Long-Term Water Quality Trends and Seasonal Drivers in the Western Mississippi Sound: A Remote Sensing and Machine Learning Approach

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Long-term water quality monitoring is essential for understanding and managing the health of aquatic ecosystems, especially as they face mounting pressures from climate change and increased human activities. This study investigates the long-term trends and seasonal drivers of water quality in the Western Mississippi Sound (WMS), a key estuarine ecosystem in the Gulf of Mexico, using a combination of field measurements and advanced remote sensing data. Field sampling was performed using an autonomous surface vessel equipped with sensors to measure key water quality indicators, such as chlorophyll-a (Chla), Colored Dissolved Organic Matter (CDOM), and turbidity, across the study area for model calibration and validation. Remote sensing data, particularly from Landsat and Sentinel-2 satellites, were used to derive predictor variables, including remote sensing reflectance and spectral indices. To ensure that the most relevant predictors were used in the analysis, multicollinearity analysis and advanced feature selection methods, such as recursive feature elimination and permutation importance, were applied. Among the machine learning (ML) models evaluated, the XGBoost algorithm was found to provide the best predictive performance. This model demonstrated a high degree of accuracy, achieving an R^2 of 0.96 and a root mean squared error (RMSE) of 0.38 µg/L for Chla, an R^2 of 0.97 and an RMSE of 1.81 Ppb for CDOM, and an R^2 of 0.95 and an RMSE of 0.52 NTU for turbidity. A robust time series for Chla, CDOM, and turbidity was generated using the XGBoost model, which was selected after a thorough evaluation of its predictive accuracy. To further analyze the temporal dynamics of water quality, generalized additive models were employed to examine trends and seasonal patterns in the data. The analysis revealed significant spatiotemporal variability in water quality parameters across the WMS. Chla concentrations showed clear seasonal peaks during the summer months, likely driven by nutrient availability, increased temperatures, and light levels, all of which promote phytoplankton growth. In contrast, CDOM levels were predominantly affected by freshwater inflows from rivers and rainfall, with higher concentrations observed during periods of heavy precipitation, while turbidity variability was shaped by these freshwater inputs in combination with wind-driven sediment resuspension. This study demonstrates the potential of integrating ML techniques with remote sensing data to enhance the monitoring and prediction of water quality in coastal and estuarine environments. By providing a detailed understanding of the temporal and spatial variability in water quality, the findings offer valuable insights into the impacts of climate change, human activities, and natural processes on aquatic ecosystems. This research contributes to coastal management by enhancing understanding of water quality dynamics, helping to inform strategies to mitigate the effects of climate change and human activities.