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Water Indices and Machine Learning Classification of Al-Razzaza Lake in Iraq: A Sustainable Perspective

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ABSTRACT

The study examined changes in the surface area of the Al-Razzaza Lake, located in the central part of Iraq, using multitemporal Landsat satellite images and water spectral indices. The analysis was based on atmospherically corrected Landsat images acquired in 2022, 2023, 2024, and 2025. The normalized difference water index (NDWI) and the normalized difference vegetation index (NDVI) were used because they have been reported to be sensitive to open water and vegetation cover, respectively. A combination of these indices minimized misclassification at water-land boundaries and provided a more reliable representation of lake dynamics than the individual indices. In addition to spectral index analysis, a supervised Random Forest classification was used to map land-cover classes related to the lake environment. Multispectral Landsat bands and spatially distributed training samples were used to develop the Random Forest model to classify water, wet soil, salt crust, vegetation, and bare land. This enabled an evaluation of changes in water surface pattern and land cover around the water surface over the study period. The results show that the surface area of Al-Razzaza Lake continued to decrease from 2022 to 2025, with a decline in 2025. The observed reduction was linked to environmental influences, such as decreased precipitation, enhanced water abstraction, and extended hydrological pressure in the basin. The NDVI analysis showed significant changes in vegetation density in the lake area, indicating that ecological changes were concurrent with variations in hydrological conditions. In general, the integration of spectral indices and Random Forest offered a consistent framework for monitoring lake surface dynamics. The results underline the need for continuous remote sensing-based monitoring to support the evaluation of water resources and the implementation of management practices in arid and semi-arid areas under increasing environmental pressure.

1. INTRODUCTION

In areas with little or scarce rain, water sources are being strained by climate change, a rise in population, and more human activities [1-4]. It is important to track the flow of water on the surface for proper water management, and this applies most to sensitive zones [5-7]. Combining Geographic Information Systems (GIS) and Remote Sensing (RS) technologies makes it possible to follow and examine how hydrological systems change over the years [8]. Landsat missions supply satellite images that can be used regularly to examine both water elements and the land near them [9]. Researchers in the field of sustainability have devoted themselves to developing quantitative indicators of sustainable development [10]. Normalized difference water index (NDWI) improves the outline of open water using a contrast to land and plants [11], but the normalized difference vegetation index (NDVI) gives information on variations in vegetation and ecology [12]. Using these indices jointly helps give a better picture of changes in both hydrology and the environment [13]. The modern era uses RS and GIS technologies together as efficient spatially inclusive tools to observe water surfaces and detect their changes economically [14-16]. Also, deep and machine learning models have potential significance in the classification processes [17-20]. Land cover mapping in GIS depends importantly on satellite image classification, which gives clear results on Earth's surface features. Among the different methods of classification, Random Forest is considered a strong machine learning algorithm because it is resilient, produces reliable results, and can handle complex data easily [21].

The largest natural lake in Iraq exists between Karbala and Anbar provinces and carries the dual names of Al-Razzaza Lake and Lake Milh [22, 23]. The reservoir maintains three vital functions in the environment, which include irrigation for farming, support of biodiversity, and development of tourist sites [24]. The Euphrates River controls water flow to the lake through managed canal systems, yet both weather changes and human activities endanger its water balance [25]. The combination of lower rainfall amounts together with higher evapotranspiration rates from climate change and expanding irrigation and water usage for people represents significant threats [26, 27]. The surface water area of Al-Razzaza Lake underwent substantial modifications through decades of dynamic changes. Therefore, demanding urgent scientific investigations to understand its complete transformation [28]. The continuous observation of surface water bodies, especially Al-Razzaza Lake, enables people to understand environmental transformations. Besides, it's significant in water resource management as well as sustainable development planning in Iraq's arid and semi-arid regions [29].

The integrative nature of GIS and RS is essential since it allows the spatial-temporal analysis of the hydrology shift on a more accurate location [30]. RS and GIS were used in research analyzing Lake Urmia in Iran to reveal the trends of drastic shrinkage relative to climate and human activities [31]. Similarly, RS-GIS applications of Lake Hamrin in Iraq demonstrated that the lake surface mapping was useful in the management of the lake during a period when rainfall reduced [26]. The examples affirm the applicability of such techniques when monitoring sensitive water bodies.

In this study, we used GIS and RS for mapping the changes of Al-Razzaza Lake in different time periods. NDWI and NDVI were combined, which made it possible to spot changes in the lake's surface and detect any related environmental changes in the nearby land. Some reasons are excessive water usage, less rainfall, and increased damage to the environment. RS supplies foundational knowledge for developing these strategies through evidence-based decision-making processes.

2. STUDY AREA

Al-Razzaza Lake lies between coordinates of (32° 27′–34° 00′) N and (43° 05′–44° 10′) E, as shown in Figure 1.

It's one of the largest lakes in Iraq, which emerged as a reservoir depression during the 1970s from natural geological processes, and serves as a flood control system for the Euphrates River.

Razzaza Lake occupies land between Kerbala and Anbar governorates at distances of 50 km southeast of Ramadi and 15 km northwest of Karbala, and 95 km southwest of Iraq's capital city, Baghdad. Razzaza Lake provided an engaging tourism destination because of its favorable natural geographical settings and environmental richness. This water basin stands as the second biggest reservoir in Iraq. The developers planned Razzaza Lake to function as a deep reservoir system with an 1810 km^2 surface dimension and 26 billion cubic meters storage capability, and a maximum flood depth of 40 meters to store 25,750 billion m^3 water in 1995 [32]. This lake experiences a climate with semi-arid conditions combined with hot, dry summers and cold, dry winters that bring 109 to 122 mm of rainfall from January through May, while evaporating 3194.3 to 3332.7 mm during the year. Research has established this area as a vital section of Iraq. Various sectors pursue interests in this lake for touristic, religious, historical, economic, social, and environmental purposes [33, 34]. GIS and RS are effective tools for evaluating and spatial management [35, 36].

Research on Al-Razzaza Lake is essential for studying its present water level decrease and growing salt content. Investigation is important to identify the negative environmental effects on both local ecosystems and biodiversity. It requires proper strategies for sustainable water resource management among nearby human communities.

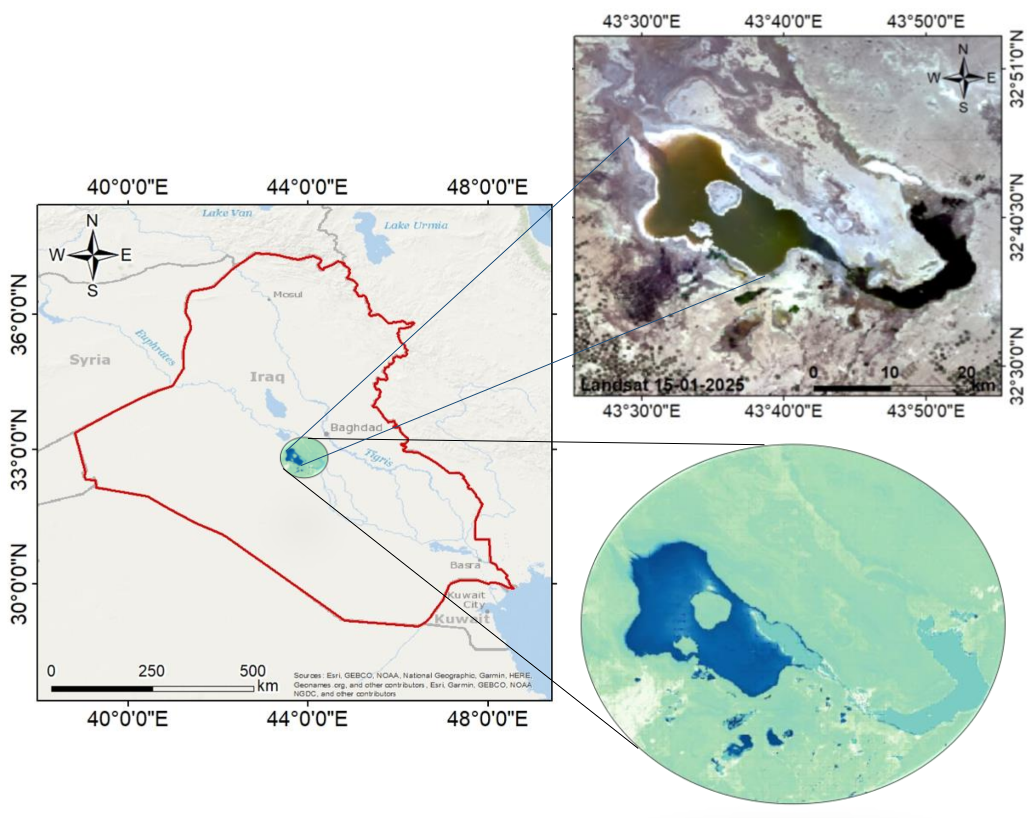

Figure 1. Al-Razzaza Lake study area

3. METHODS

The analysis used RS and GIS methods to explore the environmental dynamics in the Al-Razzaza Lake, specifically the variability of water and vegetation. The level 2 Multi-temporal Landsat 8-9 data on surface reflectance were tested to determine the change across time. Four clear clouds were picked, with the date of the acquisitions being 19 August 2022, 23 September 2023, 17 September 2024, and 19 August 2025. The selection criteria of these photos included low cloud cover 0–0.3. All datasets were handled in the WGS-84 coordinate reference system and had the same spatial resolution, which guaranteed spatial consistency of the time series. Table 1 presents the processed dataset used in this study.

To reduce seasonal differences in inter-annual surveys, the majority of the images were chosen during the dry season (August-September) when vegetation cover is minimal, and water content also remains relatively constant.

Detection of temporal change was done by using time-series and spatial comparison of NDVI, NDWI, and land-cover maps, which were classified.

The resulting outputs were visualized and interpreted to determine long-term environmental trends that influence Al-Razzaza Lake.

Moreover, Figure 2 illustrates the data collection and processing workflow, including the application of corrections and subsequent software-based analysis. Preprocessing of downloaded images was done through Environment for Visualizing Images (ENVI) and ArcGIS software and involved the radiometric correction and cloud detection processes to improve the quality of the data.

Spectral indices based on the Landsat bands were used to study vegetation and water dynamics. The near-infrared and red bands were used to derive the NDVI, which was used to assess the state of vegetation, whereas the green and near-infrared bands were used to obtain an NDWI that was used to determine the extent of surface water.

These indices presented a stable performance of monitoring time variations in vegetation density and surface area of lakes.

Random Forest classification was further used to characterize land-cover conditions using multispectral Landsat bands. The Random Forest classifier, based on a combination of randomly built decision trees based on randomly chosen feature subsets, was used to provide land-cover classifications by majority voting. In this way, the discrimination between water, moist soil, salt crust, shrubs, and bare land was enhanced.

Spatial distribution of training samples was done to minimize bias and enhance classification accuracy.

The systematic pre-processing workflow was applied to all the satellite images in order to ensure radiometric and geometric consistency, followed by analysis.

Table 1. The study dataset and metadata

ID	Image	Date	Season	Cloud	Resolution
1	Landsat 8-9 L2	19-8-2022	Summer	0.3%	30 m
2	Landsat 8-9 L2	23-9-2023	Summer	0%	30 m
3	Landsat 8-9 L2	17-9-2024	Summer	0%	30 m
4	Landsat 8-9 L2	19-8-2025	Summer	0.01%	30 m

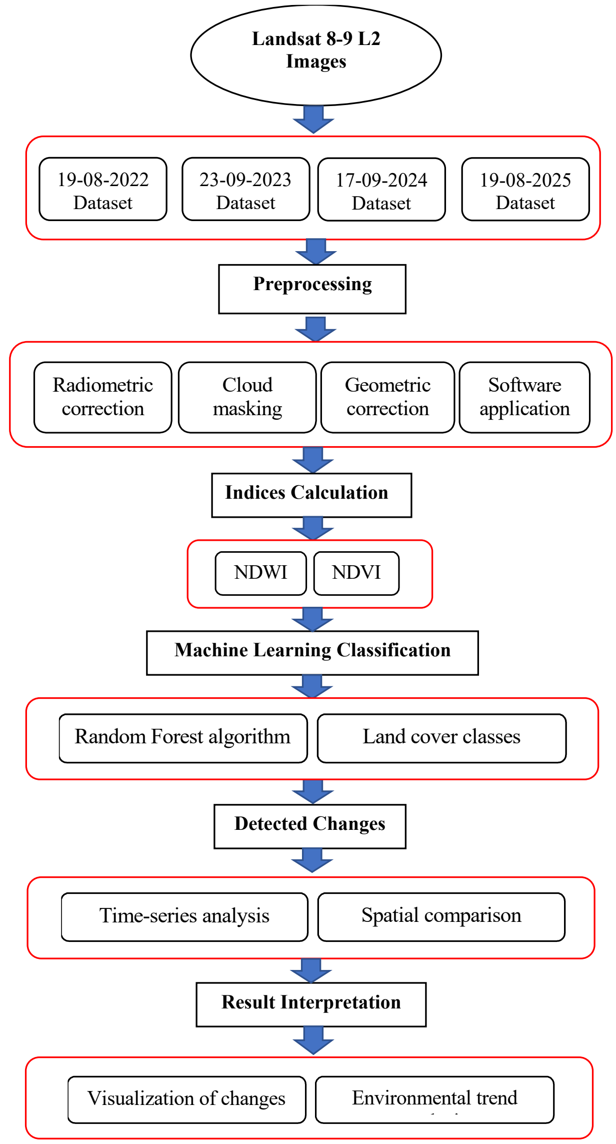

Figure 2. Flowchart of the methodology conducted

After the pre-processing, the NDVI and NDWI indices were obtained based on the corrected surface reflectance images to examine the change in the vegetation and water bodies over time.

An analysis of the NDWI allowed researchers to improve surface water detection while extracting their extent. The equation that represents NDWI can be set as [10, 37]:

$$NDWI = (G - NIR)/(G + NIR) \quad (1)$$

where, G is the Landsat green band reflectance, and NIR is the near-infrared reflectance.

The NDVI detects vegetation class through red and NIR band combinations and provides a secondary environmental indicator in semi-arid areas where vegetation depends on accessible water resources. The research incorporated NDWI together with NDVI to monitor lake water extent changes while clearly associating these impacts with regional ecological functions. The evaluation technique proves essential in central Iraq because water scarcity, desertification, and climate variability are intensifying in this region. The equation that represents NDVI can be set as:

$$NDVI = (NIR - R)/(NIR + R) \quad (2)$$

where, R is the red band.

The Random Forest classification of Al-Razzazza Lake in 2025 was based on a single-stage, supervised, pixel-based classification. Manual digitization of the training samples was made to reflect the five classes of land cover, namely, water, wet soil, salt crust, vegetation, and bare land. In order to minimize bias on dominant classes, a balanced sampling strategy was also employed by restricting the maximum number of training samples per class to about 1000 pixels to keep minority classes, e.g., water and salt crust, adequately represented. Classification was done using spectral behaviors and field information: water was considered to have low reflectance in the near-infrared; vegetation had a high spectral near-infrared reflectance, wet soil had an intermediate spectral reflectance with moisture effects; salt crust was high-brightness; and dry land had intermediate and dry spectral reflections.

Figure 3 illustrates the applied classifier with the number of trees and samples per class.

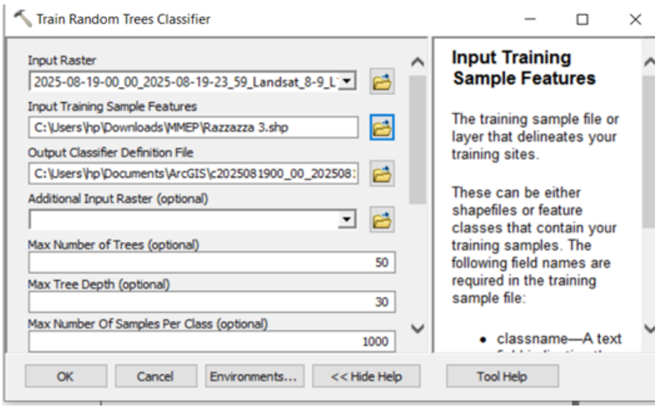

Figure 3. Random Forest classification input samples

The classification feature set was based on multi-spectral Landsat 8-9 surface reflectance bands alone without the addition of spectral indices and texture measures to ensure model simplicity and minimize redundancy. The Random Forest model was fit with 50 decision trees, each with a maximum tree depth of 30, which was sufficiently complex yet not overly complex to overfit. The importance of the features was implicitly measured by the Random Forest internal importance, which confirmed the superiority of near-infrared and shortwave infrared bands in separating classes. The effects of spatial autocorrelation were reduced through the distribution of training samples spatially in the study area as opposed to their local clustering, which enhanced the generalization potential of the model.

4. RESULTS

Figure 4 presents the NDVI-derived maps, which illustrate changes in water extent, variations in spectral response, and the spatial distribution of vegetation around the lake.

The NDVI maps indicated that there was evident spatial and temporal change in vegetation cover around Al-Razzaza Lake in the period between 2022 and 2025. Regions with more NDVI were always the vegetated regions on the lake margins and other agricultural areas, whereas areas with lower NDVI were the non-vegetated areas like open water, bare lakebed, and barren lands. There were also progressive changes in the moderate-high NDVI areas with time, with great changes in 2024 and 2025, indicating a decrease in the vegetation cover instead of outright degradation of the ecology. These variations were observed in parallel with the shrinking of the surface of the lake, which indicated a reaction of the vegetation around the lake to the hydrological variations. The variation of NDVI was seen as an absolute measure of vegetation density and distribution without any indication of salinity or ecosystem health, without any field or water-quality data to underpin the results.

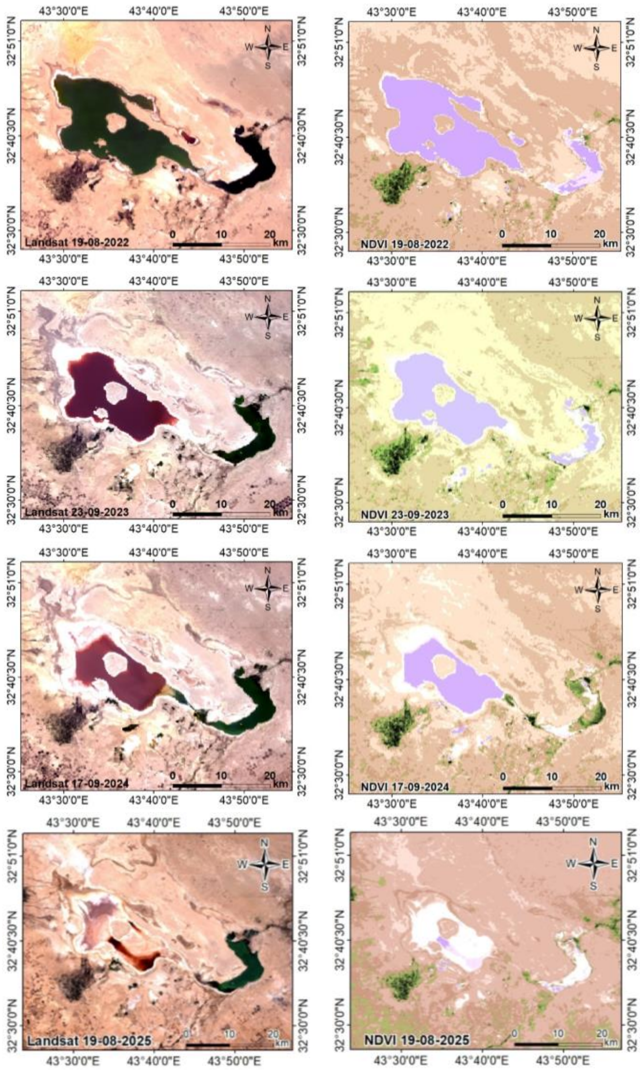

Figure 4. Normalized difference vegetation index (NDVI) maps vs. the Landsat map

Figure 5 shows both types of maps from Landsat and uses NDWI to illustrate how the surface water level of Al-Razzaza Lake in Iraq has changed. It is clear from these maps that the water in Al-Razzaza Lake is not stable and experiences deterioration.

The NDWI maps revealed clear spatial and temporal differences in surface water and in Al-Razzaza Lake between 2022 and 2025. Higher NDWI always represents the open water regions, and the lower value represents the exposed lakebed, moist soil, and adjacent arid land. There was a consistent overtime decrease in the area of NDWI-positive, which evidenced a sustained lake contraction. The lowest values of NDWI and the smallest continuous water body were observed in the year 2025, which is indicative of a strong decrease in the surface water area as compared to the past years. This trend meant that there was very little availability of water, and no water quality or depth changes.

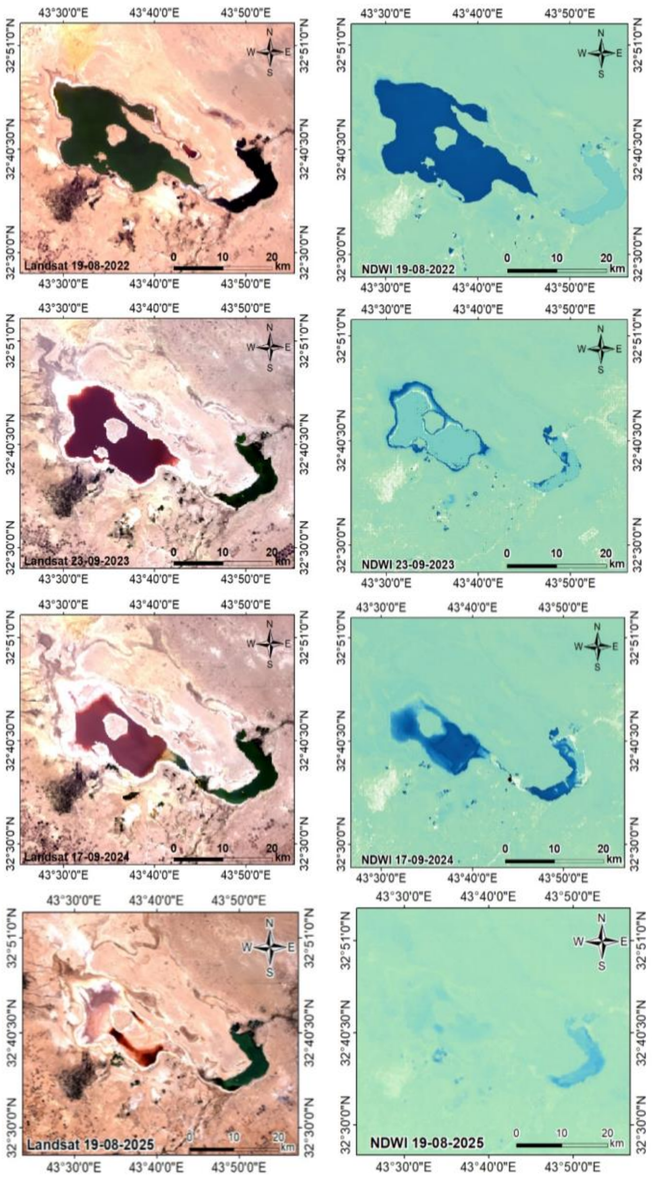

Figure 5. Normalized difference water index (NDWI) maps vs. the Landsat maps

The interpolations of NDWI were taken as inferences of the presence and size of the surface waters and aligned with the general downward trend of hydrology that was found via multi-temporal analysis.

Furthermore, estimation of the Al-Razzaza Lake water area for four years in a row was achievable through using satellite data and the Random Forest algorithm, as shown in Figure 6 and Table 2.

Moreover, Figure 7 represents the Random Forest resultant map of Al-Rzzazza Lake in 2025.

Table 2 represents Random Forest-based estimates of the Al-Razzaza Lake surface area between 2022 and 2025 and reveals a clear and steadily decreasing trend. In 2022, the lake had a total area of about 262.98 km^2, but in 2023, the area was only 193.44 km^2, meaning that the lake lost a significant part of its territory in a year. This decreased faster in 2024, as surface area dropped to approximately 121.16 km^2. The sharpest shrinkage was experienced in 2025 when the lake area was recorded to be at its minimum of 57.08 km^2. These findings validate the presence of a continuous shrinkage of the lake during the period of study, and indicate growing hydrological stress and decreased water volumes, and not seasonal variability.

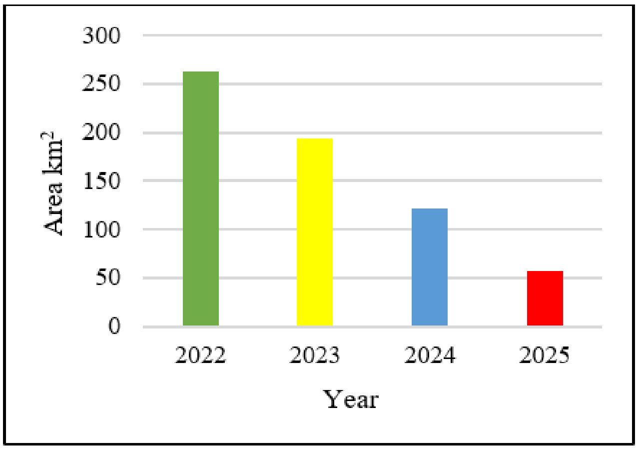

Figure 6. The surface area changes of Al-Razzaza Lake from 2022 to 2025

Table 2. Random forest-based resultant surface area

Year	Area (km^2)
2022	262.983
2023	193.436
2024	121.161
2025	57.081

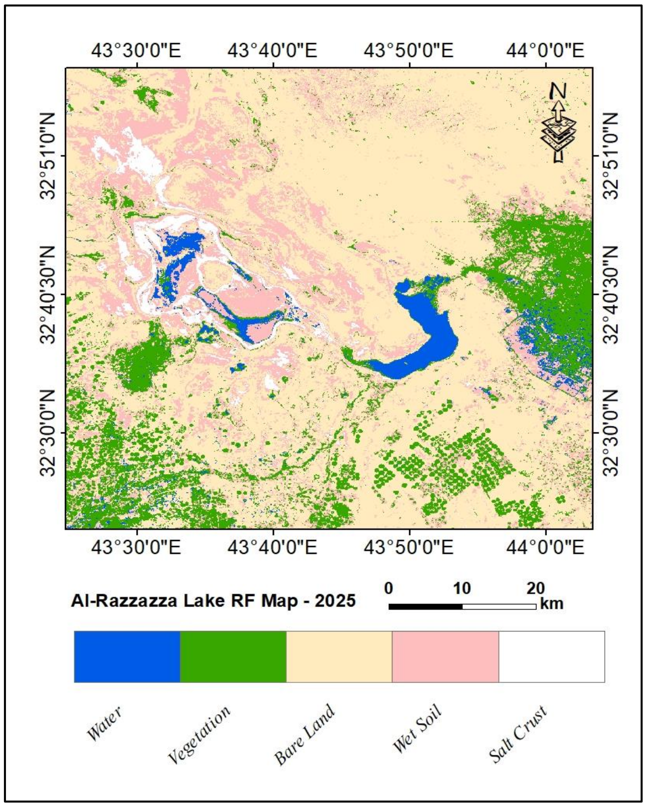

Figure 7. Random Forest resultant map of Al-Rzzazza Lake in 2025

The 2025 Random Forest classification map was a description of the land-cover condition around and within the Al-Razzaza Lake. Water bodies were well defined and extremely fine-grained, meaning that the lake surface was very much reduced and discontinuous. Classes of wet soil and of salt crust were widely spread on the former margins of the lake, showing a reputation of recent recession of the waters and exposure of evaporative surfaces. Land was largely unvegetated, with agricultural activities being localized and limited to the periphery with vegetation. The spatial distribution of classes validated strong lake contraction in the year 2025 and proved the capability of the Random Forest classifier to differentiate transitional surfaces more effectively in contrast to index-based strategies.

5. DISCUSSION

Multi-temporal evaluation of the Al-Razzaza Lake in the NDVI, NDWI, and Random Forest classification demonstrated that there is a significant and consistent decrease in the surface water cover of the lake from 2022 to 2025, indicating that the lake is embedded in a larger trend of decline in the inland lakes across various regions of the world.

As observed in the NDWI analysis, the open water area progressively decreased, with 2025 having the lowest water area, a pattern which is similar to that reported in Lake Urmia in Iran [38], where NDWI-based research reported a rapid shrinkage of the lake due to low inflow, an extended drought, and intensive extraction of water. Similar NDWI decreases include those found in the Basin of the Aral Sea, where surface water loss increased after massive hydrological changes and climate fluctuations were experienced [39].

NDVI values of Al-Razzaza Lake showed that there were spatially consistent patterns of vegetation, where large values were only found in agricultural areas and in the margins of the lakebed and barren areas, and low values prevailed in the rest of the exposed lakebed.

The time-varying decrease in moderate-high NDVI regions was observed to be the alteration of the vegetation distribution with the decrease in water availability, instead of the ecological degradation. The interpretation can be compared with the results of the studies in the Dead Sea [40], where NDVI variability was attributed to the shoreline recession and the variation in soil moisture as opposed to ecosystem wellness. Similar studies on the lake shrinkage and the redistribution of vegetation are also reported in Lake Urmia, where the shrinking water tables also shifted the surrounding agricultural and natural vegetation distribution [38].

Random Forest classification offered a more detailed description of land-cover transitions than index-based methods alone.

The Random Forest map 2025 indicated disrupted bodies of water, increased wetlands, and salt crust areas along the retreating shoreline and the prevalence of bare lands. Random Forest-based counterparts of the Aral Sea and Lake Urmia showed better ability to discriminate between water, saline surfaces, and transitional wet areas as compared to single-index threshold classification. Under such circumstances, Random Forest minimized spectral confusion and improved the identification of shoreline dynamics, especially when extreme water loss is involved. The Random Forest-generated estimates of the surface areas of Al-Razzaza Lake showed a steep decrease between the estimates of around 262.98 km^2 in 2022 and 57.08 km^2 in 2025, which is a rate of decline that is comparable with the rates of rapid shrinkage that have been recorded in Lake Urmia during severe drought years [38].

The match in the trends of NDWI and the spatial patterns of NDVI, as well as the Random Forest-based estimates of the surface areas, enhances the confidence in the findings and contributes to their similarity with the existing literature on the subject of lake-shrinkage. There was no need to use spectral indices only, as the incorporation of Random Forest classification allowed distinguishing water, wet soil, salt crust, vegetation, and bare land, just like in the case of more sophisticated methods used in other degraded lake systems. On the whole, the results show that the Al-Razzaza Lake is experiencing the same level of hydrological stress that is characterized by the same magnitude and spatial manifestations as other well-known lakes that are shrinking, which highlights the existence of regional significance in the observed changes and the ability of the integrated RS and machine learning techniques to monitor the lakes over long periods.

6. CONCLUSIONS

In this study, multi-temporal Landsat data were employed to measure land surface changes of Al-Razzaza Lake and the surrounding land cover over the period 2022-2025 using NDWI and NDVI indices and Random Forest classification.

The analysis suggests open water has been steadily decreasing, as reflected by NDWI and inferred vegetation changes from NDVI that can be described as a spatial representation not interpreted for ecological purposes.

Integrating spectral indices with supervised classification enables better separation of water, wet soil, salt crust, vegetation, and bare land and delivers a more robust platform for quantifying hydrological change than index-based mapping.

The observed patterns suggest increasing pressure on the lake system, likely associated with reduced rainfall and intensified water extraction. These findings underscore the need for continued satellite-based monitoring to track spatiotemporal changes in lake extent and surrounding land cover. Regular analysis of multi-temporal imagery can support timely hydrological assessment and inform water management strategies.

Strengthening coordination between research institutions and water management authorities is essential to enable data-driven decision-making, while policies aimed at regulating water extraction and improving water-use efficiency are critical to mitigating further lake shrinkage, particularly during prolonged dry periods. Future work should integrate in situ water-level measurements, drone-based observations, and higher-resolution imagery to enhance the accuracy and validation of satellite-derived estimates.

REFERENCES

[1] Kalantar, B., Ameen, M.H., Jumaah, H.J., Jumaah, S.J., Halin, A.A. (2020). Zab River (IRAQ) sinuosity and meandering analysis based on the remote sensing data. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 43: 91-95. https://doi.org/10.5194/isprs-archives-XLIII-B3-

2020-91-2020
[2] Maduelosi, J.N., Ezuluofor, M.U. (2023). Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies, 4(3): 1-8. https://doi.org/10.37745/bjmas.2022.0207
[3] Ishaque, W., Tanvir, R., Mukhtar, M. (2022). Climate change and water crises in Pakistan: Implications on water quality and health risks. Journal of Environmental and Public Health, 2022(1): 5484561. https://doi.org/10.1155/2022/5484561
[4] Biswas, A., Sarkar, S., Das, S., Dutta, S., et al. (2025). Water scarcity: A global hindrance to sustainable development and agricultural production–A critical review of the impacts and adaptation strategies. Cambridge Prisms: Water, 3: e4. https://doi.org/10.1017/wat.2024.16
[5] Fu, G., Jin, Y., Sun, S., Yuan, Z., Butler, D. (2022). The role of deep learning in urban water management: A critical review. Water Research, 223: 118973. https://doi.org/10.1016/j.watres.2022.118973
[6] Fatah, K.K., Mustafa, Y.T., Hassan, I.O. (2024). Groundwater potential mapping in arid and semi-arid regions of Kurdistan region of Iraq: A geoinformatics-based machine learning approach. Groundwater for Sustainable Development, 27: 101337. https://doi.org/10.1016/j.gsd.2024.101337
[7] Razavi, H.S., Nejadhashemi, A.P., Deb, K., Toscano, G., Harrigan, T., Linker, L. (2026). Artificial intelligence, optimization, and modeling techniques in water resource management: Interconnections and emerging synergies. Water Environment Research, 98(1): e70246. https://doi.org/10.1002/wer.70246
[8] Nikoo, M.R., Al Aamri, A., Etri, T., Al-Rawas, G. (2025). A review of machine learning, remote sensing, and statistical methods for reservoir water quality assessment. Journal of Hydrology, 659: 133323. https://doi.org/10.1016/j.jhydrol.2025.133323
[9] Campo, C., Tamagnone, P., Choy, S., Tran, T.D., Schumann, G.P., Kuleshov, Y. (2026). Monitoring flood inundation dynamics from space. Reviews of Geophysics, 64(1): e2025RG000885. https://doi.org/10.1029/2025RG000885
[10] Abdullah, A.F., Abdul-Rahman, M.B.A.D., Al-Attar, A.A. (2026). Investigate the mechanical characteristics and microstructure of fibrous-geopolymer concrete exposure to high temperatures. Journal of Rehabilitation in Civil Engineering, 14(1): 2141. https://doi.org/10.22075/jrce.2025.34716.2141
[11] Ashok, A., Rani, H.P., Jayakumar, K.V. (2021). Monitoring of dynamic wetland changes using NDVI and NDWI based landsat imagery. Remote Sensing Applications: Society and Environment, 23: 100547. https://doi.org/10.1016/j.rsase.2021.100547
[12] Mahmood, M.R., Jumaah, H.J. (2023). NBR index-based fire detection using sentinel-2 images and GIS: A case study in Mosul Park, Iraq. International Journal of Geoinformatics, 19(3): 67-74. https://doi.org/10.52939/ijg.v19i3.2607
[13] Ji, P., Su, R., Wu, G., Xue, L., et al. (2025). Projecting future wetland dynamics under climate change and land use pressure: A machine learning approach using remote sensing and Markov chain modeling. Remote Sensing, 17(6): 1089. https://doi.org/10.3390/rs17061089
[14] Nozad, A.A., Shareef, M.A. (2024). Using GIS spatial analysis for examination the utility of the suggested suitability energy farms over Kirkuk City. NTU Journal of Engineering and Technology, 3(3). https://doi.org/10.56286/aph1k052
[15] Morale, D., Parente, C., Bolognesi, S.F. (2025). Comparison of machine-learning algorithms for SPOT 7 multispectral image classification. Geomatics and Environmental Engineering, 19(2): 71-97.
[16] Huq, M.E., Lopez-Carr, D., Tariq, A., Wu, X.J., et al. (2025). Advancements in remote sensing and GIS for water resource management and SDG monitoring. In Utilizing Earth Observation Data in Reaching Sustainable Development Goals, pp. 189-218. https://doi.org/10.1016/B978-0-443-30204-6.00007-3
[17] Thanoon, K.H., Shareef, A.F., Alsaif, O.A. (2022). Digital processing and deep learning techniques: A review of the literature. NTU Journal of Engineering and Technology, 1(3). https://doi.org/10.56286/ntujet.v1i3.223
[18] Hasan, S.Q. (2023). Shallow model and deep learning model for features extraction of images. NTU Journal of Engineering and Technology, 2(3). https://doi.org/10.56286/ntujet.v2i3.449
[19] Riche, A., Drias, A., Ricci, R., Souissi, B., Melgani, F. (2026). Predicting LULC changes and assessing their impact on surface runoff with machine learning and remote sensing data. Water Resources Management, 40: 182. https://doi.org/10.1007/s11269-026-04560-z
[20] Abdullah, M.H., Mustafa, Y.T. (2025). Machine learning and SHAP-based analysis of deforestation and forest degradation dynamics along the Iraq–Turkey border. Earth, 6(2): 49. https://doi.org/10.3390/earth6020049
[21] Pal, M. (2005). Random forest classifier for remote sensing classification. International Journal of Remote Sensing, 26(1): 217-222. https://doi.org/10.1080/01431160412331269698
[22] Al-Kindi, G.Y., Al-Sultan, A.A. (2024). Evaluation of environmental quality for Al-Razzaza Lake in Iraq. Innovative Infrastructure Solutions, 9(11): 418. https://doi.org/10.1007/s41062-024-01731-y
[23] Awadh, S.M. (2024). Potential geopark and geotourism in Iraq. In The Geography of Iraq, pp. 269-294. https://doi.org/10.1007/978-3-031-71356-9_12
[24] Mohammad, M.K., Al-Zubaidi, A.A. (2017). Geodiversity and its importance on vertebrate diversity near Razzaza Lake, middle of Iraq. The Iraqi Geological Journal, 50(1): 104-123. https://doi.org/10.46717/igj.50.1.8Ms-2017-06-30
[25] Hassan, W.H., Ghazi, Z.N. (2023). Assessing artificial recharge on groundwater quantity using wells recharge. Civil Engineering Journal, 9(9): 2233-2248.
[26] Jumaah, H.J., Ameen, M.H., Kalantar, B. (2023). Surface water changes and water depletion of Lake Hamrin, Eastern Iraq, using Sentinel-2 images and geographic information systems. Advances in Environmental and Engineering Research, 4(1): 1-11. http://doi.org/10.21926/aeer.2301006
[27] Khair-Allah, Z.H. Khassaf, S.I. (2026). Impact of climate change and upstream development on domestic water security in the Euphrates River Basin, Iraq. The Iraqi Geological Journal, 59(1B): 18-35. https://doi.org/10.46717/igj.2026.59.1B.2
[28] Al-Qaraghuli, S.A., Hassan, A.A., Albaldawi, R.A., Abd, O.K. (2021). The effect of climate changes on the

fluctuation of the water level of Al-Razzaza Lake, Iraq. Iraqi Journal of Science, 62(11): 4464-4474. https://doi.org/10.24996/ijs.2021.62.11(SI).27

[29] Abdullah, A.F., Ezuldin, N.Y., Ahmed, I.M., Al-Khafaji, Z. (2025). Enhancing the sustainability of concrete mixes utilizing supplementary cementitious materials in renewable energy buildings. Engineering, Technology & Applied Science Research, 15(5): 28041-28049. https://doi.org/10.48084/etasr.12936

[30] Jumaah, H.J., Khursheed, N.K., Salahalden, V.F., Sulyman, M.H.A. (2025). Integration of remote sensing and artificial intelligence in detecting the environmental changes of Najaf Sea in Iraq using NDWI and GIS. Engineering, Technology & Applied Science Research, 15(4): 26107-26112. https://doi.org/10.48084/etasr.12265

[31] Kazemi Garajeh, M., Akbari, R., Aghaei Chaleshtori, S., Shenavaei Abbasi, M., Tramutoli, V., Lim, S., Sadeqi, A. (2024). A comprehensive assessment of climate change and anthropogenic effects on surface Water resources in the Lake Urmia Basin, Iran. Remote Sensing, 16(11): 1960. https://doi.org/10.3390/rs16111960

[32] Ali Al-Anbari, M., Yahya Othman, N., Mulahasan, S., Abeyes, H.H., Hussein Buraihi Al-Ganem, F., Muslem Owayed, M. (2022). Razzaza Lake, a natural water body: Its hydraulic characteristics and water quality. Innovative Infrastructure Solutions, 7(3): 225. https://doi.org/10.1007/s41062-022-00824-w

[33] Mashee, F.K., Ali, A.R.B., Jasim, M.S. (2020). Spatial monitoring for degradation Al-Razzaza Lake by analysis temporal of remote sensing data using geographic information system techniques. EurAsian Journal of BioSciences, 14: 4777-4781.

[34] Rashed, A.M., Alhadithi, M., Alattar, F.M. (2024). Applying geographic information systems (GIS) techniques to estimate surface area of Al-Razzaza Lake, Karbala province, Iraq. IOP Conference Series: Earth and Environmental Science, 1300(1): 012008. https://doi.org/10.1088/1755-1315/1300/1/012008

[35] Mohammed, Z.B., Kamal, A.A.K., Resheq, A.S., Alabdraba, W.M.S. (2019). Assessment of air pollution over Baghdad City using fixed annual stations and GIS techniques. Journal of Southwest Jiaotong University, 54(6): 1-12. https://doi.org/10.35741/issn.0258-2724.54.6.36

[36] Mohammed, Z., Ziboon, A., Kamal, A., Alfaraj, M. (2018). Urban air quality evaluation over Kut city using field survey and Geomatic techniques. MATEC Web of Conferences, 162: 05023. https://doi.org/10.1051/matecconf/201816205023

[37] McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7): 1425-1432. https://doi.org/10.1080/01431169608948714

[38] Bulti, W.A. (2019). Combining satellite imagery and radar altimetry for estimating Lake Ziway storage variation. Doctoral Dissertation, Arbaminch University.

[39] Wang, X., Chen, Y., Li, Z., Fang, G., Wang, F., Liu, H. (2020). The impact of climate change and human activities on the Aral Sea Basin over the past 50 years. Atmospheric Research, 245: 105125. https://doi.org/10.1016/j.atmosres.2020.105125

[40] Ali, E.A., Elnagar, A.S., Rebouh, N.Y., Fadl, M.E. (2025). Assessing land degradation through remote sensing and geospatial techniques for sustainable development under the Mediterranean conditions. Sustainability, 17(13): 6087. https://doi.org/10.3390/su17136087