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Using of Different Satellite-Derived Indices to Detect the Spatiotemporal Changes of the Al-Razzaza Lake, Iraq

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Abstract

Remote sensing and GIS applications (Geoinformatics tools) involve a wide range of techniques for providing a solution for future water resources management and offer an excellent means to improve knowledge of sustainable planning. Al-Razzaza is the second largest lake in Iraq; it is a common source of fishery fortune and floodwater reservoir in southwestern Iraq. In recent years, the lake faced a noticeable amount of desiccation, which is considered a threat to the biodiversity and wildlife of the lake. The study aimed to detect the Lake's spatiotemporal changes from 1988 to 2018. Multi satellite-derived indices were investigated for the extracting of the lake water body. Results showed that the lake volume decreased by about 30% from 1990-2002, while it was about 70% from 1990-2014. A slight rise in the lake area was recorded in 2016 by about 40% compared with 2014. The accurate measurement was achieved to find a method showing the spatiotemporal aspects of lake changes.

Keywords: Changes detection, Vegetation index differencing, Water indices (WI_s), Geoinformatics tools, Al Razzaza Lake.

استخدام مؤشرات مختلفة مشتقة من الاقمار الصناعية للكشف عن التغيرات الزمانية المكانية لبحيرة الرزازة، العراق

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الخلاصة

تتضمن تطبيقات الاستشعار عن بعد ونظم المعلومات الجغرافية GIS (الجوماتكس) مجموعة واسعة من التقنيات لتوفير حل لإدارة موارد المياه في المستقبل وتوفر وسيلة رائعة لتحسين المعرفة والتخطيط المستدام. الرزازة هي ثاني أكبر بحيرة في العراق ، وهي مصدر مشترك للثروة السمكية ، وخزان لمياه السيول في جنوب غرب العراق. في السنوات الأخيرة ، واجهت البحيرة مدى ملحوظًا من الجفاف الذي يعتبر تهديدًا للتنوع البيولوجي والحياة البرية في البحيرة. كان الغرض من الدراسة هو الكشف عن التغيرات الزمانية المكانية للبحيرة خلال الفترة من 1988 إلى 2018. تم فحص المؤشرات المشتقة من الأقمار الصناعية المتعددة لاستخراج الجسم المائي للبحيرة. أشارت النتائج إلى أن تناقص حجم البحيرة بلغ حوالي 30٪ خلال الفترة 1990–2002 ، بينما كان حوالي 70٪ في 1990–2014. تم تسجيل ارتفاع طفيف في منطقة البحيرة في عام 2016 بنحو 40٪ مقارنة بعام 2014. تم تحقيق القياس الدقيق من أجل ايجاد نموذج يوضح الجوانب الزمانية المكانية للتغيرات الحاصلة في البحيرة

1. Introduction

Detecting environmental change in an area is intended to identify differences in the studied area through monitoring during different periods. Change detection is the key to determining seasonal effects of phenomena using time-series datasets and is considered the essential application of remotely sensed data obtained from satellite images [1].

As an essential source for change detection-survey, Remote Sensing (RS) data has appointed those changes in the goal, where the reflectance properties of an object would change, in addition to the effect of factors like atmospheric status, illumination, viewing angles, and soil moistures on the spectral behavior (reflectance or local texture) [2]. The main goal of creating Al-Razzaza Lake was to relent flood water, and many researchers studied this area using different techniques and methods. They were trying to make new models that detect spatiotemporal changes. One of the studies covering pre-processing, processing, and post-processing stages with supervised classification showed a significant change in the lake surface area in the same period covered by current work [3]. Another contribution was extracted from thematic maps with five classes which showed that the Al-Razzaza lake area decreased by 86.21% in 2018 using supervised classification with the support vector machine method (SVM) [4]. Many satellite-derived indices like normalized difference water and normalized difference vegetation index were tested to differentiate lake surface water, showing a rapid decrease in the lake area [5].

In the last 20 years, many image processing algorithms have been checked by: visual analysis, algebraic, transformation, Geographical Information systems, and other approaches [1]. These techniques were applied to detect water features by remote sensing data; the feature extraction technique represented a perfect water feature extraction approach [6]. Furthermore, it is a good idea for such environment analysis, monitoring shifting cultivation, assessing deforestation, and finding differences in the state of an object or phenomena [7]. Spectral indices have been widely used as an indicator of change detection due to their easy usage and link with many ecosystem features. For example, the normalized difference vegetation index (NDVI) value that is derived from (MODIS) sensor can be used as a simple and suitable way to control drought in Iraq [8]. In addition, using Spot (Multi-temporal data) to monitor the Nile rose plant growth using NDVI [9].

The matching of the Standardized Precipitation Index (SPI) and NDVI helped determine the selected area for drought risks. In 2011, B. Killough and J. Keyes (Committee on Earth

Observation Satellites) showed that many conditions could affect NDVI values, such as photovoltaic activity, vegetation cover, plant biomass, soil moisture, and plant stress [10]. NDVI, as a result, is associated with several ecosystem features, making it possible to compare the same area images over time to look for critical environmental changes. Vegetation indices are mathematical expressions (or transformations) that have been derived from satellite images for monitoring vegetation under multispectral and enhancing the spectral differences based on strong vegetation absorbance in the red region and high reflectance of radiation in the Near Infrared (NIR) region [1,11,12].

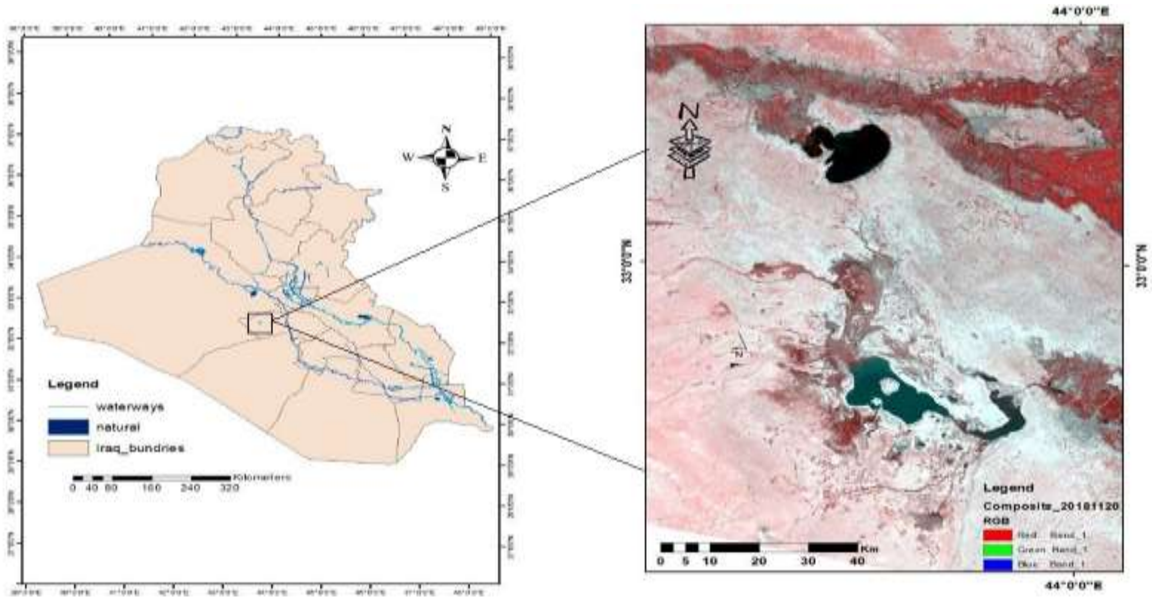
Researchers have proposed several water indices (WIs) to extract water features from RS data. McFeeters [13] proposed the NDWI to differentiate surface water bodies from Landsat TM images using the green band (band 2) and NIR band (band 4) [14]. Rogers and Kearney [15] presented NDWI for water extraction from the same Thematic Mapper (TM) of Landsat images using red (band 3) and SWIR (band 5). McFeeters [13] stated a threshold value of zero to extract water features from the raw data of Landsat images, where all positive NDWI values were categorized as water, while the negative values were for another feature. CPM [16] used the water index (WI) to observe the area status and to calculate the water area body depending on solid absorbance in the red region and the Short Wave Infrared (SWIR) band.
In general, integration of RS data with GIS has used different techniques such as automatic or semi-automatic water body mapping and extraction and superficial mathematical relationships to analyze spatial data; the simplicity characterizes it through processing. In addition, it reduces the time, effort, and financial cost and the amount of tabular information and restricts it to specified numbers [17].

This study aimed from a new perspective to find a method that shows spatiotemporal changes in Al-Razzaza Lake in the last 25 years using Landsat data, including Landsat-5 (TM), Landsat-7 Enhanced Thematic Mapper Plus (Landsat-7 ETM+), and Landsat-8 Operational Land Imager (Landsat-8 OLI) data. First, many surface water differentiation techniques were examined, and the most powerful technique was used to extract and map the lake's spatiotemporal changes.

2. Material and Methods

2.1 Study Area Description

Al-Razzaza Lake is located about 15 km northwest of Karbala Province in the central sector of the Mesopotamian Plain (Figure-1), between the latitudes 33º 31`-32º 25` N and longitudes 43º19`- 44º 17` E accordingly.



(a) **(b)**

Figure 1: Iraq Map with selected (a) study area (b) Landsat-8 OLI image captured on Nov. 20, 2018, shows the geographic location of Al-Razzaza Lake.

Al-Razzaza Lake is part of the western plateau, predominating by semi-arid weather, hot summer, and cold, dry winter. The annual rainfall rates range from 109–122 mm, with an evaporation rate of 3000 mm [18]. The Lake has created in 1969 southern Euphrates River to prevent floods by deriving waters from the river that would take place in southern Iraq. The Lake was planned for several tourist, religious, historical, economic, social, and environmental projects [19]. The Lake's storage capacity has reached 26 billion m^3, with a maximum level of 40 m above sea level. The lake's surface area was 1621 Km^2, 40 m in depth, conserved 25750 billion m^3 of water in 1995. The lake represented a problematic issue in the last ten years because of the increase in temperatures, scarcity of rain, dryness, fluctuation in rainfall, and increasing evaporation with the frequency of dust storms. These caused decreased water levels and increasing salinity, consequently a considerable change in the lake water quality [18]. In 2013, the Lake was 5-10 m in depth with 271 Km^2 in size, which conserved 4300 billion m^3 of water.

Al-Razzaza Lake is surrounded by Tertiary sediments of different ages and quaternary sediments, which are found in the south and southwest directions of Al-Razzaza Lake and cover a vast area of the lake vicinity. The surrounding area is of simple topography, having smooth slope terrains toward the eastern side of the lake where the land surface slope is minimal, and the slope of beds is less than one degree in the direction of east and northeast with elevations of 65-35 m above mean sea level. The unconfined and confined aquifers represent two hydrogeological units defined in the study area, The unconfined aquifer in the studied area is represented by the Euphrates-Nifayil formations [20]. The confined aquifers are represented by the Dammam formation, one of the most vital aquifers in western Iraq. Cavities and canals characterize it in addition to fractures, fissures, and joints, which cause the formation to have the highest transmissivity and permeability, with considered a discharge area to the Al-Razzaz Lake. More details of the geologist's description of the surrounding area were explained in [20, 21,22,23].

2.2. Dataset collection and processing

Many tasks were performed to determine the surface area changes, including derived indices pre-processing and comparison, and finally calculated the lake surface area in each temporal image [6]. Different scenes of the Landsat dataset were obtained from the US Geological Survey (USGS) Global Visualization Viewer, and thirty-one Landsat imageries were used to detect, assess, and map the study area changes during the period 1988-2018.

The remotely sensed data were geometrically adjusted to the datum WGS 84 and projection of UTM N38; radiometric calibration following atmospheric correction was applied, as stated by [6]. The ERDAS IMAGEN 2014 program processed satellite images and subtracted the study area from the overall scene.

The spatiotemporal changes of Al-Razzaza Lake during 1988–2018 were examined using Landsat TM, ETM+, and OLI data by applying classification methods, while mathematical equations for four tactical indices: NDVI, NDWI, NDMI, and WI, were applied for two periods, 2002 and 2016 which represented a significant and low change in the water body. The performances of different satellite-derived indexes were checked and evaluated for water body extraction (Table 1). ArcGIS v.10.6 software was integrated with the RS dataset for semiautomatic water body extraction and mapping.

Table 1: Satellite imagery derived indices used in this study for lake water body extraction [6]

Index	Equation
Normalized Difference Vegetation Index	NDVI = (NIR − Red)/(NIR + Red)
Normalized Difference Moisture Index	NDMI = (NIR − MIR)/(NIR + MIR)
Normalized Difference Water Index	NDWI = (Green − NIR)/(Green + NIR)
Water Index	WI = (NIR + SWIR) / 2

2.3. Statistical data and Process of validation

Different accuracy assessment analyses were performed to evaluate the effectiveness of the proposed indices for change detection of Al-Razzaza Lake. The performance of different approaches has been executed by absolute error calculation, using the method to detect changed areas. In this route, the lake surface area differs from 1988 to 2018 was done mathematically with each method (followed by the absolute error calculations) based on the resulting change as a reference, and many statistical parameters were measured to stand the assessment analysis accuracy (such as Kappa Coefficient, Producer's and User's Accuracies for change pixels).

3. Results and Discussion

The results showed significant variations in Al-Razzaza surface areas during 1988-2018. The most intense changes occurred between 1990 and 2012, with about 1285 km^2. Figure 2 shows that the lake's surface area was about 1450 km^2 in 1998 and 370 km^2 in 2018. Table 2 illustrates the dramatic decrease of the lake area over 20 years. These sharp variations in the lake area proved that Iraq witnessed unprecedented climate change in the last 60 years.

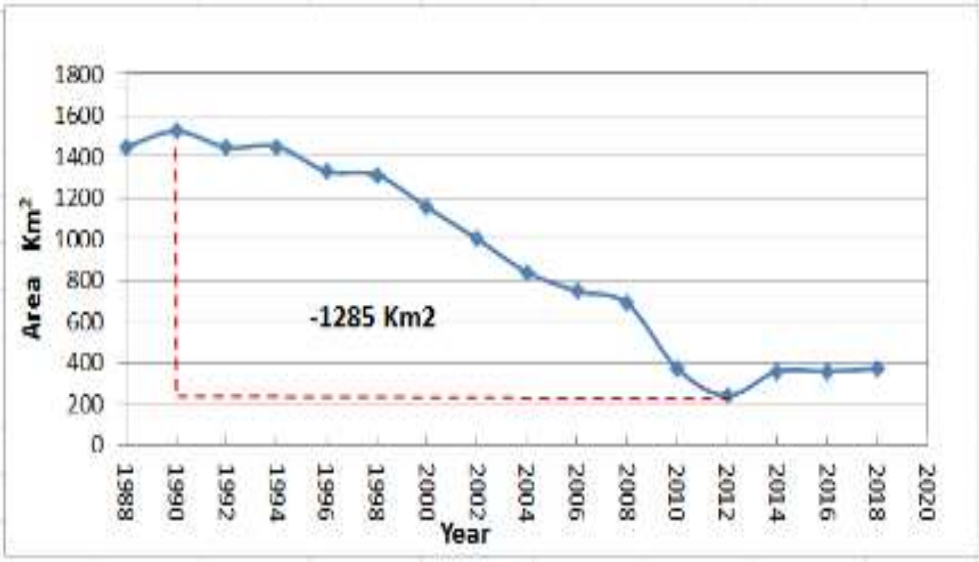


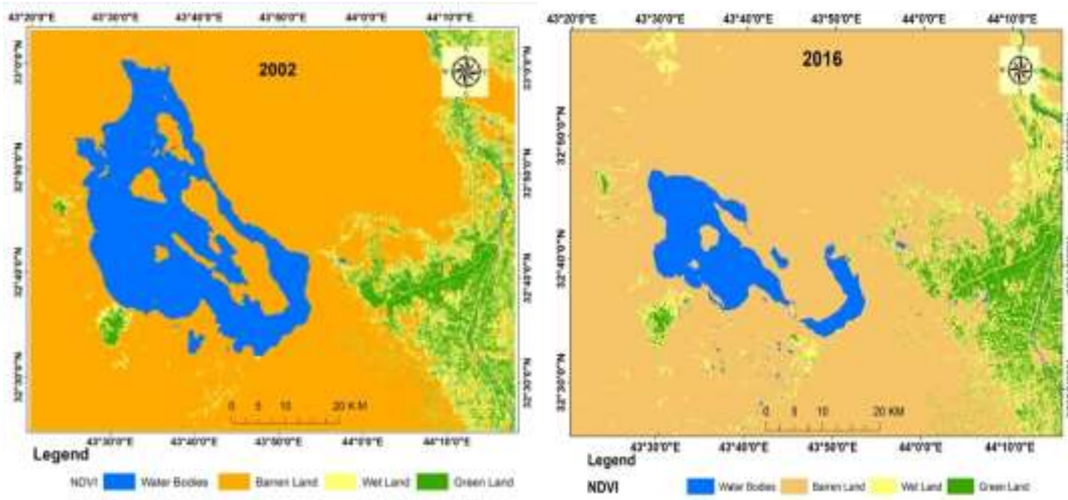
Figure 2: Changes in the Al-Razzaza surface area during 1988-2018

Table 2: Statistical results illustrated the spatiotemporal changes in Al-Razzaza Lake

No	Year	Area of the Lake (km^2)	Area Difference (km^2)
1	1988	1450	
2	1990	1524	
3	1992	1446	
4	1994	1450	
5	1996	1329	+74 -1285
6	1998	1310	
7	2000	1155	
8	2002	1001	
9	2004	839	
10	2006	748	
11	2008	687	
12	2010	371	+118 +13
13	2012	239	
14	2014	357	
15	2016	357	
16	2018	370	

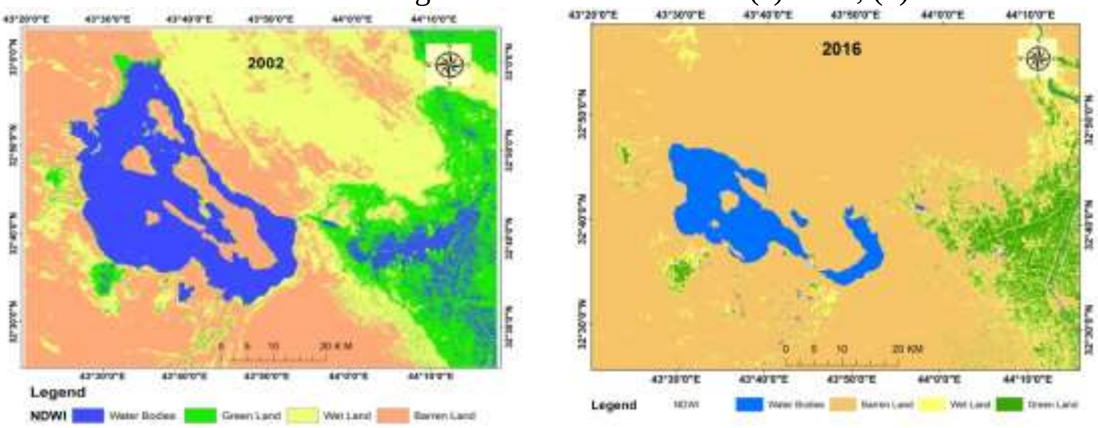
3.1. Change detection of surface water using the RS indices

According to the above results, different satellite-derived indices, including NDVI, NDMI, NDWI, and WI, were computed and tested for the extraction of the Al-Razzaza water body using the Landsat ETM 2002 and OLI 2016 imageries dataset. These images were selected as high and low changes in the water body during the spatiotemporal changes of Al-Razzaza Lake. The classification technique was applied for each indices image to extract the water body yearly, as shown in Figures 3, 4, 5, and 6. The Absolute Error, Overall Accuracy, and Kappa Coefficient were calculated to assess the accuracy of the results.



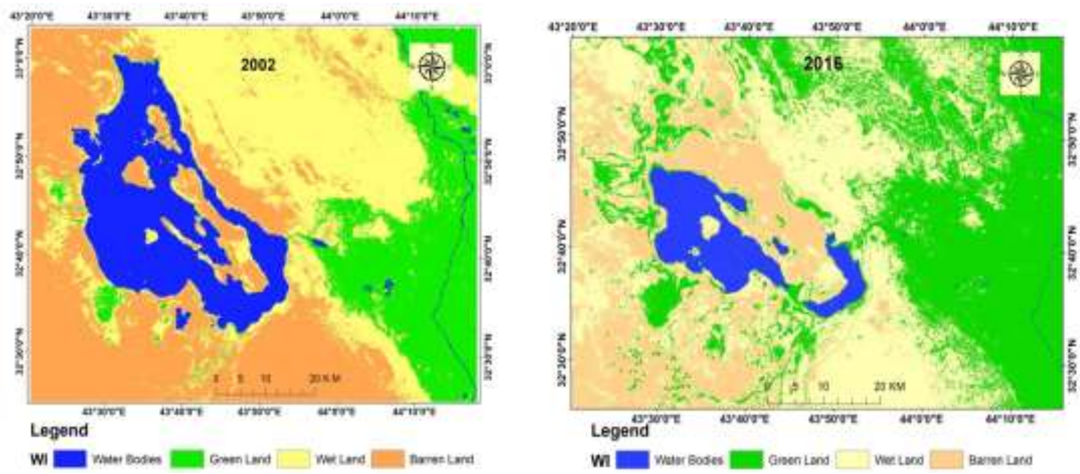
(a) **(b)**

Figure 3: Normalized Difference Vegetation Index (NDVI) to extract water features for Al Razzaza lake from two Landsat imageries for different times: (a) 2002, (b) 2016



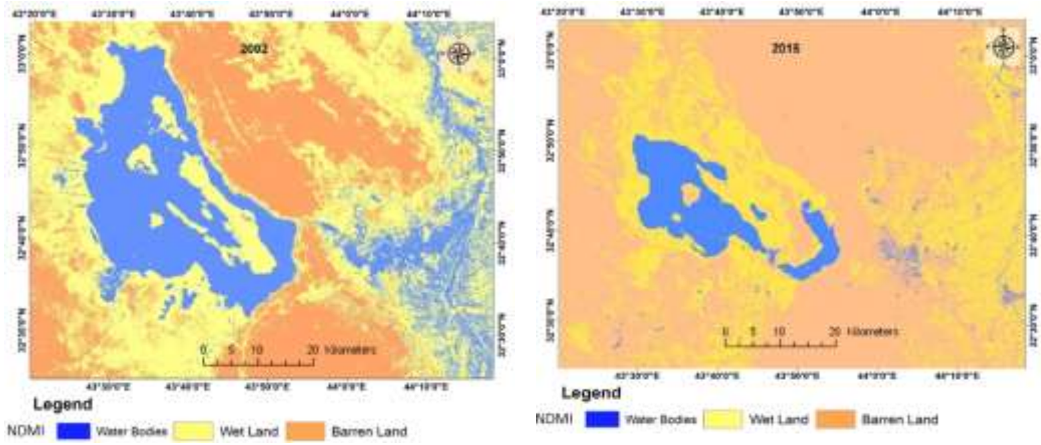
(a) **(b)**

Figure 4: Normalized Difference Water Index (NDWI) to extract water features for Al Razzaza lake from two Landsat imageries for different times: (a) 2002 (b) 2016



(a) **(b)**

Figure 5: Water Index (WI) to extract water features for Al Razzaza lake from two Landsat imageries for different times: (a) 2002 (b) 2016



(a) **(b)**

Figure 6: Normalized Difference Moisture Index (NDMI) to extract water features for Al-Razzaza lake from two Landsat imageries for different times: (a) 2002 (b) 2016

The lake surface areas were estimated using the selected image-specific thresholds, as shown in Table- 3. The accuracy evaluation indicated perfect application of the NDWI compared with the four indices illustrated in Table- 4. The correlation ratio (R^2) of the NDVI showed a higher value if compared with the other four indices used in this study, as shown in Table-5 and Figure-7.

Table 3: The estimation of lake water body extracted from different indices images

Index	LWT*	Lake Area 2002 (km^2)	LWT*	Lake Area 2016 (km^2)
Reference		1001		357
NDVI	0.197	956	0.170	325
WI	0.259	842	0.288	307
NDWI	-0.283	543	-0.221	427

Table 4: Accuracy assessment analyses

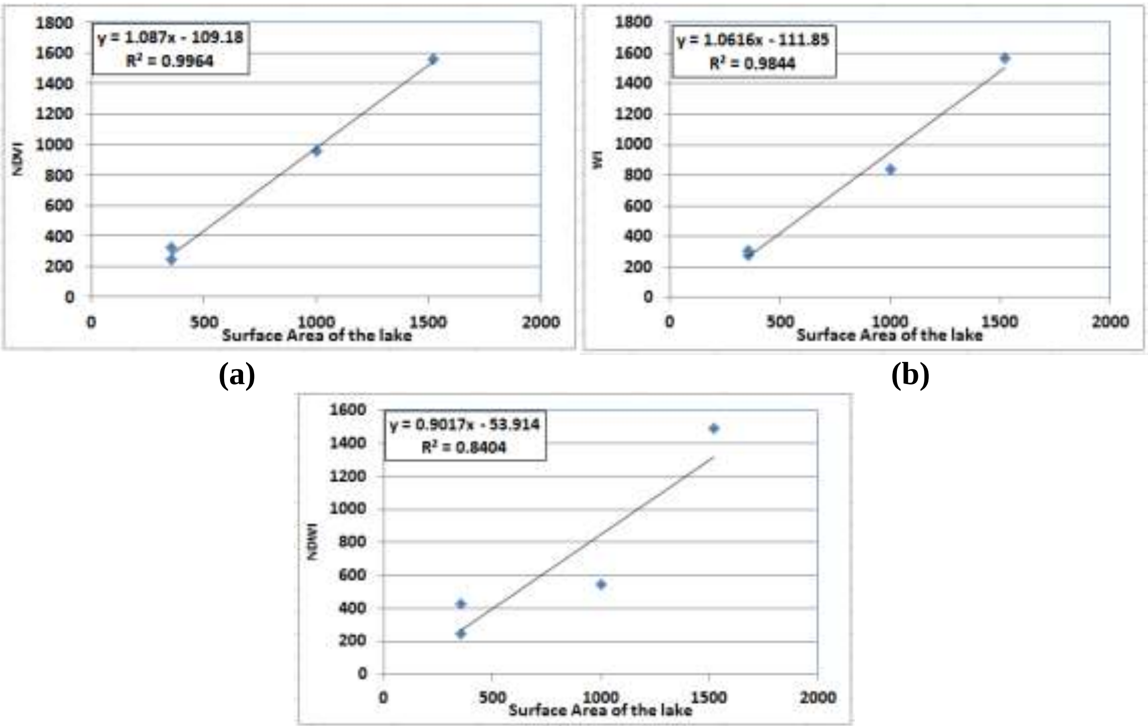
Index	**Landsat7- ETM+ for 2002**			**Landsat8- OLI for 2016**		
	A E (km^2)	**OA (%)**	**KC**	**A E (km^2)**	**OA (%)**	**KC**
NDVI	39	95.7	0.90	27	95.8	0.91
WI	279	91.0	0.86	109	87.1	0.88
NDWI	19	93.8	0.89	25	98.6	0.93

Table 5: Correlation analysis between NDVI, WI, and NDWI and Al-Razzaza lake surface area

	Surface area	NDVI	WI	NDWI
Surface area	1	.998**	.992**	.917*
NDVI	.998**	1	.995**	.932*
WI	.992**	.995**	1	.959*
NDWI	.917*	.932*	.959*	1

****. Correlation is significant at the 0.01 level (1-tailed).**

***. Correlation is significant at the 0.05 level (1-tailed).**



(a) **(b)**

(c)

Figure 7: Scatter plots of (a) NDVI, (b) WI, and (c) NDWI against Al-Razzaza lake Surface Area

According to the results, the NDVI, WI, and NDWI are considered functional indices to model the spatiotemporal changes of Al-Razzaza Lake with precision. In addition, the results of the accuracy assessment analyses revealed that the NDMI was insufficient extraction of the Lake water body, while the WI provided fewer accuracy results.

4. Conclusions

The study concluded that successive declines in the surface water area of Al-Razzaza Lake from 1988 to 2018 with a very high shrinkage value caused a noticeable change in the lake's morphological shape, specifically from the years 1990 and 2012. Al-Razzaza Lake is a part of the western plateau, predominating by semi-arid weather, hot, dry summer, and cold, dry winter. Due to the climate change crisis, the annual rainfall rates range from 109–122 mm, with the evaporation rate reaching 3000 mm, which affected Al-Razzaza lake surface water levels. Using the time series of Landsat images presented robust data of the spatiotemporal changes detection of Al-Razzaza Lake in the thirty years using Landsat TM, ETM+, and OLI imageries. The indices: NDVI, WI, and NDWI provided accurate change detection measurements for extracting surface water bodies from Landsat data with a higher correlation ratio. The lake's surface water decreased by 74% from 1450 km^2 in 1998 to 370 km^2 in 2018, especially in the north and east parts of the lake. This shrinkage and the lake surface water area reduction predict next year's aridity stage if no severe steps are considered to avoid that.

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Conflict of Interest: The authors declare that they have no conflicts of interest.

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