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Effect of Climate Change on Wetland Areas in West Iraq Using Satellite Data and GIS Techniques

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Abstract

Iraq is considered to amongst those countries in the Middle Eastern region that are most exposed to the effects of climate change, which will have notable effects on wet areas and lakes. Natural or industrial water resources must be paid particular attention due to their importance in preserving environmental and biological systems, in addition to their economic and social importance. As a result of the effects of climatic change, water resources in Iraq have seen a multitude of changes. The aim of this study is to determine changes in the wetland area around AL-Razzaza Lake, Karbala province, Iraq, during the years 2000, 2005, 2010, 2015, and 2023. Landsat 5 satellite data from 2000, 2005, and 2010, and Landsat 8 and 9 data for 2015 and 2023, respectively, were used in this analysis, which was conducted using NDWI as a free, open-source program (ArcMap 10.8) to detect these changes; NDWI is a natural water anisotropy index used to detect the surface area of bodies of water in satellite images. The results revealed a clear decrease throughout the study period, as the wetland area of the lake in 2000 was 1189.7 km^2, which represents a decrease of 34.3% compared to the total area of the lake (1810 km^2); it decreased by 52.7% in 2005 (855.5 km^2) and continued to decrease for 2010, 2015, and 2023, by 79.2%, 80%, and 85%, (376.5 km^2, 362.9 km^2, and 270.4 km^2, respectively). The wetland area of Al-Razzaza Lake decreased between 2000 and 2023 by 919.3 km2, that is, an average of 40 km^2 per year. It was found that the lake wetland area sharply declined over the study period due to a lack of water surface resources via the Euphrates River, as well as climatic changes and poor water resource management. It is anticipated that the lake will lose more than half its current wetland area by 2040 if the current decline continues. These results are considered important in terms of preparing a strategic plan to preserve water bodies and wet areas in Iraq, including Al-Razzaza Lake. Remote sensing and GIS technologies have played a major and essential role in detecting such changes.

Keywords: AL-Razzaza Lake; GIS; Wetland Area; Satellite Data; NDWI; Remote Sensing.

1. Introduction

Climate changes directly affect wetland areas, and these changes are represented by rising temperatures that lead to increased evaporation, decreased rainfall, etc. [1, 2]. The past five decades are considered the highest temperatures since 1850, and the past decade from 2011 to 2020 is considered the highest temperature ever, and 2023 is considered the highest temperature year ever. Therefore, planners, researchers, implementers, and decision-makers must pay attention to the issue of the continuous rise in temperatures in general and the effects of these rises on wetland areas in particular [3, 4] (https://www.un.org/ar/climatechange/what-is-climate-change). In addition, human activities, represented by agricultural and industrial activities, affect the area of wetlands. The world's population growth continues, which leads to an increase in demand for food, water, and industry to meet the population's requirements, thus increasing water consumption [5, 6].

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Iraq is considered among those countries in the Middle Eastern region that are most exposed to the effects of climate change [7–10]. Bodies of water or lakes are considered to be worthy of special attention because preserving them has a positive impact on ecosystems, especially in areas that experience desert or semi-desert climates, like Iraq [11–13]. Water resources in Iraq have suffered from many changes due to a variety of factors, most notably climate change, represented by decreased rainfall and high temperatures, which have resulted in increased evaporation; consequently, the wetland areas associated with such resources have decreased [14]. The Tigris and Euphrates rivers are the basic sources of drinking water and irrigation, as well as energy production, etc., in the region; in addition, though, a group of natural and artificial lakes and reservoirs are spread throughout Iraq, which are supplied with water from these rivers for storage purposes during flood seasons, in order to both mitigate the effects of flooding in addition to taking advantage of the water so stored at some later point [15].

Reviewing studies related to lakes and bodies of water is very important because water is the basis of animal, plant, and indeed human life [16]. Many researchers have used remote sensing techniques to study the impact of climate change on water bodies and wet areas [17–24]. Such efforts have included remote sensing with GIS to detect changes in the area of lakes and wetlands [25–31]. The importance of water resource management has also been extensively studied [32–37]. The subject of studying the impact of climate changes on the area of wetlands must be on an ongoing basis in order to know the path of these changes and thus reduce their negative effects as much as possible. Most previous studies on changes in the area of wetlands of Al-Razzaza Lake did not address the cause of these changes clearly and the solutions that must be followed by decision makers to limit these changes, and this will be explained in this study.

The importance of using remote sensing devices, represented by satellite images, with geographic information systems techniques, which process this data, lies in their ability to determine the changes that occur for land cover, especially water marshes or lakes, for very large areas as well as over very long periods of time, thus saving effort, cost, and reducing the time required for researchers, planners, and decision makers to manage and sustain land, including water [38, 39]. Remote sensing can be defined as a technology and science that consists of obtaining information about an object located on the surface of the Earth without the need for invasive study, as achieved through the use of various regions of the electromagnetic spectrum [40].

Geographic information systems are integrated computer systems that enable users to collect, store, analyze, and display geographical and spatial information (related to the locations and geographic distribution) of various phenomena on the Earth's surface. These systems are an effective tool for understanding the relationships and interactions between spatial and geographic elements and making appropriate decisions in fields such as urban planning, sustainable development, environmental sciences, and indeed others. This geographic data includes, for example, maps, aerial photographs, terrain, demographic, economic, regulatory, and other data [41-43].

The aim of the study is to detect changes in the wetland area of AL-Razzaza Lake for the period from 2000 to 2023 in order to develop the necessary solutions that will allow decision makers to reduce the impact of these changes.

2. Study Area

Al-Razzaza Lake is a body of water located divided between the governorates of Karbala and Anbar, found within latitude 32°27'00" to 34°00'00" North and longitude 43°05'00" to 44°10'00" East. It is supplied with water from the Euphrates River, and is considered the second-largest lake in Iraq. It is part of a wide valley that includes Lakes Al-Tharthar and Al-Habbaniya, and the Sea of Najaf. Its total area is estimated to be 1810 km^2, and its total storage capacity is 26 billion m^3, with a maximum storage level 40 meters above sea level [28, 29]. Figure 1 illustrates the graphical location of the lake.

Al-Razzaza Lake was previously large and deep, but its water level has decreased significantly over the past two decades until its total depth is now only in the region of 5-10 meters. As a result, the salinity of the water in the lake has increased significantly. Therefore, its water cannot be used for agricultural or industrial activities [23]. Al-Razzaza Lake was actually only indirectly supplied with water from the Euphrates River through Lake Habbaniyah. However, over the last few decades, these supplies have decreased significantly, and the lake has become far more dependent on rainfall, springs, and groundwater to maintain its current level, in addition to the sewage water mixed with agricultural drainage water that is pumped into the lake through a canal located in the north of Karbala Governorate [23, 44]. The water of Al-Razzaza Lake is considered to have a high salinity, especially the water located in the northern part of the lake, while the water located in the southern part of the lake is of lower salinity due to mixing with these various wastewaters. Despite this high salinity, the lake water is still suitable for the irrigation of crops that can tolerate such conditions [44–46]. The importance of Al-Razzaza Lake lies in it being one of the important bird areas in Iraq, in addition to its importance in preserving biological diversity. It is considered a wetland of international importance [47].

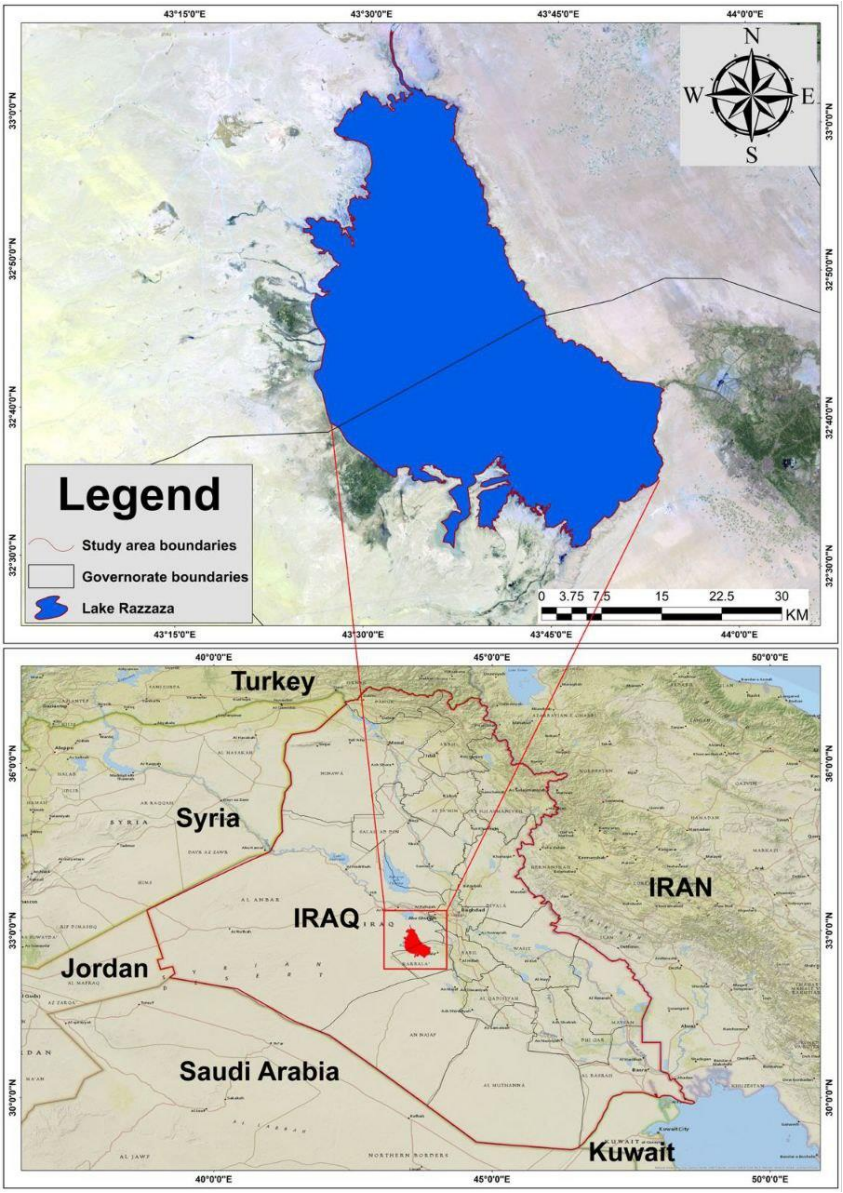


Figure 1. Location of AL-Razzaza Lake in central Iraq

3. Methodology

3.1. Data Collection

Satellite data provided by the US Geological Survey (USGS) website was used, where five satellite images were downloaded for the years 2000, 2005, 2010, 2015, and 2023, the details of which are reported in Table 1.

Table 1. Information on satellite data utilized in the study

Date of photography		Sensor	Sensor Type	Spatial Resolution	Number of Bands	Format
2000	11 / 11 / 2000	Landsat 5	TM	30m	7	Geo TIFF
2005	24 / 10 / 2005	Landsat 5	TM	30m	7	Geo TIFF
2010	30 / 11 / 2010	Landsat 5	TM	30m	7	Geo TIFF
2015	21 / 11 / 2015	Landsat 8	OLI-TIRS	30m	7	Geo TIFF
2023	10 / 11 / 2023	Landsat 9	OLI-TIRS	30m	7	Geo TIFF

The importance of satellite images lies in their ability to allow the spatial distribution of land cover types to be straightforwardly determined, including water bodies and lakes, with a wide frame and high spatial accuracy. It is also possible through satellite images to study changes in various terrestrial phenomena, including floods and droughts, in addition to the possibility of recording changes in these phenomena in the form of data, and on a permanent basis, so that changes in such can be studied at some later date [48-50].

3.2. Satellite Image Processing

In this study, the free, open-source program ArcMap 10.8 was used. The aim of processing satellite images prior to use in classification or analysis processes is to optimize the results drawn from those images in terms of accuracy. The initial satellite images, or preprocessed satellite images, will generally contain certain defects that must be addressed before use. In addition, there are other detailed steps involved in processing such images, such as improving and classifying them, and the final preparation of the spatial information and maps extracted from the satellite images [51].

Preprocessing of satellite images includes geometric correction, radiometric correction, atmospherics correction, and noise removal [52-54].

Geometric correction: This is used to correct distortions in the satellite image that occur due to the effects of the satellite's speed, as well as the effects of the displacement that occurs on the satellite image resulting from the terrain, and of the refraction of rays through the various layers of the atmosphere. Therefore, satellite images will contain certain geometric distortions that must be treated and removed prior to using the satellite image for the required purpose [55].

Radiometric correction: Satellite images are affected by anomalies that can cause radiation distortions, such as errors in sensors or the effects of atmospheric layers. Radiometric correction deals with the sources of these errors to overcome any distortions that may be present in the raw images [56].

Atmospherics correction: This is the removal of atmospheric effects from remote sensing data, and which arise from the scattering and absorption of sunlight by particles in the atmosphere. This leads to improved quality in the images captured of the Earth's surface and even greater accuracy in terms of classification of Earth-based objects [57].

Noise removal: The computer program applies certain mathematical equations and algorithms to remove any noise or other distortions that may have occurred during the sensing process itself [58].

Figures 2 to 4 show the satellite images used in the study in 2000, 2005, 2010, 2015, and 2023.

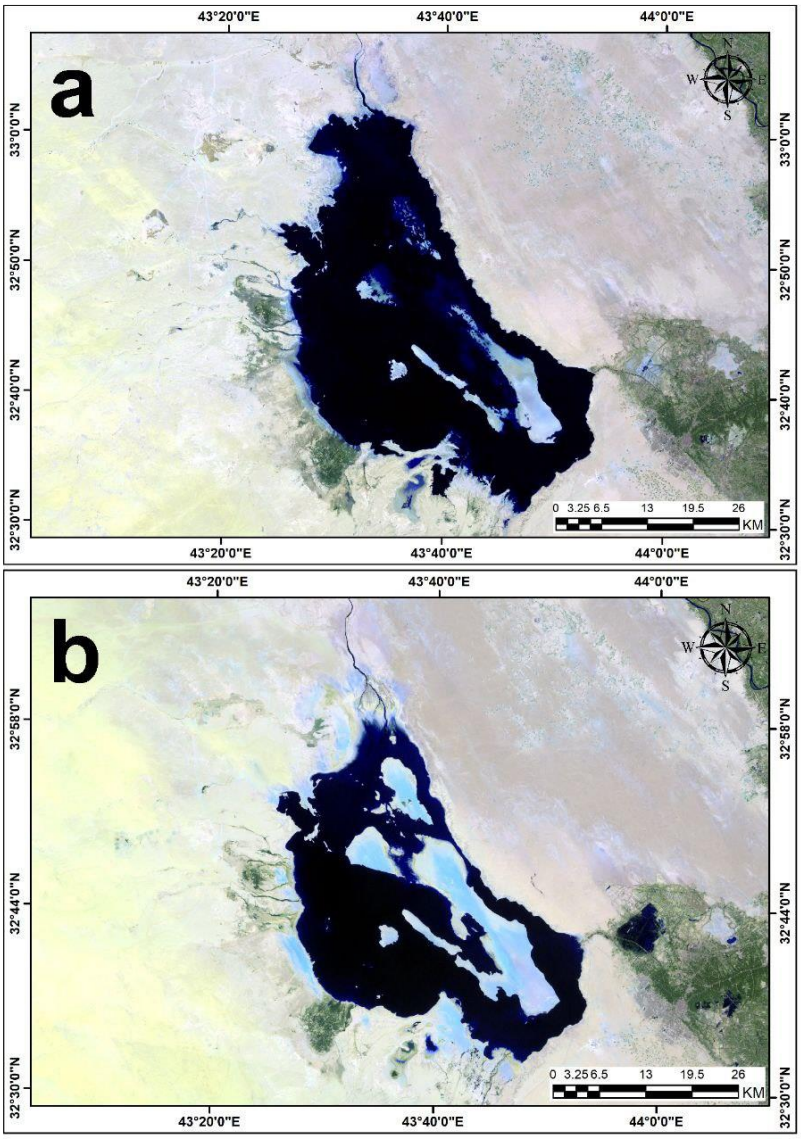


Figure 2. Satellite images utilized in the study: (a) in 2000, and (b) in 2005

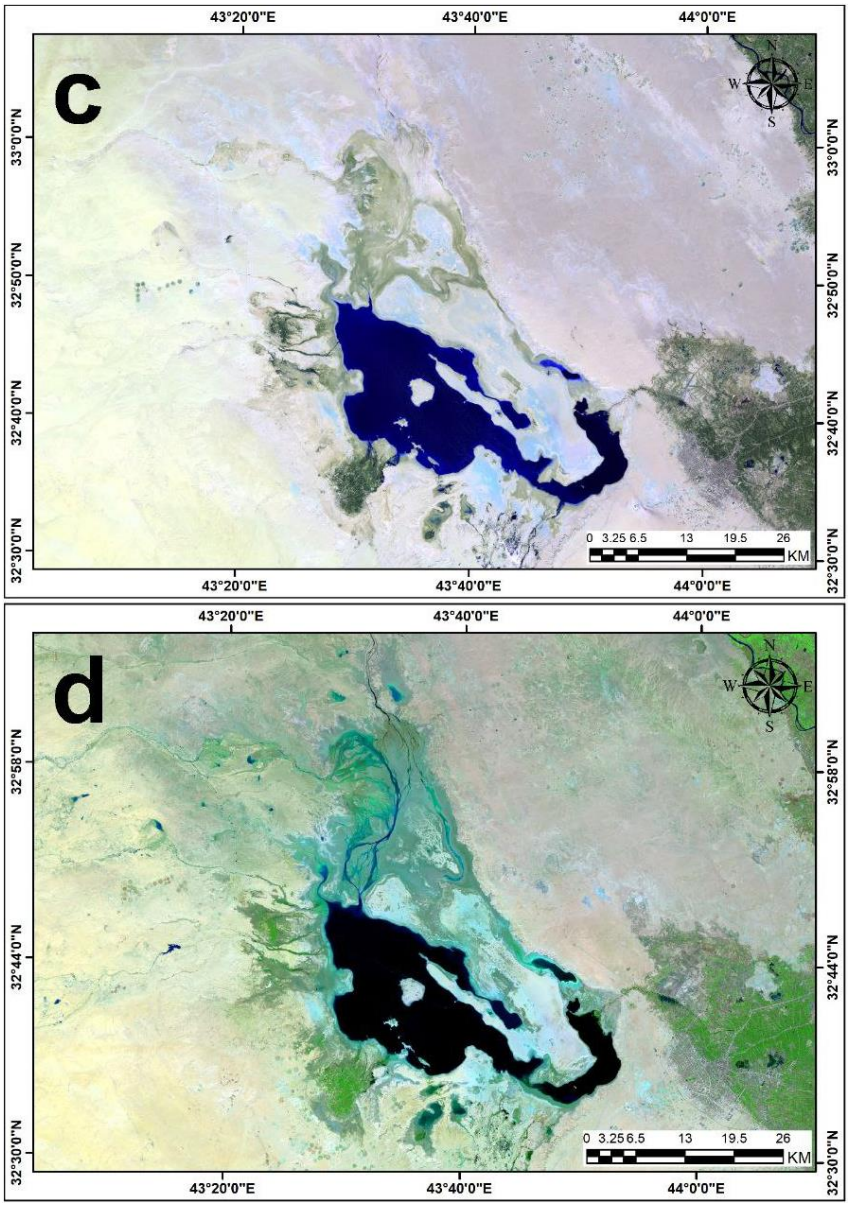


Figure 3. Additional satellite images utilized in the study: (c) in 2010, and (d) in 2015

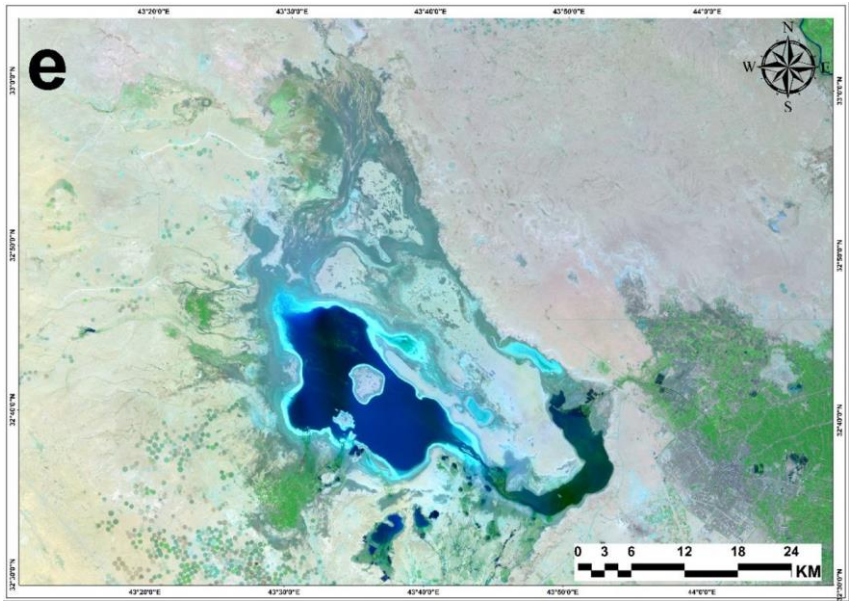


Figure 4. Satellite images utilized in the study: (e) in 2023

3.3. Image Enhancement

The main aim of improving digital satellite images is to facilitate the process of image interpretation of the images derived from the original corrected images, such as to make them more suitable to the interpretation and analysis of targets and ground features by increasing the distinctions between image features [59].

3.4. Normalized Difference Water Index (NDWI)

In this study, the NDWI was used to distinguish wetland areas from the rest of the lake's surface features, and which can be calculated according to the following equation [60, 61]:

$$\text{NDWI} = \frac{\text{Band Green} - \text{Band NIR}}{\text{Band Green} + \text{Band NIR}} \quad (1)$$

The application for the TM sensor is as follows:

$$\text{NNDWI} = \frac{\text{Band2} - \text{Band4}}{\text{Band2} + \text{Band4}} \quad (2)$$

And for the TIRS-OLI sensor:

$$\text{NDWI} = \frac{\text{Band3} - \text{Band5}}{\text{Band3} + \text{Band5}} \quad (3)$$

This indicator is amongst those that help to monitor the condition of surface water masses and distinguish them from other terrestrial features. The value of this indicator ranges between 0 and 1. Values that are greater than zero indicate water surfaces, while values that are less than or equal to zero indicate non-water surfaces [62]. This indicator was applied to the images used in this study. Figure 5 shows an outline of the methodology used in the current study.

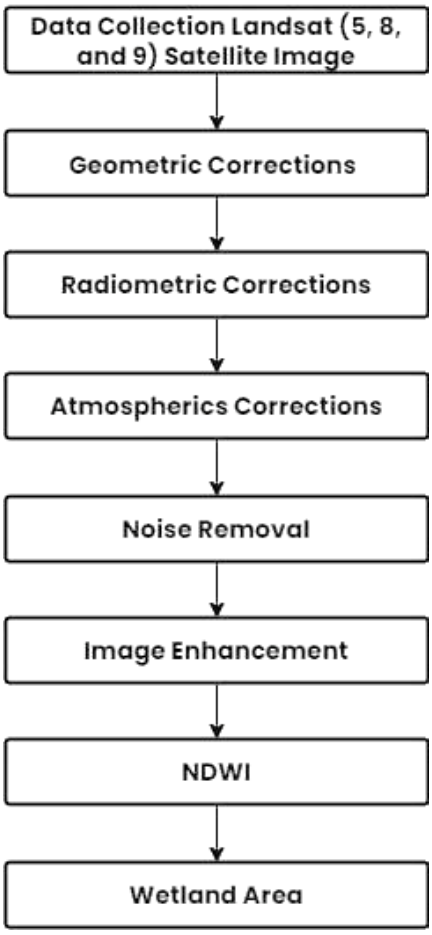


Figure 5. Outline of the methodology used in the current study

4. Results and Discussion

The NDWI was used for the purpose of calculating the wetland area of AL-Razzaza Lake for the years 2000, 2005, 2010, 2015, and 2023, where the area of the lake's water borders in the satellite image for 2000 was adopted as the basis for comparison for the changes to the wetland area of the lake during the subsequent years considered. These were calculated the area was (1344.9 km^2), and that area includes (1189.7 km^2 water) and (155.2 km^2 land located in the middle of the lake). The results indicate that the wetland area of AL-Razzaza Lake for 2000, 2005, 2010, 2015, and 2023 was 1189.7 km^2, 855.5 km^2, 376.5 km^2, 362.9 km^2, and 270.4 km^2, respectively. These results were compared with the results by previous studies of the researchers [15, 23]. By using the ratio and proportion of the calculated areas of Al-Razzaza Lake during the years of those studies with the years of this study, it was found that they roughly match each other.

Table 2 reports the wetland area and the water-free land area of AL-Razzaza Lake, while Table 3 reports the total area, wetland area, and percentages of lost and remaining wetland areas of AL-Razzaza Lake. Figure 6 shows the change in the wetland area of AL-Razzaza Lake during the period between 2000 and 2023. The results indicate a continuous decrease in the area of the lake's wetlands during the study period.

Table 2. The wetland area and the water-free land area of AL-Razzaza Lake

	2000	2005	2010	2015	2023
Water (km^2)	1189.7	855.5	376.5	362.8	270.4
Land (km^2)	155.2	489.4	968.4	982.1	1074.5
Total (km^2)	1344.9	1344.9	1344.9	1344.9	1344.9

Table 3. The total area, wetland area, and percentages of lost and remaining wetland areas of AL-Razzaza Lake

No.	Year	The total area of AL-Razzaza Lake (km^2)	The wetland area of AL-Razzaza Lake (km^2)	Percentage of the lost wetland area of AL-Razzaza Lake (%)	Percentage of the remaining wetland area of AL-Razzaza Lake (%)
1	2000	1810	1189.7	34.3	65.7
2	2005	1810	855.5	52.7	47.3
3	2010	1810	376.5	79.2	20.8
4	2015	1810	362.9	80	20
5	2023	1810	270.4	85	15

The SPSS statistical program was used to predict future changes in the wetland area of Al-Razzaza Lake. Figure 7 illustrates the relationship between the wetland area of AL-Razzaza Lake (Y) and time period (X), from which it is clear that there is a significant decrease during the study period and which continues to decrease thereafter.

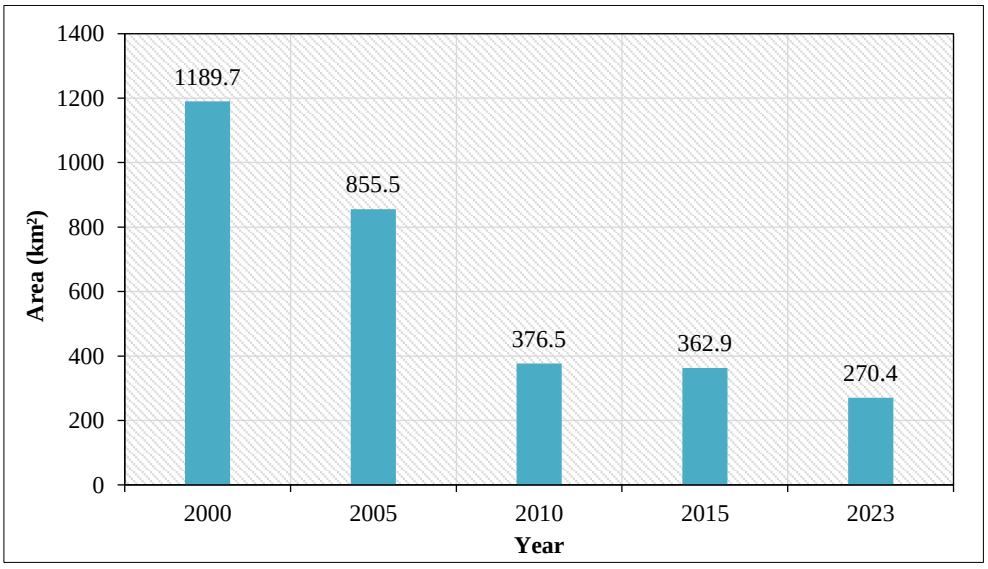


Figure 6. The change in the wetland area of AL-Razzaza Lake during the period between 2000 and 2023

Figure 8 shows the wetland area of AL-Razzaza Lake (a) in 2000, (b) in 2005, whilst Figure 9 shows the wetland area (c) in 2010, and (d) in 2015, and Figure 10 shows the wetland area (e) in 2023. It appears that the decrease in the area of the lake's wetlands began around the northern region of the lake in 2005; by 2010, however, this decrease had spread from the northern region of the lake to encompass the eastern part. In 2015, it became clear that there had been

only a relatively small decrease, and the shape of the lake did not differ much from that in 2010. Finally, in 2023, the decline in the northern and eastern regions of the lake could be seen to have continued, with a relatively small increase in the southern part of the lake due to the mixed wastewater being pumped into it.

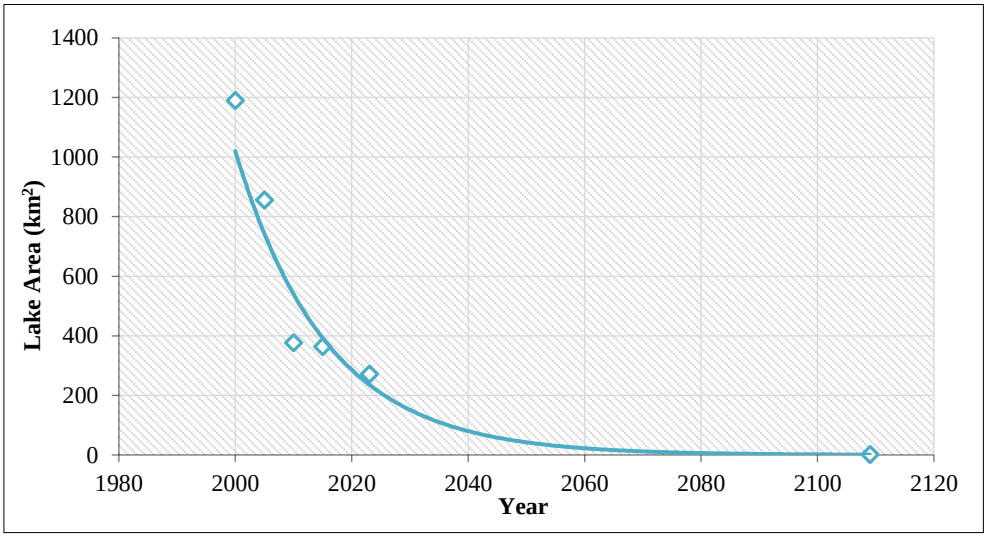
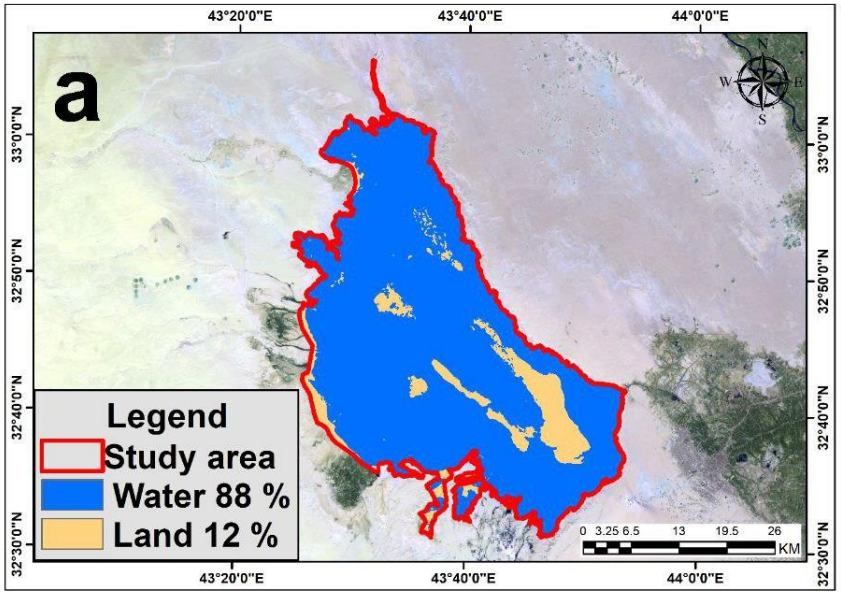


Figure 7. Illustration of the relationship between the wetland area of AL-Razzaza Lake (Y) and time period (X)

The results of the NDWI analysis were verified by using satellite images related to the study, where the area of the lake was calculated in those images for the years 2000, 2005, 2010, 2015, and 2023. They were compared with the results of the NDWI analysis, and it was found that the wetland areas of Al-Razzaza Lake in both methods are similar. Satellite images have been verified using the Gogol Earth program, where pictures of the lake were downloaded for the required study years, and the area of the lake was calculated in each picture [63]. It was found that these areas are close to the areas of the lake that were calculated using satellite images. Visited the lake site at the end of the year 2023, and the satellite images and Google Earth images were roughly matched with the reality of the situation in parts of the lake's borders. It was found that the images roughly match the reality of the situation. The lake site was also visited in the middle of the year 2024, through observing the lake's shoreline, it was concluded that there was a slight decrease in the lake's area. After cross-checking with the available observed data from the meteorological stations, all the climate data (temperature and precipitation) for the selected meteorological stations near the lake was downloaded and used from NASA's website. The climate data results were consistent with a clear decrease in the lake area. Temperatures increased and rainfall decreased during the observed period.

The main reason for the relatively large decreases in the northern and eastern regions compared to the rest of the lake is simply because the level of the lake bottom in the northern and eastern regions is higher than in the western and southern regions. The study's results provide a fresh perspective and crucial insights for decision-makers and engineering planners, enabling them to explore innovative strategies to halt the decline of wetlands in Iraq, which is a result of climate change and water scarcity. Boosting water income from Lake Habbaniyah and the Euphrates River, along with the potential to utilize large amounts of treated water (tertiary treatment), could revitalize Lake Al-Razzaza.



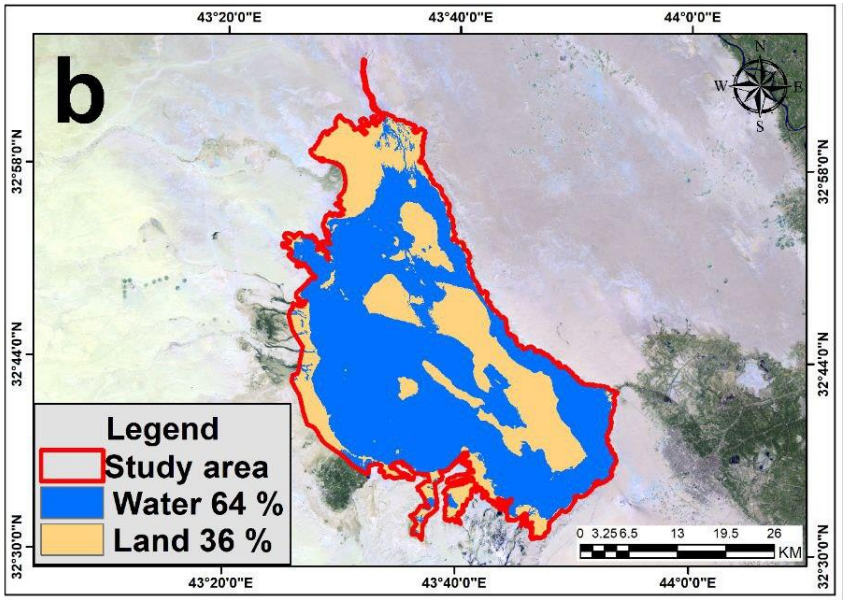


Figure 8. The wetland area of AL-Razzaza Lake: (a) in 2000, and (b) in 2005

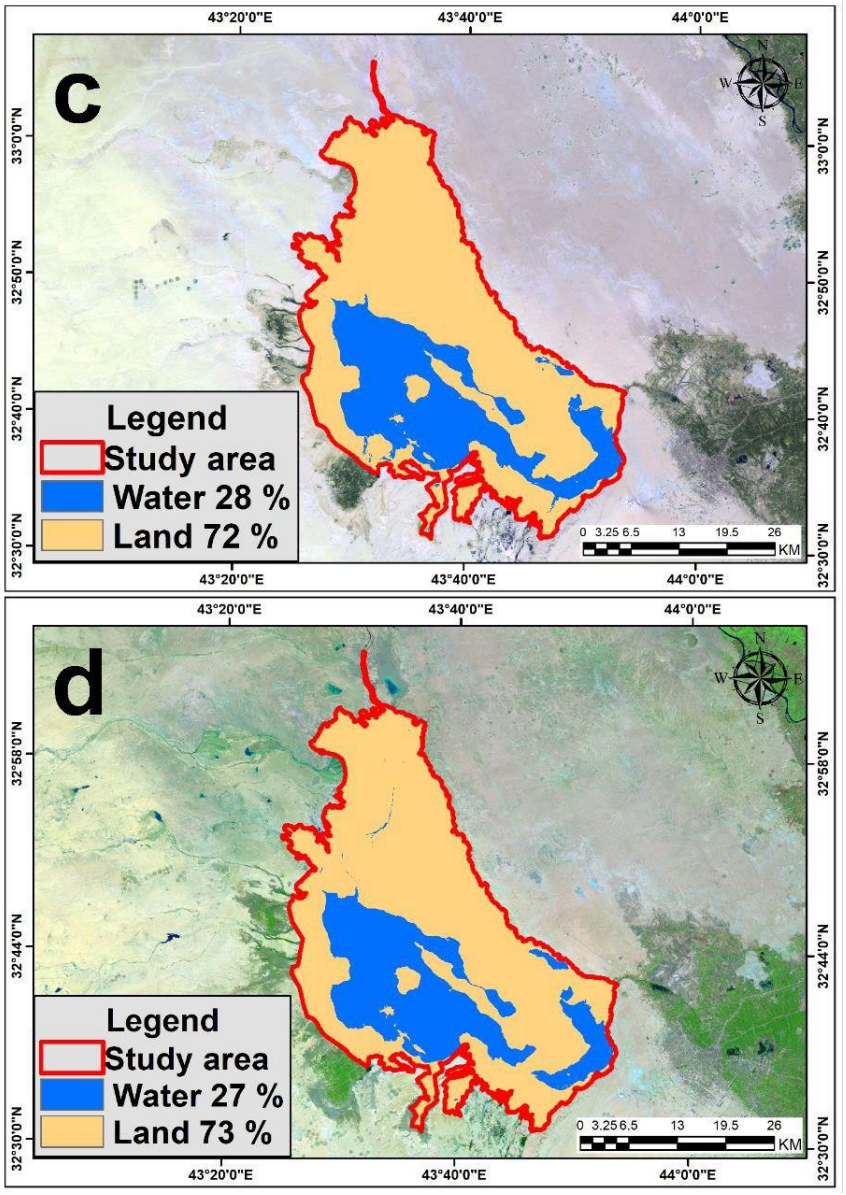


Figure 9. Shows the wetland area of AL-Razzaza Lake: (c) in 2010, and (d) in 2015

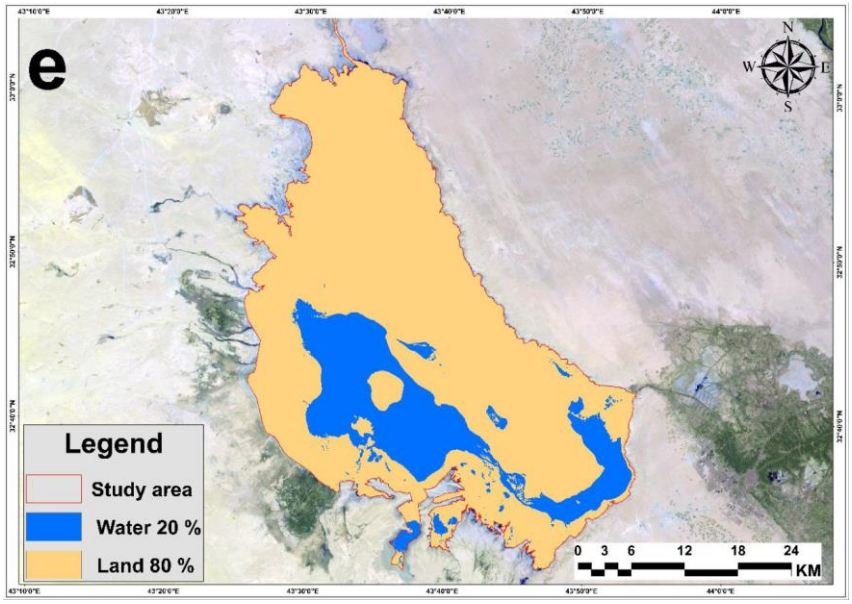


Figure 10. Shows the wetland area of AL-Razzaza Lake: (e) in 2023

5. Conclusion

Remote sensing data and GIS were used to detect changes in the wetland area of Al-Razzaza Lake during the period between 2000 and 2023. This study revealed significant changes in the wetland area of Al-Razzaza Lake over the study period, with the wetland area in 2000 standing at 1189.7 km^2, which was already considered low at 34.3% of the lake's total area of 1810 km^2. By 2005, the wetland area decreased by 52.7% of the total area of the lake, declining to 855.5 km^2, a trend that continued in later years with decreases for 2010, 2015, and 2023 of 79.2%, 80%, and 85%, declining to 376.5 km^2, 362.9 km^2, and 270.4 km^2, respectively. In absolute terms, the wetland area of Al-Razzaza Lake decreased between 2000 and 2023 by 919.3 km^2 or an average of 40 km^2 per year.

The reasons for the continuous decrease in the lake's wetland area are the lack of water reaching it from Al-Habbaniya Lake and poor water resource management, as well as climate change, as represented by the reduced amounts of rainfall and rising temperatures that lead to increased evaporation. The study period revealed a sharp decline in the lake's wetlands area, with projections indicating that without any changes, the lake could lose more than half of its current area by 2040. These findings are considered critical to the preparation of a strategic plan to preserve water bodies and wet areas in Iraq, including Al-Razzaza Lake. In order to preserve what remains of AL-Razzaza Lake, decision-makers must increase water release from AL-Habbaniya Lake, as well as reduce the use of groundwater in the areas surrounding the lake. It also becomes clear from this study that remote sensing techniques and GIS have played a major and essential role in detecting changes in land cover patterns, especially water, during the study period.

6. Declarations

6.1. Author Contributions

Conceptualization, S.T. and W.H.; methodology, W.H.; software, S.T.; validation, W.H., S.T., and M.H.; formal analysis, S.T.; investigation, W.H.; resources, M.H.; data curation, S.T.; writing—original draft preparation, S.T.; writing—review and editing, W.H.; visualization, S.T.; supervision, W.H. and M.H.; project administration, W.H.; funding acquisition, S.T. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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