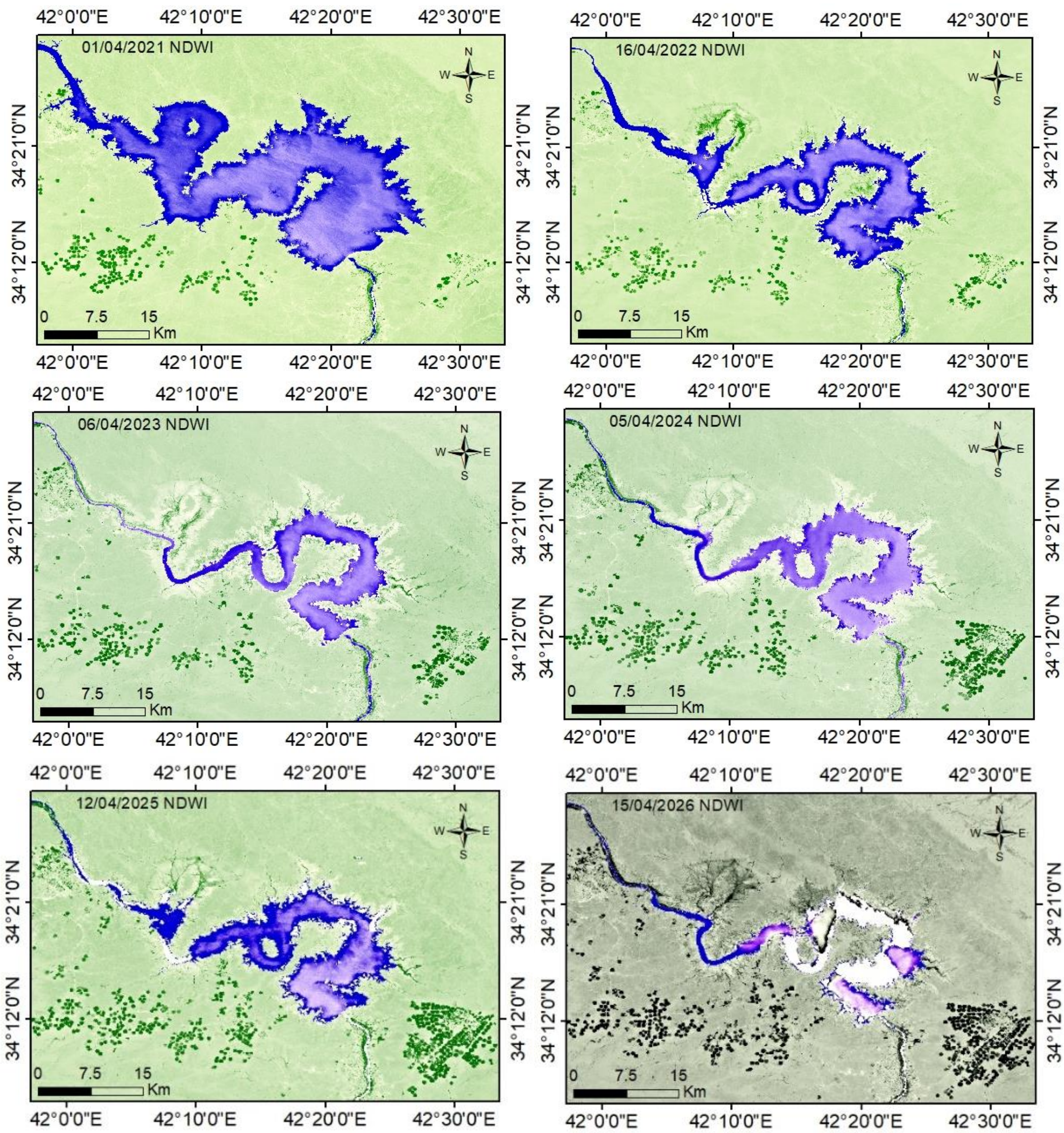


Fig 4: NDWI maps of Haditha Lake since 2021-2026.

Table 1: Indices based water levels

Year	Area (km²)	Variation (%)	Water Level
2021	195	0	Higher levels
2022	171	-12	Drop in water levels is beginning
2023	120	-30	Severe drought and high decrease
2024	134	+12	Partial increasing levels after rainfall
2025	145	+8	Relative stable levels with fluctuations
2026	110	-35	High fluctuation and decreasing levels

The 2021-2026 Normalized Difference Water Index (NDWI) analysis presents a dynamic trend of surface water changes, indicating the variability of the environment and potential anthropogenic factors in the study region. The maximum water area covered during the research was found in 2021 and calculated to be 195 km^2, which is the baseline water extent. The year is used as a reference point, which means quite favorable hydrological conditions that might be related to sufficient precipitation and constant inflow regimes.

There was a noticeable decrease in 2022, as the water extent fell to 171 km^2, which is equivalent to a decrease of around 12% of the water extent. This contraction is an indication of drier conditions or decreased inflow that can be attributed to decreased intensity of rainfall, higher rates of evaporation, or water management upstream. This reduction is visually supported by the NDWI maps and is indicated by shrinking of the coastal zone and fragmentation of peripheral water areas.

The biggest drop is seen in 2023 as the area falls drastically to 120 km^2, representing a considerable decrease of approximately 30 percent compared to the year before. Such a drastic decrease indicates a serious hydrological change, which may be caused by the long-term drought or an increase in water extraction. The spatial distribution of NDWI data of this year shows that there was a strong recession of water bodies, and previously interconnected bodies turned into independent bodies, which is an indicator of severe water stress.

The partial recovery is seen in 2024 when the water extent is at 134 km^2, and this is an improvement of about 12%. This recovery is an indication of a temporary upgrade in hydrological conditions, perhaps as a result of more rainfall or a decrease in water demand. The NDWI images reveal re-expansion of water boundaries especially in central and upstream areas but not to the same levels as in 2021.

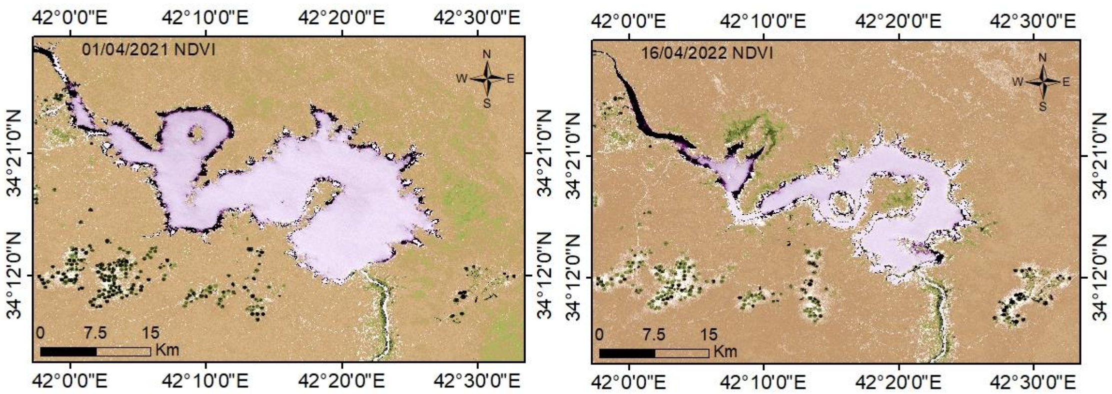
In 2025, the trend is on the increase with the water area growing to 145 km^2, a growth of approximately 8% over the year 2024. The fact that this recovery is gradual shows that there is a stabilization phase, during which the system is starting to recover part of its lost extent. Nevertheless, even with this enhancement, the water coverage per the baseline year is still lower hence showing that full recovery is yet to be realized.

In 2026, the opposite trend is observed, as the water area began to decrease rapidly, reaching 110 km^2, which is a very considerable decline of about 35%. This decrease is the lowest value at this time of the study and indicates a relapse to the severe conditions of water shortage. The NDWI outcomes of this year have depicted a significant shrinkage in water where it is now channelized in limited channels and central areas, which implies that the water body is more vulnerable.

In general, the NDWI-based evaluation shows that the surface water cover in the period between 2021 and 2026 varies significantly in terms of interannual variability. The oscillations point to a tendency of decrease, some revival, and the following decrease, which shows the vulnerability of the water system to the changes in climate and possible anthropogenic stress. These conclusions highlight the significance of relying on continuous monitoring and managing water resources sustainably to reduce losses in future and secure the hydrological balance in the long-term.

6. NDVI Results

Figure 5 represents NDVI maps of Haditha Lake since 2021-2026.



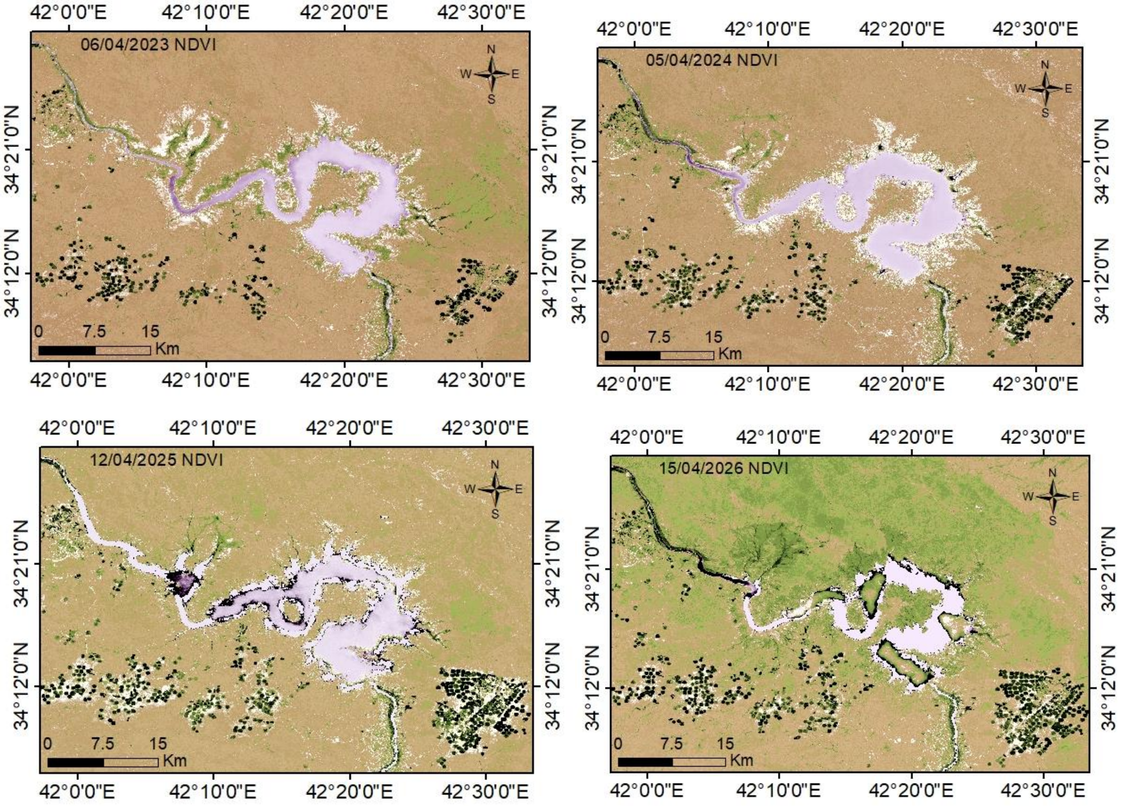


Fig 5: NDWI maps of Haditha Lake since 2021-2026.

The 2021-2026 NDVI series does not only indicate dynamics in vegetation vitality but also the impact of surface water availability, as the values in the maps reflect the water-dominated areas in the landscape. At the beginning of the period, the situation seems to be quite stable, with high NDVI values of strong vegetation and enough moisture. The spatial distribution indicates that the presence of water had a positive influence on adjacent vegetation, thereby fostering thick layered and continuous vegetation.

Next year, a more modest decrease (−12) can be observed. This decrease indicates a minor shrinkage in the supply of moisture, which starts to influence vegetation condition. The vegetation in the areas around such areas becomes less green and the first signs of disintegration are observed. Here, the connection between water and vegetation is more obvious, as the lack of water decreases the levels of soil moisture and undermines the health of plants. The subsequent step (−30%) is a more drastic decrease that suggests an important decrease in water-related impact across the landscape. This decrease is linked to severe stress in vegetation, in which vegetation cover is sparse and intermittent. The response of weakening NDVI indicates that vegetation is no longer getting sufficient moisture to support and hence the biomass and general degradation of the plant community.

After this stress period, a period of recovery is observed (+12%) during which the moisture conditions are improved and probably lead to the resurgence of vegetation. With a resurgence of water, vegetation is responding positively with more consistent and explicit NDVI signals. This underlines the high reliance of the vegetation dynamics of the study area on the availability of water.

The trend is positive in the following year (+8%) which is an indication of further stabilization. The vegetation is more regular and healthier, and the relative improvement of the hydrological conditions is provided. Even though the recovery is slow, it shows the strength of vegetation in case the water supply increases and the ecosystems can restore their form and their functioning partially.

But in the last-year there is a steep drop (−35) and this is another indication of a significant decrease in water-related influence. In parallel to this reduction, vegetation degrades considerably, with the NDVI values decreasing and plant cover being almost completely fragmented. The spatial pattern indicates that vegetation growth is highly limited by the limited availability of water, resulting in extensive stress and low ecological productivity.

On the whole, NDVI patterns indicate that there is a strong correlation between the presence of water and the condition of vegetation. The changes in the values indicate variations in the availability of moisture which directly regulate the health and distribution of vegetation. The high values offer better water conditions and vegetation growth, whereas the decrease of values representation is the water scarcity and stress in the ecosystem. The relationship underscores the importance of water in maintaining vegetation and the sensitivity of the system to the environmental changes.

7. Discussion

The NDWI-NDVI dynamics that have been observed in this study are in line with the results of various recent remote sensing studies. IOP Conference Series Earth and Environmental Science reported similar variations between water availability and vegetation response, with the combined NDWI and NDVI analysis being able to effectively differentiate between land cover and moisture changes based on Sentinel-2 data [22]. Similarly, in research conducted in Lake Tisza, NDWI was shown to be good in delineating water whereas NDVI indicates the density of vegetation, and there are robust interdependencies between hydrological changes and vegetation dynamics [23]. A study that was conducted in Remote Sensing validated the claim that NDVI is a significant correlation with soil moisture and NDWI is a strong proxy of water stress in plants [24]. Also, research on the Iraqi large Lakes demonstrated the efficiency of combining NDWI to track the lake and drought [25]. Other recent developments also demonstrate better drought monitoring in the case of combining Sentinel-2 indices with other datasets [26]. While in other studies Internet of things and technologies for drought monitoring have been applied by [27]. In general, the current findings are consistent with those of the world literature, as they prove that vegetation is sensitive to changes in water.

8. Conclusion

The drought conditions and water depletion analysis in Haditha Lake between 2021 and 2026 reveals high variability in the environment and the growing stress on water resources. The combination of NDWI and NDVI using the Sentinel-2 image and GIS analysis provided an in-depth insight into the interaction between vegetation response and surface water dynamics. The findings show a distinct trend of variability, starting with the stable conditions, then gradually falling in the water-related signals, a period of brief recovery, and finally a rapid fall that shows extreme stress of drought.

The values recorded to be lower in some years have been attributed to years of less water availability which could be as a result of climatic conditions like a reduction in precipitation and evaporation and potentially the upstream water management practices. Such decreases were directly linked to the decline in vegetation status, which proved the high level of reliance of plant well-being on the availability of water in the area. On the other hand, the times when values were improving were the same with the partial vegetation recovery meaning that the ecosystem was resilient to the temporary restoration of favorable conditions.

Nevertheless, at the end of the analysis, the critical decrease can be observed, which points to the fact that the system is more exposed to the long-term drought and water shortage. The repetitive ups and downs show that there is not enough time to recuperate to have long-term losses, which is an indicator of the overall trend of environmental stress. This has significant effects on the local ecosystems, agriculture and sustainability of water resources.

The research establishes that remote sensing measures like NDWI and NDVI are efficient to track drought and determine environmental change with time. Based on these joint indices, more integrated interpretations of water demand and ecological conditions can be applied. On the whole, the results highlight the necessity of developing sustainable water management, monitoring the environment, and planning adaptively to reduce the effects of drought and secure the long-term sustainability of Haditha Lake and the ecosystems surrounding this lake.

References

1. Schwabe K, Albiac J, Connor JD, Hassan RM, González LM. Drought in arid and semi-arid regions. Vol. 10. Springer; 2015.
2. Pulwarty RS, Sivakumar MV. Information systems in a changing climate: Early warnings and drought risk management. Weather Clim Extrem. 2014;3:14-21.
3. Abbas N, Wasimi S, Al-Ansari N, Sultana N. Water resources problems of Iraq: Climate change adaptation and mitigation. J Environ Hydrol. 2018;26.
4. AghaKouchak A, Farahmand A, Melton FS, Teixeira JC, Anderson MC, Wardlow BD, *et al.* Remote sensing of drought: Progress, challenges and opportunities. Rev Geophys. 2015;53(2):452-80.
5. Ajaj QM, Abdullah HA, Bakr SA, Jumaah HJ. Spatiotemporal Analysis of Al-Dalmaj Marsh in Iraq Using Sentinel-2 Imagery and GIS-Based Classification Methods. Int J Des Nat Ecodynamics. 2025;20(9):1965-76.
6. Chen L, Liu L, Liu S, Shi Z, Shi C. The application of remote sensing technology in inland water quality monitoring and water environment science: Recent progress and perspectives. Remote Sens. 2025;17(4):667.
7. Meteab MA, Abdullah AF, Jumaah HJ, Ameen MH. Water Indices and Machine Learning Classification of Al-Razzaza Lake in Iraq: A Sustainable Perspective. Math Model Eng Probl. 2026;13(2):305.
8. Ghanbari A, Jumaah HJ. Monitoring surface water area changes of Najaf Sea in Iraq using RS and GIS for sustainable development. Adv Eng Days. 2024;9:323-5.
9. Mahmood MR, Jumaah HJ. NBR index-based fire detection using sentinel-2 images and GIS: A case study in mosul park, Iraq. Int J Geoinformatics. 2023;19(3):67-74.
10. Ashok A, Rani HP, Jayakumar KV. Monitoring of dynamic wetland changes using NDVI and NDWI based landsat imagery. Remote Sens Appl Soc Environ. 2021;23:100547.
11. Nozad AA, Shareef MA. Using GIS Spatial Analysis for Examination the Utility of the Suggested Suitability Energy Farms Over Kirkuk City. NTU J Eng Technol. 2024;3(3).
12. Jumaah HJ, Kamran KV, Hasan WA, Ibraheem ZH. A Comprehensive Research of Air Quality Modeling Methods: A Case Study Kirkuk, Iraq. NTU J Eng Technol. 2026;5(1).
13. Lalmuanzuala B, Sathyamoorthy NK, Dheebakaran G, Jagadeeswaran R, Ravikumar R, Sumathi CS. A comprehensive review of meteorological and remote sensing indices for drought monitoring and their in situ application in India. Environ Rev. 2025;33:1-15.
14. Mallick J, Alqadhi S, Talukdar S, Hang HT. Evaluating groundwater sustainability and vegetation dynamics in arid regions: Advanced remote sensing and spatiotemporal analysis in Saudi Arabia. Environ Technol Innov. 2025;38:104203.
15. Bojer AK, Abshare MW, Mesfin F, Al-Quraishi AMF. Assessing climate and land use impacts on surface water yield using remote sensing and machine learning. Sci Rep. 2025;15(1):18477.
16. Jumaah HJ, Ghanbari A, Jasim AT, Khalaf ZA. Using RS and AI GIS in land management and urban planning in Mosul, Iraq for sustainable development. Geodesy Cartogr. 2025;51(3):165-77.
17. Granata F, Di Nunno F. Pathways for hydrological resilience: strategies for adaptation in a changing climate. Earth Syst Environ. 2026;10(1):203-31.
18. Dheeraj VP, Singh CS, Sonkar AK. Spatiotemporal analysis of land use changes and their impact on surface temperature in Korba coalfield region, India using remote sensing and GIS techniques. Environ Dev Sustain. 2026:1-30.
19. Jumaah HJ, Ameen MH, Mohamed GH, Ajaj QM.

Monitoring and evaluation Al-Razzaza lake changes in Iraq using GIS and remote sensing technology. Egypt J Remote Sens Space Sci. 2022;25(1):313-21.
20. Jumaah HJ, Rashid AA, Saleh SAR, Jumaah SJ. Deep neural remote sensing and Sentinel-2 satellite image processing of Kirkuk City, Iraq for sustainable prospective. J Opt Photonics Res. 2025;2(3):172-80.
21. Jumaah HJ, Ameen MH, Kalantar B. Surface water changes and water depletion of Lake Hamrin, Eastern Iraq, using Sentinel-2 images and geographic information systems. Adv Environ Eng Res. 2023;4(1):1-11.
22. Latuamury B, Imlabla WN, Sahusilawane F, Marasabessy H. Spatial Patterns of NDVI Vegetation Greenness Index and NDWI Water Content Index Using Sentinel 2A Imagery. IOP Conf Ser Earth Environ Sci. 2025;1527(1):012002.
23. Mohsen A, Fleit G, Kiss T, Baranya S. Decoding spatiotemporal dynamics of suspended sediment and vegetation in shallow reservoirs with Sentinel-2 and ANNs: A case study of Lake Tisza, Hungary. Environ Monit Assess. 2025;197(11):1249.
24. Varghese D, Radulovic M, Stojkovic S, Crnojevic V. Reviewing the potential of Sentinel-2 in assessing the drought. Remote Sens. 2021;13:3355.
25. Mahmood MR, Abrahem BI, Jumaah HJ, Alalwan HA, Mohammed MM. Drought monitoring of large lakes in Iraq using remote sensing images and normalized difference water index (NDWI). Results Eng. 2025;25:103854.
26. Li M, Wang P, Tansey K, Sun Y, Guo F, Zhou J. Improved field-scale drought monitoring using MODIS and Sentinel-2 data for vegetation temperature condition index generation through a fusion framework. Comput Electron Agric. 2025;234:110256.
27. Alsammak HN, Mohammed ZS. Internet of things (IoT) work and communication technologies in smart farm irrigation management: a survey. NTU J Eng Technol. 2022;1(3).

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