Spatiotemporal Evaluation of Eutrophication State in The Hammar Marsh Using A Satellite-Based Model

Bayda A Dhaidan¹, Imzahim A Alwan², Mahmoud S Al-Khafaji³
¹² University of Technology, Civil Engineering Department, Baghdad, Iraq.
³ University of Al-Nahrain, Baghdad, Iraq.

Abstract. Water pollution is now a major threat to the existence of living beings. Accordingly, water quality monitoring is an important activity toward restoring water quality. As wetland eutrophication is one of the essential ecosystem elements, devastation of this element is a significant issue. The Trophic State Index (TSI) provides information about trophic condition of water bodies. This paper aims to conduct spatiotemporal monitoring for the eutrophication of the west part of Al-Hammar Marsh for the period 2013-2020. To this end, a satellite-based TSI computation model was developed and implemented by using a series of OLI Landsat satellite images. The results showed that there was no improvement in the eutrophication state in the marsh, the percentage of the low class of TSI decreased in 2015 and 2018 to 7.9% and 2.6% and increased in 2017 and 2020 to 39.8%, and 56.3%. In general, the TSI was in the poor class in all the considered periods. Fluctuation of quantity and quality of the inflow prevents restoring the eutrophication of the marsh because this process requires stability in the levels of inundation above the critical limits for the water depth and periods. Therefore, it is necessary to find suitable alternatives to provide water drainage in quantities and quality that ensure the sustainability of the marsh ecosystem.

1. Introduction
Eutrophication is one of the important ecosystem parameters that must be monitored and controlled in any aquatic environment. Factors related to autotrophic production, such as algal biomass, water column nutrients, and water transparency, define trophic state functionally. A trophic state is essential to the structure of an ecosystem; it is intrinsically linked to biotic integrity as well as water quality [1]. Some researchers used field measurements to calculate TSI such as [2]–[7]. Remote sensing has been successfully used over the last 40 years to estimate water quality worldwide [8]–[12]. Monitoring water quality in a large water body by direct sampling is costly and does not cover the entire area at the same time. In contrast, remote sensing provides continuous spatial coverage of multispectral data over the complete geographic area of the water body. This areal determination of relevant parameters generates synoptic and significant information on water quality to facilitate decision-making for basin management and proper regulation of the water entering the lakes from the tributaries [13], [14].

Al-Hammar Marsh is one of the three largest marshes in Iraq, is located south of the Euphrates River, and has an area ranging from 2800 km² of contiguous permanent marsh to 4500 km² during...
flooding periods. Al-Hammar Marsh had been desiccated for more than a decade; however, after 2003 a policy was initiated to restore the marsh. West Al-Hammar Marsh's environment was harmed by a variety of issues, including fluctuations in water levels and an increase in salinity as a result of various factors such as a decrease in discharge. Therefore, the goal of this paper is to use the trophic state index to assess the restored environment of west A-Hammar Marsh.

2. Materials and Methods
In this paper, the evaluation methodology started with the pre-processing of Landsat Images for the study period then a model builder within the environment of GIS was used to develop a satellite-based model for monitoring the eutrophication state by using the Carlson’s Trophic State Index (TSI). This index is computed based on the blue and red spectral bands of Landsat 8 satellite images. Applying this model, the spatiotemporal change in TSI of the study area for the period 2013-2020 was computed. This methodology can be summarized as shown in Figure 1.

![Figure 1. Schematic diagram of the methodology.](image_url)

2.1. Study Area
Al-Hammar Marsh is one of the major Iraqi marshlands in the south of Iraq. It is extended between latitudes 30° 33’ 00” to 30° 58’ 00” N and longitudes 46° 24’ 00” to 47° 39’ 00” E along the right side of the Euphrates River, from the outskirts of Basra City in the east to the Nasiriyah City in the west, Figure 2. It is bounded from the south by the Main Outfall Drain (MOD). Historically this marsh had a permanent area of approximately 2800 km². This area expands to be 4500 km² during the flood years with a length width and water depth range of approximately 120 km, 25 km and 1.8 to 3. The marsh included a variety of natural and man-made features such as islands, waterways, security dikes, and railways [15].

At the year 2013, the marsh was separated into two parts by an earth dike named Al-Hammar Dike. The main part of the divided marsh is the western part of the marsh, see Figure 2. This part is located within Thi-Qar Governorate and has an area of 1326 km² (as specified by IMoWR in 2013). This part extended from the south of Nasiriyah City to the north of Basrah Governorate. It is feeding from many rivers branching from Euphrates River and from the MOD. These branches are: Al-
Hamedy, UmNakhal and AlKurmashia River. Also, this part is feeding and/or drained by five sub-rivers named Central opening, BC3 opening, BC4 opening, BC3 and BC4. These sub-rivers convey water into this part of the marsh from Euphrates River and vice versa according to the state of water levels in this part of the marsh and Euphrates River. In addition, Al-Khamissiya canal convey some MOD water into this part of the marsh during the dry seasons. However, the second part, which is named the East Part is located within the Basrah Governorate and the mean feeding source is the Shatt Al-Arab River through he Salal River as consequence of the tidal phenomenon.

**Figure 2.** Study Area with Feeders and Outlets.

### 2.2. Inflow to the Western Part of the Marsh

The inflow to the western part of the Al-Hammar Marsh was measured and recorded by the Center for the Restoration of Iraqi Marsh and Wetland (CRIMW), the monthly inflows conveyed to this part of the marsh from the Euphrates River and MOD for the period 2013-2021 are shown in Figure 3.

**Figure 3.** Monthly inflow (based on CRIMW 2021, unpublished data).
2.3. Acquisition and Preprocessing of Satellite Images
In this paper, the Landsat 8 satellite images data were used due to the suitability of the spatial (30 m), spectral (11 bands) and temporal resolution (16 days). This satellite 8 images of the considered part of the Al-Hammar Marsh were not uniformly available on the United States Geological Survey (USGS) website for the study period 2013-2020. Furthermore, the spatial extent of this part of the marsh required two Landsat swaths to cover it, also this part can only be assessed if two synchronous adjacent images are available. Accordingly, the available free cloud images for the study area during the considered period (2013-2020) are listed in Table 1. These images were downloaded from the USGS website (https://earthexplorer.usgs.gov/). Subsequently, these images were converted to top-of-atmosphere spectral reflectance values to account for radiometric contrast and then mosaicked by using the ENVI 5.3 software package.

Table 1. Available Landsat 8 images for the Western of the Al Hammar Marsh.

| Satellite | Acquisition date | Path/Row | Acquisition date | Path/Row |
|-----------|------------------|----------|------------------|----------|
| Landsat 8 | 12/07/2013       | 166/39   | 03/07/2013       | 167/39   |
|           | 15/07/2014       |          | 06/07/2014       |          |
|           | 18/07/2015       |          | 09/07/2015       |          |
|           | 05/08/2016       |          | 27/07/2016       |          |
|           | 23/07/2017       |          | 30/07/2017       |          |
|           | 27/08/2018       |          | 17/07/2018       |          |
|           | 27/06/2019       |          | 04/07/2019       |          |
|           | 29/06/2020       |          | 06/07/2020       |          |

2.4. Trophic State Index (TSI)
The Trophic State Index was developed by [16] on a scale between 0 to 100, defining trophic status in lakes. Each major division (ten, twenty, thirty, and so on) represents a doubling of algal biomass. It is possible to compute this index using a Secchi depth (SD) under equation 1.

$$\text{TSI}(SD) = 60 - 14.41 \ln(SD)$$

(1)
The Secchi depth is the depth of disappearance (SD). Water clarity, as measured by the SD, was found to have strong correlations with light in the blue and red bands of the spectrum reflected from the lake's water surfaces and measured as "brightness" by satellite sensors and can be estimated using the general predictive equation discovered for estimating water clarity, which has the following form [17].

$$\ln(SD) = a(TM1/TM3) + b(TM1) + c$$

(2)
Where a, b, and c are coefficients fitted to the calibration data and TM1 and TM3 are the reflectance of blue and red bands, respectively. This technique was applied by [18] to evaluate the TSI in the Al-Haweizeh Marsh via using the model maker tools within the environment of the ERDAS software package. This TSI model was calibrated and validated using sets of in-field-measured SD. The quasi-Newton optimization method was used to perform the calibration process using the synchronous spectrum reflectance obtained from the Landsat ETM image-2006 to compute the coefficients fitted to the calibration data in Eq.(2). Consequently, the obtained value of the coefficients a, b and, c were 2.309, -0.094 and -0.199 respectively.

3. Results
3.1. TSI Model
The TSI model was developed by using the model builder tool within the ArcGIS 10.4 environment based on equations 1 and 2, as shown in Figure 4, and saved as a toolbox as shown in Figure 5 to compute the spatial distribution of Trophic State Index within the marsh area.
Figure 4. Trophic State Index model.

Figure 5. Input and output menu of the TSI model.

3.2. Spatiotemporal Distribution of the TSI
The spatial distributions of TSI within the marsh for the period 2013-2020 are shown in Figure 6. These distributions indicate that TSI values in the water and vegetation parts of the marsh fluctuated between 10% and 30% while, the soil part of the marsh the TSI values range from 30% to 40%.

Figure 7 shows that the class of extremely very low TSI (0-10) constitutes a small percentage of the marsh's area in all studied periods, less than 5.0% except in 2019 increased to 17.2% from the marsh area. However, the class of low TSI (10-20) was 37.0% in 2013 from the total area of the marsh and increased in 2014, 2017, and 2020 to be 57.8%, 39.8%, and 56.3% respectively while decreased in 2015 and 2018 to 7.9% and 2.6%. The class of moderate TSI (20-30) was 30.56% from the marsh's area in 2013 then increased in 2015 and 2018 to be 38.87% and 26.68% from the total area. While decreased in the rest years to the lowest value in 2017 about 17.78% from the total marsh's area. Generally, TSI (10-20) increased in conjunction with increasing inflow discharge while TSI (20-30) decreased with increasing inflow discharge. The TSI value variance from range (10-20) and (20-30) is still in the oligotrophic class (poor), despite the increase in water area in 2019 and 2020, TSI is still in the poor class. However, the trophic state of the marsh is in the poor class of all the study periods.
Figure 6. The Trophic State Index (TSI) distribution on the marsh's area for the summer season of the period 2013 to 2020.
Figure 7. Variability of the TSI area.

4. Conclusions
Remote sensing and GIS techniques were used to develop a satellite image-based model to compute the spatiotemporal distribution of TSI for investigating the eutrophication conditions within the western part of the Al-Hammar Marsh for the period 2013-2020. Landsat satellite images with aid of ENVI 5.3 and ARC GIS 10.4 software were used in developing and implementing this model. From the obtained results, the following point can be concluded: The integration between remote sensing techniques and GIS is an efficient tool in monitoring the eutrophication conditions of wetlands, which gives more effective results, continuous, spatiotemporal, and low-cost monitoring of the large wetland area, especially when using a time series of appropriate periods that allows continuous monitoring of the changes that occur in the study area. It also assists in studying the changes, which gives clear results about the reality of the marsh and the response of the ecological system to the implemented inundation processes. The developed satellite model that was implemented by using model builder tool in the ArcGIS 10.4 environment, was effective tools for allowing redundancy and consistency in performing recursive computations by removing human error factors and increasing the speed of computations. Although the TSI increased in conjunction with the increase in flow discharge in the water area especially in the years 2019 and 2020, the value of TSI is still in the poor class. In general, the trophic status of the marshes was in the poor class in all the study periods. The developed TSI model can be sufficiently applied to monitor and evaluate the spatiotemporal change of the trophic state in the marsh. Fluctuation of quantity and quality of the inflow reduces the possibility of restoring the eutrophication of the marsh because this process requires stability in the levels of inundation above the critical limits for the water depth and time periods. Therefore, steps must be urged to develop and implement plans and find suitable alternatives to provide water discharge in quantities and qualities that ensure the sustainability of the marsh ecosystem.

Acknowledgments
The authors would like to thank the Iraqi Ministry of Water Resources for providing the required data and technical assistance. It is inevitable that many people have contributed to this work, and we would like to acknowledge the support and assistance we have received from several friends and colleagues.
References

[1] W. K. Dodds, “Trophic state, eutrophication and nutrient criteria in streams,” *Trends Ecol. Evol.*, vol. 22, no. 12, pp. 669–676, 2007, doi: 10.1016/j.tree.2007.07.010.

[2] A. R. M. Mohamed, A. A. Al-Saboonchi, and F. K. Raadi, “Ecological assessment of East Hammar marsh, Iraq using a number of ecological guides,” *J. King Abdulaziz Univ. Mar. Sci.*, vol. 26, no. 2, pp. 11–22, 2016, doi: 10.4197/Mar.26-2.2.

[3] G. A. Takayama Colli, R. L. Duarte, C. da Silva, R. de Oliveira Pereira, L. D. B. da Silva, and J. B. G. Silva, “Impacts on soil use and occupation in the production area with vegetables in Barra Mansa, Brazil,” *Rev. em Agronegocio e Meio Ambient.*, vol. 13, no. 2, 2020, doi: 10.17765/2176-9168.2020V13N2P621-644.

[4] T. Akkan, O. Yazicioglu, R. Yazici, and M. Yilmaz, “Assessment of irrigation water quality of turkey using multivariate statistical techniques and water quality index: Siddiklı Dam lake,” *Desalin. Water Treat.*, vol. 115, 2018, doi: 10.5004/dwt.2018.22302.

[5] S. Sawestri, N. K. Suryati, and D. Muthmainnah, “Determination of potential fisheries areas based on trophic status (Case study in Situ Gede, Tasikmalaya),” *Depik*, vol. 10, no. 2, 2021, doi: 10.13170/depik.10.2.2020V13N2P621-644.

[6] B.-P. Han, Z. Liu, and H. J. Dumont, “Water Supply and Eutrophication of Reservoirs in Guangdong Province, South China,” 2012, pp. 279–292.

[7] Z. Wang, B. Han, R. Hu, and Q. Lin, “Phytoplankton community structure and eutrophication of reservoirs in Guangdong Province, China,” *Chinese J. Ecol.*, vol. 24, no. 4, pp. 402–405, 2005.

[8] N. Bin Chang, S. Imen, and B. Vannah, “Remote sensing for monitoring surface water quality status and ecosystem state in relation to the nutrient cycle: A 40-year perspective,” *Crit. Rev. Environ. Sci. Technol.*, vol. 45, no. 2, pp. 101–166, 2015, doi: 10.1080/10643389.2013.829981.

[9] A. N. Tyler, E. Svab, T. Preston, M. Présing, and W. A. Kovács, “Remote sensing of the water quality of shallow lakes: A mixture modelling approach to quantifying phytoplankton in water characterized by high-suspended sediment,” *Int. J. Remote Sens.*, vol. 27, no. 8, pp. 1521–1537, 2006, doi: 10.1080/01431169308904379.

[10] A. G. Dekker and S. W. M. Peters, “The use of the thematic mapper for the analysis of eutrophic lakes: A case study in the netherlands,” *Int. J. Remote Sens.*, vol. 14, no. 5, 1993, doi: 10.1080/01431169308904379.

[11] A. S. Membrillo-Abad, M. A. Torres-Vera, J. Alcocer, R. M. Prol-Ledesma, L. A. Oseguera, and J. R. Ruiz-Armenta, “Trophic state index estimation from remote sensing of lake Chapala, Mexico,” *Rev. Mex. Ciencias Geol.*, vol. 33, no. 2, pp. 183–191, 2016, doi: 10.22201/cgeo.20072902e.2016.2.495.

[12] J. K. Dhillon and A. K. Mishra, “Estimation of Trophic State Index of Sukhna Lake Using Remote Sensing and GIS,” *J. Indian Soc. Remote Sens.*, vol. 42, no. 2, pp. 469–474, 2014, doi: 10.1007/s12524-013-0321-0.

[13] N. Usali and M. H. Ismail, “Use of Remote Sensing and GIS in Monitoring Water Quality,” *J. Sustain. Dev.*, vol. 3, no. 3, 2010, doi: 10.5539/jsd.v3n3p228.

[14] L. M. Fuller and R. J. Minnerick, “Predicting Water Quality by Relating Secchi-Disk Transparency and Chlorophyll a Measurements to Landsat Satellite Imagery for Michigan Inland Lakes, 2001–2006,” *Usgs*, no. August 2007, 2007.

[15] Z. A. Abdulraheem, “Allocating the best representative water quality monitoring station dacity,” p. M.Sc. Thesis, 2015.

[16] R. E. Carlson, “A trophic state index for lakes,” *Limnol. Oceanogr.*, vol. 22, no. 2, pp. 361–369, 1977, doi: 10.4319/lo.1977.22.2.0361.

[17] S. M. Kloiber, P. L. Brezonik, L. G. Olmanson, and M. E. Bauer, “A procedure for regional lake water clarity assessment using Landsat multispectral data,” *Remote Sens. Environ.*, vol. 82, no. 1, pp. 38–47, 2002, doi: 10.1016/S0034-4257(02)00022-6.

[18] A. R. T. Ziboon, K. Z. Al Zubaidy, and M. S. Al Khafaji, “Remote Sensing Model for Monitoring Trophic State of Al Huweizah Marsh,” *Eng Tech. J.*, vol. 28, no. 16, pp. 5213–5222, 2010, [Online]. Available: www.pdffactory.com.