Detection and driving factor analysis of hypoxia in river estuarine zones by entropy methods

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Abstract: Dissolved oxygen (DO) serves as a critical parameter in surface water quality assessment, directly reflecting aquatic environmental conditions and the degree of waterbody contamination. Hypoxia, typically defined as DO concentrations below 2 mg/L, represents a prevalent environmental issue in estuarine systems experiencing severe eutrophication. Hypoxic conditions in river estuaries present substantial ecological threats and challenges to water resource security; however, the availability of long-term, high-frequency monitoring data necessary for comprehensive analysis remains limited.

This research examines the dynamics of hypoxia within the Shenzhen River Estuary (SRE) through the utilization of a two-year, high-frequency monitoring dataset. A hybrid anomaly detection framework integrating wavelet transform analysis and temporal information entropy was developed to effectively identify hypoxia events. Additionally, the driving factors of hypoxia were analysed using correlation coefficients and transfer entropy (TE).

Findings indicate recurrent hypoxia occurrences during spring and summer seasons. Wavelet analysis demonstrates superior capability in identifying pattern-based anomalies within time series data, while the temporal entropy index method excels in threshold-based anomaly detection, suggesting complementary strengths in qualitative and quantitative identification, respectively. The integrated anomaly detection approach establishes a synergistic "high-frequency localization and low-frequency assessment" framework, significantly enhancing the capacity to detect and characterize hypoxia events. Temporal information entropy exhibited reliable performance in threshold-driven anomaly identification.

In the Shenzhen River system, although temperature fluctuations occasionally influenced hypoxia development, it was not identified as a primary causal factor. Turbidity and total nitrogen (TN) concentrations showed significant negative correlations with DO, along with time-lagged effects, where transfer entropy peaked at 0.05 with time lags of 36 and 72 hours, respectively.

Wastewater treatment plant (WWTP) discharge loads, particularly suspended solids (SSs), exhibited a linear negative relationship with estuarine DO concentrations. Notably, correlation strengths in 2022 data remained low (excluding SSs) due to elevated baseline pollution levels, whereas post-remediation 2023 data revealed stronger linear associations, particularly for SSs ($r = -0.81$). This observed enhancement indicates an increasing influence of upstream pollutant loading on estuarine hypoxia formation.

The proposed "high-frequency localization–low-frequency assessment" detection framework demonstrated high accuracy in hypoxia event identification, while mechanistic analysis confirmed the presence of time-lagged pollutant impacts. These findings contribute to the advancement of hypoxia detection methodologies and emphasize the significant roles of turbidity and SSs in estuarine oxygen depletion, providing valuable insights for adaptive water quality management strategies.

Keywords: *hypoxia; estuarine zone; wavelet analysis; temporal entropy index; transfer entropy*

