ECWS-8 2024 Conference

The 8th International Electronic Conference on Water Sciences

14–16 October 2024 | Online

MDPI

Enhanced Chlorophyll-a Estimation in Anzali Wetland Using Sentinel 2 and 3 Satellite and a Machine Learning Fusion model

Parisa Dodangeh, Reza Shah-Hosseini

1 Ph.D. Student; School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran, Tehran

2 Associate Professor; School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran, Tehran

INTRODUCTION & AIM

Wetland ecosystems play a crucial role in supporting biodiversity, purifying water, and regulating climate, yet they face significant threats from human activities and climate change. Monitoring chlorophyll-a (Chl-a) concentrations serves as a vital indicator of phytoplankton biomass and water quality, necessitating advanced techniques to address the limitations of traditional measurement methods. This study aims to innovate Chl-a estimation in Anzali wetland, Iran, by integrating Sentinel-3 and Sentinel-2 satellite data alongside three advanced models—Gilerson, Gurlin, and Mishra—enhanced by machine learning for improved spatial resolution. By refining these methodologies and integrating machine learning algorithms, our research seeks to elevate the precision and effectiveness of Chl-a monitoring, ultimately contributing to better environmental management and conservation efforts.

METHOD

This study focuses on the Anzali Wetland, located on the southwestern coast of the Caspian Sea, between 48°45' and 49°42' E longitude and 36°55' and 37°32' N latitude, near Bandar-e-Anzali. The wetland, a representative example of a natural ecosystem along the Caspian Sea, has been included on the Montreux Record due to threats from urban pollution, agricultural runoff, upstream sedimentation, and increased hunting pressure.

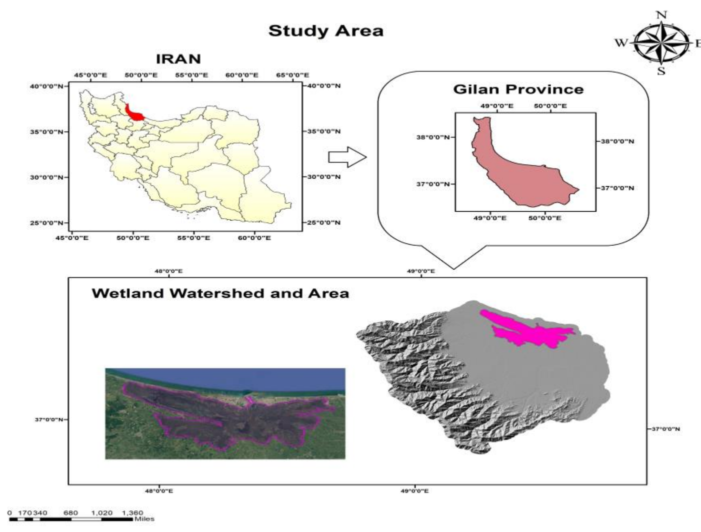

Fig 1 Study area

To assess chlorophyll-a (Chl-a) concentrations, this research utilizes satellite imagery from Sentinel-2 and Sentinel-3. The Sentinel-2 data (COPERNICUS/S2_SR_HARMONIZED) for July 9, 2023, was processed to derive various vegetation indices, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Leaf Area Index (LAI). Meanwhile, the Sentinel-3 data (COPERNICUS/S3/OLCI) provided radiance values essential for Chl-a estimation using the Gurlin, Gilerson, and Mishra models.The methodology comprises several key steps:

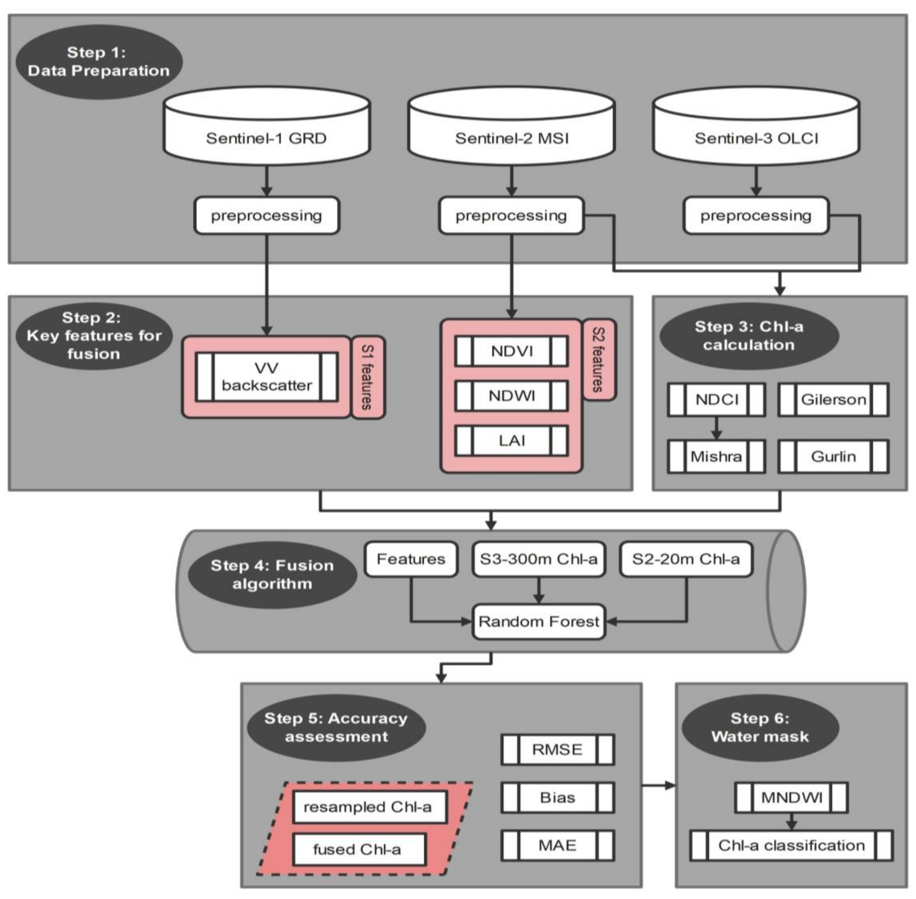

Fig 2 Proposed method

1. Data Preparation: *Preprocessing of Sentinel-1 GRD, Sentinel-2 MSI, and Sentinel-3 OLCI data to ensure quality and usability for analysis.*
2. Key Features for Fusion: *Identification of significant features for data fusion, including VV backscatter from Sentinel-1 and the vegetation indices derived from Sentinel-2.*
3. Chl-a Calculation: *Application of the Gurlin, Gilerson, and Mishra models to calculate Chl-a concentrations from Sentinel-3 data.*
4. Fusion Algorithm: *Integration of Sentinel-2 and Sentinel-3 Chl-a data using a Random Forest classifier, which enhances spatial resolution to 20 meters.*
5. Accuracy Assessment: *Evaluation of the model's performance through accuracy metrics, including RMSE, Bias, MAE, and MNDWI for water masking.*
6. Water Mask: *Finalizing the analysis with a water mask to isolate the aquatic areas for better Chl-a classification.*
This comprehensive methodology, combining advanced satellite data and machine learning techniques, aims to improve the precision of Chl-a monitoring in the Anzali Wetland, providing valuable insights for environmental management and conservation.

RESULTS & DISCUSSION

The quantification of chlorophyll-a (Chl-a) concentrations in wetland ecosystems is crucial for assessing phytoplankton biomass and overall water quality. In this study, we evaluated Chl-a concentrations in the Anzali Wetland, Iran, utilizing three distinct models—Gilerson, Gulin, and Mishra—applied to Sentinel-3 satellite data collected in 2023. Covering approximately 25 hectares along the southwestern coast of the Caspian Sea, the Anzali Wetland is recognized as one of northern Iran's most significant and biodiverse ecosystems.
Each model adopted different methodologies for Chl-a estimation. The Gilerson and Gulin models employed band ratio approaches, specifically focusing on the red-edge band ratio, while the Mishra model utilized an empirical methodology based on the Normalized Difference Chlorophyll Index (NDCI). Although these models initially produced Chl-a maps with lower spatial resolutions, the data was subsequently enhanced to a 20-meter resolution through feature extraction from Sentinel-2 imagery. A Random Forest classifier was applied, trained on these extracted features, effectively refining the Chl-a maps derived from Sentinel-3 data and improving spatial resolution across the wetland.
For accuracy assessment, Sentinel-3 data were resampled to a 20-meter resolution and validated against in-situ measurements of Chl-a concentrations, ensuring robust ground truthing. Evaluation of model performance yielded the following accuracy metrics:

- ***Gilerson Model:*** *RMSE = 3.71, Bias = 0.65, MAE = 2.85*
- ***Gulin Model:*** *RMSE = 10.12, Bias = 1.46, MAE = 7.74*
- ***Mishra Model:*** *RMSE = 11.63, Bias = 2.64, MAE = 8.83*

The results indicate that the Gilerson model outperformed the others, achieving the highest accuracy in Chl-a estimation, followed by the Gulin and Mishra models.

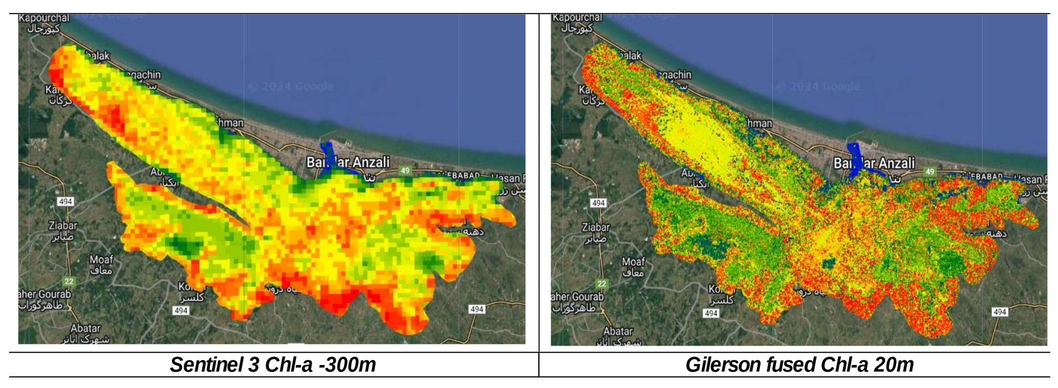

Fig 3 Example of results

This study emphasizes the effectiveness of integrating remote sensing techniques with machine learning methodologies for Chl-a estimation, underscoring its potential to enhance our understanding of wetland dynamics and inform conservation strategies. The research also highlights the significance of the Anzali Lagoon area, advocating for precise chlorophyll estimation. The synergistic fusion of Sentinel-2 and Sentinel-3 data significantly enhances both spatial and temporal resolution, providing critical insights into Chl-a dynamics across varying scales. These findings are instrumental in refining management strategies and preserving the health of wetland ecosystems.

CONCLUSION

This study successfully demonstrated the application of remote sensing techniques and machine learning algorithms to accurately quantify chlorophyll-a concentrations in the Anzali Wetland, utilizing Sentinel-2 and Sentinel-3 satellite data. The findings revealed that the Gilerson model provided the most reliable estimates of Chl-a, underscoring the importance of selecting appropriate methodologies for ecological monitoring. As wetlands face increasing pressures from urbanization, agricultural runoff, and other anthropogenic factors, the ability to monitor their health through advanced remote sensing techniques becomes essential for effective management and conservation efforts.
Future work should focus on enhancing the spatial and temporal resolution of chlorophyll-a estimations by exploring additional machine learning models and integrating other relevant datasets, such as climate variables and land use changes. Furthermore, long-term monitoring of the Anzali Wetland will be critical to assess the impacts of environmental changes on its ecosystem dynamics.

REFERENCES

1. wetlands located in the Limpopo Transboundary River Basin, South Africa', *Physics and Chemistry of the Earth, Parts A/B/C*, 127: 103193.
2. Lu, Bing, and Yuhong He. 2021. 'Assessing the Impacts of Species Composition on the Accuracy of Mapping Chlorophyll Content in Heterogeneous Ecosystems', *Remote Sensing*, 13: 4671.
3. Bai, Jueying, Qian Cui, Wen Zhang, and Lingkui Meng. 2019. 'An approach for downscaling SMAP soil moisture by combining Sentinel-1 SAR and MODIS data', Remote Sensing, 11: 2736.
4. Markogianni, Vassiliki, Dionissios Kalivas, George P Petropoulos, and Elias Dimitriou. 2020. 'Estimating chlorophyll-a of inland water bodies in Greece based on landsat data', *Remote Sensing*, 12: 2087.
5. Silveira Kupssinskü, Lucas, Tainá Thomassim Guimarães, Eniuce Menezes de Souza, Daniel C. Zanotta, Mauricio Roberto Veronez, Luiz Gonzaga Jr, and Frederico Fabio Mauad. 2020. 'A method for chlorophyll-a and suspended solids prediction through remote sensing and machine learning', *Sensors*, 20: 2125.