Integration of Remote Sensing and Artificial Intelligence in Detecting the Environmental Changes of Najaf Sea in Iraq Using NDWI and GIS

Huda Jamal Jumaah
Department of Environment and Pollution Engineering, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, 36001, Iraq
Huda80@ntu.edu.iq (corresponding author)

Nawal Kamal Khursheed
Department of Environment and Pollution Engineering, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, 36001, Iraq
Nawalkamal@ntu.edu.iq

Veyan Farhad Salahalden
Department of Surveying Engineering, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, 36001, Iraq
veyan.farhad@ntu.edu.iq

Maryam Hassan Ahmed Sulyman
Department of Environment and Pollution Engineering, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, 36001, Iraq
marynamh4l@ntu.edu.iq

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ABSTRACT

The Najaf Sea is undergoing significant environmental changes due to the climate change and urban expansion, resulting in decreasing water levels that affect the surrounding areas. The present study employs two technologies, Remote Sensing (RS) and Artificial Intelligence (AI), to monitor the environmental changes as part of the sustainability assessments. It aims to observe and analyze the changes between 2018 and 2025, tracking the variations in the water bodies and evaluating the impacts of the climate and human activity on sustainable resource management. Additionally, this supports rational decision-making regarding the environmental conservation, sustainable development, and resource management in the region. The Normalized Difference Water Index (NDWI), Support Vector Machine (SVM), Geographic Information Systems (GIS), and Sentinel-2 images were utilized to analyze the changes in the water bodies and their associated environmental impacts. Through change detection, AI models deliver highly accurate predictions of sustainable water resources. This paper highlights the critical role of advanced technologies in monitoring and forecasting the changes to water resources. The findings promote ecological protection and help local communities adapt to the environmental shifts through data-driven management. This research provides essential information to help experts develop resilient strategies for environmental conservation and climate change mitigation. As demonstrated, these technologies enhance monitoring in sensitive areas, such as the Najaf Sea. The study fosters ecological balance, protects the environment, and encourages development through technological advancements for the benefit of the local population.

Keywords-AI; SVM; NDWI; remote sensing; GIS

I. INTRODUCTION

Given its importance in hydrology and ecology, the Najaf Sea is a valuable water body in southwestern Iraq [1]. The size of a seasonal lake is affected by rainfall, groundwater, and human activities [2]. Additionally, the expansion of agriculture and increased industrial activity have impacted the lake's environment [3]. These changes have caused environmental problems in the area, affected the availability of water for local use, and harmed communities and ecosystems [4]. Modern technology requires more effective methods to observe and predict how the environmental changes may occur. Using RS and AI, it is possible to efficiently monitor the changes in the water bodies [5] and gather large, real-time datasets to support assessments of the past and current environmental trends. This approach is enhanced by GIS and spatial analysis capabilities, which improve the visualization and spatial data management [6]. The development of these techniques has become a reliable analytical method for RS data, leading to significant progress in all RS application fields [7].

NDWI is often utilized as a standard method for identifying water bodies [7], and it functions as a specific index for extracting water from satellite images by analyzing the differences between the water and other land cover types [8]. NDWI enhances satellite water imagery by incorporating the green and near-infrared bands. The NDWI technology demonstrates an exceptional ability to distinguish between the water bodies, vegetation, and urban structures, making it vital for ocean monitoring and proving valuable in hydrological studies [9]. NDWI enables the monitoring of the water bodies by observing the changes in the water volume. It utilizes the ocean's strong absorption ability in the infrared part of the electromagnetic spectrum to perform its measurements [10]. Hydrological and environmental researchers greatly benefit from Sentinel-2, as this European Space Agency (ESA) mission offers accurate multispectral satellite imagery [11].

The water levels and quality of the lake fluctuate greatly due to the rising temperatures, changing precipitation patterns, and increased evaporation rates [12]. The combination of severe droughts and decreased rainfall causes further negative effects, resulting in lower water availability and higher salinity levels across the region [13]. The expanding urban areas demand more water supplies, which also leads to land redevelopment and the release of pollutants into the environment. The use of fertilizers and irrigation methods in agriculture puts additional pressure on the water quality and reduces its overall availability [14]. Industrial activities in the area contribute to environmental stress by causing water pollution and habitat destruction [15]. A comprehensive assessment of these combined activities requires the use of RS techniques and AI-driven models to evaluate their overall impact [16].

Environmental monitoring has made significant advances in change detection due to the adoption of AI-based models, which are implemented through computerization [17]. The classification of the land cover changes, as well as the prediction of the water body fluctuations and environmental risk assessment, can be carried out using SVM, Random Forest (RF), and Deep Learning (DL) algorithms [18]. This process results in the accurate identification of the key features. It automatically detects and classifies features in images to enhance the identification and estimation capabilities [19]. AI predictive models help scientists achieve their goals for sustainable water resource management and support conservation planning [20].

As noted in [21], technology-driven GIS modeling supports sustainable operations. In water resource management, accurate precipitation forecasting is crucial for mitigating droughts, a natural hazard that affects every region worldwide [22]. GIS helps identify the high-risk zones, monitor the land use changes, and assess the conservation efforts [23]. AI is among the leading technological trends today [24]. Combining AI with GIS provides valuable insights that guide sustainable development and resource management strategies [8].

Climate change and increased human activities have rapidly expanded urban areas, harmed the environment of the Najaf Sea, and caused ecological imbalance and a decline in the water levels. Traditional monitoring methods are inadequate for capturing these complex changes. To promote sustainable water resource management, it is crucial to explore and adopt advanced technologies, like RS and AI, for analyzing, monitoring, and managing the water resources. This study aims to (i) observe and evaluate the environmental changes in the Najaf Sea from 2018 to 2025 using NDWI, SVM, GIS, and Sentinel-2 images, (ii) assess how the climate change and human activities influence the water bodies through change detection, and (iii) provide evidence-based data to support the sustainable water management, environmental conservation, and improved practice decision-making.

II. METHODOLOGY

A. Study area

In Najaf City, southern Iraq, there is a seasonal water body known as the Najaf Sea or Lake Najaf [5]. Najaf Sea is a seasonal water body situated southwest of Najaf, near the western border of the Euphrates River [25]. Its elevation ranges from 22 m to 25 m above sea level. The water level influences its size, expanding from 300 km² during the wet season to a smaller area in dry periods [26]. The surrounding landscape consists of semi-arid deserts with extensive limestone and gypsum outcroppings [27]. The climate is characterized by high evaporation rates, ranging from arid to semi-arid conditions, with summer temperatures often exceeding 45°C and mild winters, along with a minimal annual rainfall of 100–150 mm. The lake is replenished by groundwater seepage, rainfall, and occasional flow from the Euphrates River. The water levels fluctuate seasonally, rising during the wet season due to increased Euphrates flow and rainfall, and then decreasing due to evaporation, which can sometimes cause parts of the lake to dry up [3]. Nearby aquifers contribute to the lake's water supply by providing groundwater that helps maintain the water levels [28]. However, the climate change, with its rising temperatures and altered precipitation patterns, poses a threat to the water availability [29].

Figure 1 shows the location of the Najaf Sea in the southwestern part of Najaf province, Iraq. The Najaf Sea, a

significant water body, faces numerous threats. Effective water resource management solutions are essential in that area due to its geographic location, shifting flow patterns, and environmental challenges that endanger the ecosystems and inhabited regions.

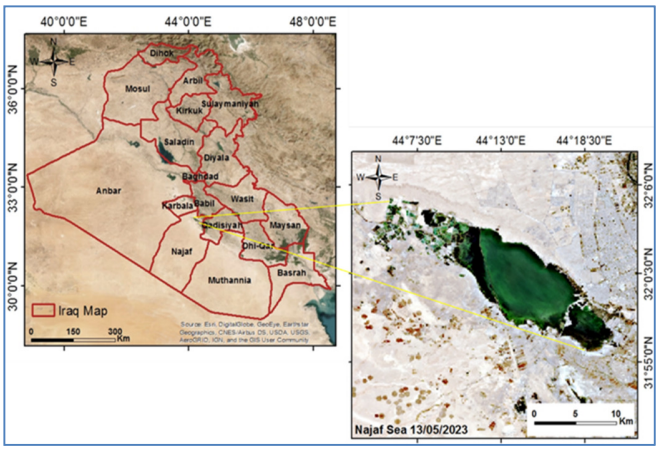

Fig. 1. Location of Najaf Sea in Najaf province, Iraq.

B. Dataset

The research incorporates RS, GIS, and AI to identify and analyze the environmental changes at the Najaf Sea from a sustainability perspective. The dataset attributes employed in the study are displayed in Table I.

TABLE I. THE SENTINEL-2 DATASET ATTRIBUTES

Image name	Sensing date	Image resolution	Cloud cover	Coordinate system
Sentinel-2_L2A	15-12-2018	Lat.: (2.9sec/px) Long.: (3.4sec/px)	0%	WGS 84
Sentinel-2_L2A	30-11- 2019	Lat.: (2.9sec/px) Long.: (3.4sec/px)	0%	WGS 84
Sentinel-2_L2A	14-12-2020	Lat.: (2.9sec/px) (3.4sec/px)	0%	WGS 84
Sentinel-2_L2A	14-11-2021	Lat.: (2.9sec/px) Long.: (3.4sec/px)	1.3%	WGS 84
Sentinel-2_L2A	19-11-2022	Lat.: (1.3sec/px) Long.: (1.5sec/px)	0.1%	WGS 84
Sentinel-2_L2A	13-05-2023	Lat.: (1.4sec/px) Long.: (1.7sec/px)	0.2%	WGS 84
Sentinel-2_L2A	11-02-2025	Lat.(1.3sec/px) Long.:(1.5sec/px)	0%	WGS 84

C. Processing

Multiple periods of Sentinel-2 satellite imagery were obtained from the ESA to monitor the long-term changes. Additional information was gathered through hydrological records and meteorological data. Rainfall data were sourced from an online application focused on renewable energy and agroclimatology [30].

The water extraction used NDWI, preprocessing, and an SVM classifier, which is an effective supervised learning technique for image classification. It performs well with high-dimensional data and provides clear separation between the land cover classes. Images were obtained from Sentinel Hub, covering the period from 2018 to 2025 (Table I). NDWI was used from 2018 to 2023, while SVM classification was applied to the 2025 Sentinel-2 image to analyze the recent changes between water and non-water areas. The NDWI values from Sentinel-2 help identify the water bodies, and SVM aids in distinguishing water from other surfaces. The multi-temporal analysis compares the water masks derived from NDWI over different periods to detect the spatial changes. Supervised classification algorithms detect the landscape changes, while the temporal analysis evaluates the water extent over short and long periods, aiding in understanding the environmental patterns.

III. RESULTS AND DISCUSSION

The time-series analysis of Sentinel-2 images reveals essential information about the environmental changes [31, 32]. Figure 2 displays the Sentinel-2 maps of Najaf Sea. These images, compiled as a series, illustrate the changes in Najaf Sea, Iraq, based on Sentinel-2 data captured from December 2018 to May 2023. The images reveal changes in the water size, color, and land over time. The surface area of water fluctuates significantly in size and shape. A notable reduction in the large water body was observed in November 2019, possibly indicating a drought or a reduced water supply. Water recovery became evident in November 2021, marked by an increase in the water extent. In 2022, the water shifted from a deep green to a pale and blue-green hue, likely reflecting changes in sediment, algae, and water quality.

The images show uneven vegetation around the lake. Green areas are more prominent in water surface observations from 2020 and 2021, suggesting that vegetation was present due to water availability during these periods. The year 2019 is especially known for its dry landscapes caused by arid conditions. The color variations in the area may be influenced by the natural seasonal rainfall, as well as water extraction activities associated with the agricultural development and urban expansion. Lower rainfall levels, combined with the changes in water policies, appear to have contributed to the lake's water depletion during late 2022 and early 2023 [22].

According to Figure 3, the NDWI mapping of Najaf Sea uses Sentinel-2 satellite images from various dates between December 2018 and May 2023. Using the NDWI RS technology, one can improve the water body detection by analyzing reflectance data from the NIR and SWIR bands. The image illustrates the extent and variability of the water bodies, with blue areas representing water, and displays temporal changes in their spatial distribution. The water coverage varies significantly over time; some years, like 2019, show a reduction in water, whereas other years, such as 2020-2021, exhibit an expansion (Figure 3).

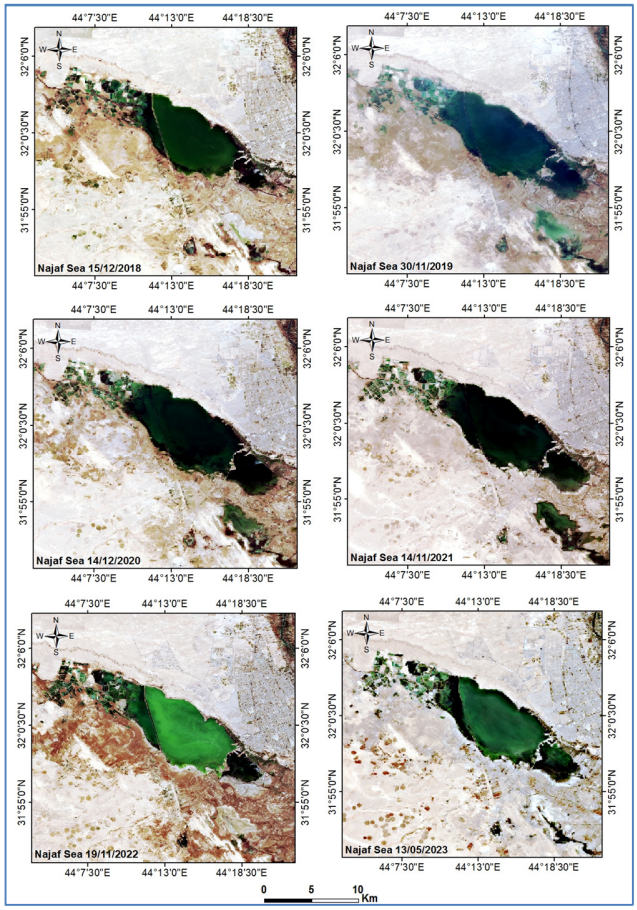

Fig. 2. Sentinel-2 maps of the Najaf Sea for the period 2018-2023.

The data show that the water levels remained steady from 2020 to 2021, then declined in 2022 and peaked significantly in 2023. The image visualizes the vegetation changes through its green color scale, which depicts the density patterns around the water body. The NDWI values indicate variations in the water body, likely due to seasonal patterns or climate trends. The water body improvement in 2020-2021 may have resulted from the increased precipitation, changes in hydrological inputs, and potential restoration efforts. The reduced water extent during 2022-2023 seems to have been affected by either drought conditions or the combined effects of the high evaporation rates and human water extraction activities.

Figure 4 portrays the hydrological data collected from 2018 to 2022. The hydrological data were obtained from [30], which included monthly and annual rainfall data covering the period from January 1, 2018, to December 31, 2022. The location is situated in the center of the lake, with a latitude of 32.02° and a longitude of 44.11°, based on the Modern-Era Retrospective analysis for Research and Applications (MERRA-2).

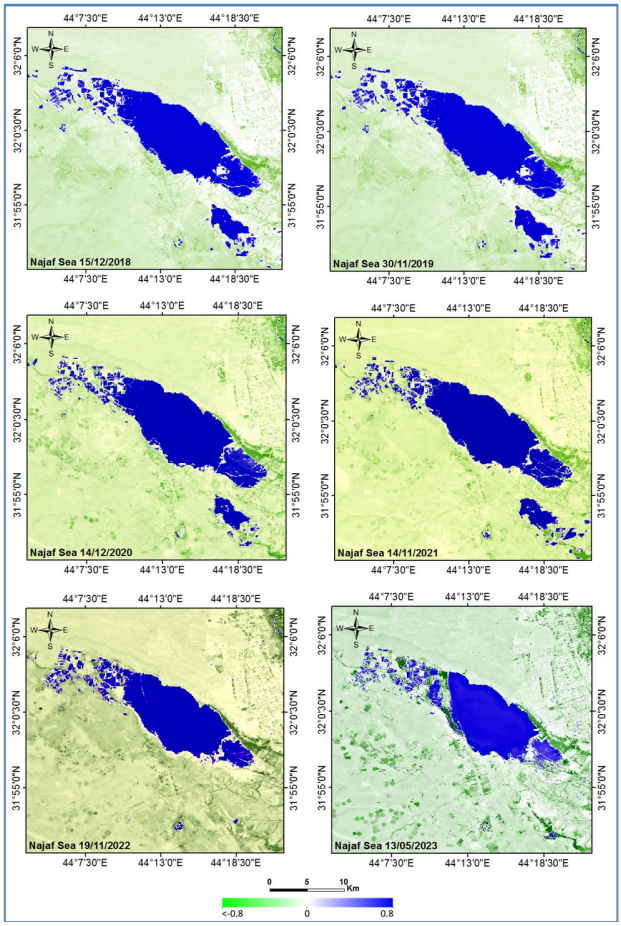

Fig. 3. NDWI maps of Najaf Sea for the period 2018-2023.

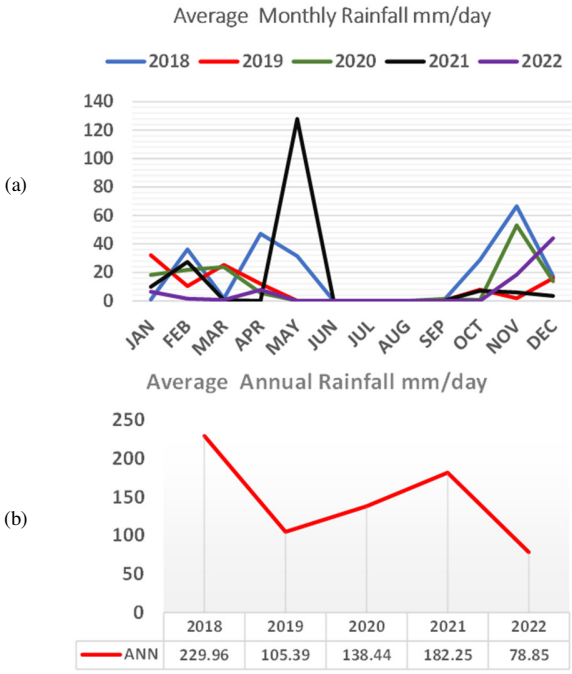

Fig. 4. Hydrological data collected from 2018 to 2022: (a) average monthly rainfall, (b) average annual rainfall.

In 2025, there seems to be some recovery in the water area, as shown in Figure 5, which displays the NDWI and SVM maps. The water body replenishment becomes possible through the increased rainfall and seasonal variability caused by the natural changes in weather patterns and shifting climate conditions. The excessive rainfall in late 2024 or early 2025 increased the surface runoff and consequently filled lakes and reservoirs. The water tables increase gradually during periods of higher rainfall or when the water extraction decreased. The water availability in 2025 is expected to increase due to the improved water management, higher rainfall, effective groundwater recharge strategies, and more stable weather conditions. The investigation would need hydrological data, including rainfall, groundwater levels, and river flow measurements, to identify the exact contributing factor. The use of RS and AI to detect the environmental changes in the Najaf Sea shows the potential of advanced technologies in solving ecological problems. The combination of NDWI and SVM technologies, along with GIS, when applied to satellite imagery, creates a robust system for detecting the changes in the water bodies and their associated environmental impacts [33, 34].

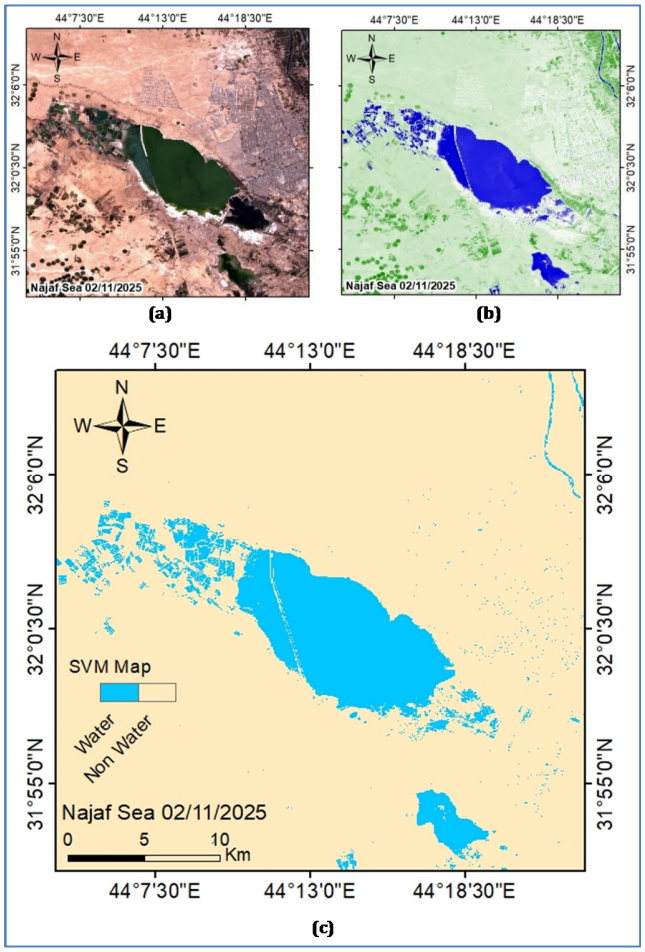

Fig. 5. Classification in 2025: (a) Sentinal-2 map, (b) NDWI map, (c) SVM map.

The findings of this research produce positive socio-economic benefits for the people living near the Najaf Sea. Sustainable water resource management enables the domestic, industrial, and agricultural sectors to access water, thereby promoting economic growth and improving residents' living standards.

IV. CONCLUSION

The environmental sustainability and ecosystem stability in the Najaf Sea region are supported by the significant findings revealed in this research. The paper outlines environmental guidelines along with strategies to reduce the climate change impacts and procedures for sustainable land use. Stakeholders collaborate with the community members through a structured process to implement sustainable solutions. This methodology incorporates multiple components to create a comprehensive framework for monitoring the environmental changes in the Najaf Sea, thereby improving its future survival prospects and sustainability performance. Using Normalized Difference Water Index (NDWI)-based analysis of Sentinel-2 imagery, combined with Support Vector Machine (SVM) analysis, proved to be a valuable tool for monitoring the surface water. Satellite monitoring provides vital insights into the changes in water extent in the Najaf Sea, given its essential role in environmental studies and water resource management. Future water body variability studies require the use of NDWI in conjunction with precipitation data when applying hydrological models for analysis. The present study encourages the local environmental agencies to utilize NDWI and Sentinel-2 imagery for the daily assessments of their water resources. Additionally, sustainable land use planning is promoted around the Najaf Sea to decrease the human stress on this water body.

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