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Key Points:

- Seawalls disrupt tidal groundwater connectivity and isolate landward coastal wetlands
- Seawall isolation reduces hydrological exchange, alters water quality, and enhances groundwater responses to rainfall events
- Seawall isolation is associated with reduced *Phragmites australis* dominance and more diverse terrestrial vegetation

Supporting Information:

Supporting Information may be found in the online version of this article.

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Seawall-Induced Isolation Alters Hydrological-Biogeochemical Conditions in Coastal Wetlands

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Abstract Coastal wetlands are increasingly impacted by tropical cyclones and storm surges. Seawalls and levees built to reduce these hazards disconnect wetlands from adjacent uplands, yet their hydroecological effects remain poorly understood. Using continuous hydrological observations in Chongming Island, Changjiang Estuary, China, we compared seaward and landward wetlands separated by a seawall. CTD sensor data, water quality measurements, and plot surveys revealed that seawall construction weakens tidal connectivity and reduces hydrological exchange landward. Seaward wetlands exhibit tidal-dominated dynamics with higher salinity and lower chlorophyll (CHL), chemical oxygen demand (COD), and total organic carbon (TOC), associated with presence of *Phragmites australis*. Interior wetlands show reduced salinity, higher values of CHL, COD and TOC, stronger rainfall-driven responses, and are characterized by more terrestrial vegetation species. These findings suggest that seawalls can substantially alter wetland hydrodynamics and ecosystem structure, highlighting the importance of incorporating hydrological connectivity into seawall design to sustain wetland functions.

Plain Language Summary Seawalls are often built along coasts to protect towns and farms from storms and flooding. However, these walls also reduce the connection between coastal wetlands and the land behind them, changing how water flows in and out of the wetland. We studied the largest wetland on Chongming Island in China's Yangtze River estuary, comparing the side of the wetland facing the sea with the side behind the seawall. We found that the seawall slows water exchange and reduces tidal flushing behind it. The sea-facing part of the wetland remains salty and supports healthy reed growth, while the area behind the wall has lower salinity, altered groundwater conditions, and more terrestrial vegetation species. Our results show that seawalls can alter how coastal wetlands function, not just how they look. When planning or upgrading seawalls, keeping wetlands connected to the tides can help them stay healthy and function properly.

1. Introduction

To mitigate flood hazards and safeguard human communities, coastal defense structures such as seawalls, levees, dikes, and breakwaters have been extensively employed (Morris et al., 2018). In China, over 60% of the coastlines are now protected by such “gray” engineering structures, with a total length exceeding that of the ancient Great Wall (Ma et al., 2014). Although these structures protect coastal communities and infrastructure, they can fragment the land–ocean interface and disrupt hydrological processes that sustain coastal wetlands (Gittman et al., 2016; Lee & Nepf, 2024). Seawalls often disrupt tidal dynamics and hydrological and salinity regimes (Chen et al., 2024; Cousins et al., 2017), which may lead to a persistent degradation of wetland functions, particularly in salt marshes where vegetation is sensitive to flooding and salinity (Barbier et al., 2011; Bishop et al., 2017).

Previous studies have extensively characterized how seawalls alter surface tidal hydrodynamics and drive wave-induced salinity intrusion, leading to the visible contraction of marsh habitats (Byun et al., 2004; Li et al., 2021; White & Kaplan, 2017). However, their effects may extend to subsurface processes (Xin et al., 2022). Seawall foundations can reconfigure groundwater flow paths and attenuate tidal pressure propagation, thereby disrupting porewater exchange (Heiss & Michael, 2014; Sadat-Noori et al., 2025). These changes may modify root-zone salinity and nutrient cycling, with consequences for vegetation growth and community structure (Barbier

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et al., 2011; LeRoux et al., 2023). To date, the extent to which seawall construction disrupts subsurface hydrological connectivity, and whether such changes propagate to salt marsh vegetation, remain poorly understood.

Here, we investigate whether seawall-induced hydrological isolation alters groundwater dynamics and, in turn, affects salt marsh vegetation. Specifically, we (a) characterize groundwater depth dynamics inside and outside the seawall, (b) determine the relative contributions of tidal forcing and precipitation to groundwater variability, and (c) assess whether seawall-induced hydrological changes are associated with shifts in wetland vegetation and ecological structure. These findings provide insights into the potential role of seawall-induced hydrological isolation in modifying subsurface hydrological connectivity and wetland ecological processes.

2. Methods

2.1. Site Description

The study was conducted at Chongming Dongtan (CMD) on Chongming Island in the Yangtze Estuary, China (Figure 1a). Chongming Island contains extensive tidal salt marshes and is bordered by a seawall system exceeding 200 km in length (W. Zhang et al., 2023; X. Zhang et al., 2023). At CMD, the seawall system was reinforced and expanded during 2014–2017, integrating coastal defense with habitat restoration and invasive species management (Figure 1b; Text S1 in Supporting Information S1). CMD is divided by the seawall into landward and seaward domains that differ in their hydrological connectivity to the tidal system. Sampling sites were selected within *Phragmites australis* beds on both sides of the seawall (Figure 1c).

2.2. Data Collection

Two monitoring wells, each approximately 1.5 m deep, were installed in *Phragmites australis* beds to monitor near-surface groundwater, with one inside (D1) and one outside (D2) the seawall (Figure 1c). The sites were within 100 m of each other, with adjacent bare-ground elevations differing by approximately 0.25 m based on the UAV-derived DSM. Groundwater monitoring was conducted from March 2 to 16 April 2025, when monsoonal rainfall and typhoon disturbances were relatively limited, to characterize groundwater fluctuations and tidal influence across the seawall. RBR Concerto3 CTD sensors and multiparameter water quality probes were deployed at D1 and D2 to continuously monitor groundwater depth and water quality (Table S1 in Supporting Information S1). The measured parameters included chlorophyll (CHL), chemical oxygen demand (COD), and total organic carbon (TOC). These parameters were used as complementary indicators to characterize variations in groundwater environmental conditions across the seawall (Boyer et al., 2009; Park et al., 2022).

Vegetation surveys were conducted on 2 August 2025, when *P. australis* was in the active growing season with well-developed morphological traits, allowing characterization of vegetation structural differences between the two zones. Two 1 m × 1 m quadrats were established at each site (D1 and D2) for vegetation characterization (Table S1 in Supporting Information S1). Within each quadrat, shoot density was first recorded (Figure S1 in Supporting Information S1). Ten individuals were then randomly selected across different size classes to ensure both randomness and representation of morphological variability (Welch et al., 2006). Following the Vegetation Quadrat Survey Data Standard, plant height, stem diameter, and leaf number were measured, and the mean values for each parameter were calculated (Plant Science Data Center, 2022).

Furthermore, tidal data from Sheshan Station (National Marine Data and Information Service, 2024) was used to analyze tidal influences on groundwater fluctuations inside and outside the seawall. Hourly precipitation data from the Copernicus Climate Change Service Climate Data Store was used to evaluate groundwater responses to rainfall (Hersbach et al., 2023).

2.3. Data Analysis

2.3.1. Wavelet Transform Analysis

Water level time series in coastal wetlands are influenced by tides, precipitation, and storm surges, showing complex, non-stationary variability (Zhang et al., 2019). Wavelet analysis is widely used in coastal hydrology to resolve such multi-scale variability in the time-frequency domain (Dai et al., 2019; Henderson et al., 2009; Nordio & Fagherazzi, 2022). We performed continuous wavelet transform (CWT) and wavelet coherence (WTC) analyses using a Morlet wavelet in MATLAB 2024a (Text S2 in Supporting Information S1). The Morlet wavelet

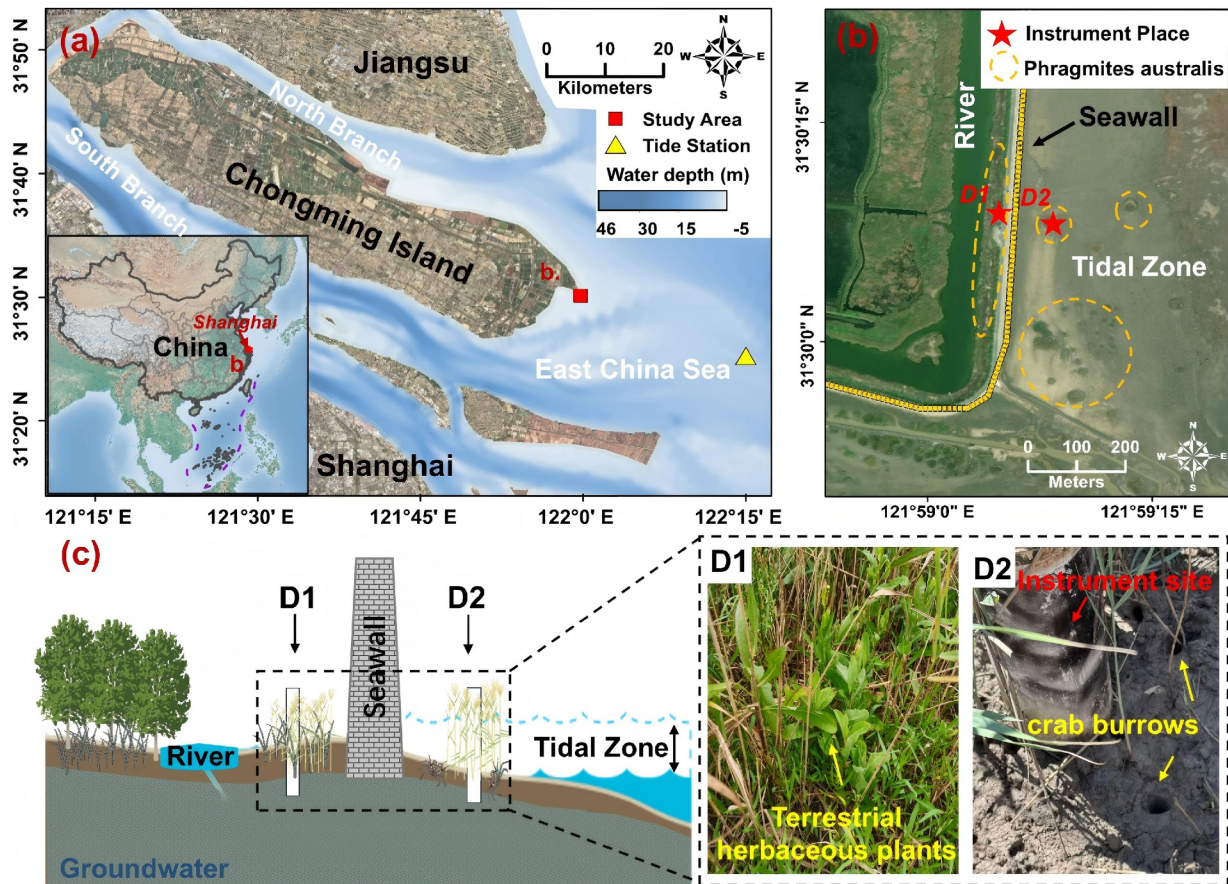


Figure 1. Study area. (a) Location of Chongming Island in China, (b) Station layout and (c) Instrument deployment and habitat conditions at D1 (inside) and D2 (outside) the seawall.

was selected because groundwater depth variations associated with tidal forcing exhibit smooth oscillatory behavior (Morlet et al., 1982). Its complex formulation provides time-frequency localization and phase information, enabling identification of tidal periodicities and quantification of phase lags between groundwater responses and tidal forcing. CWT was used to identify dominant periodicities and their controlling factors, whereas WTC quantified scale-dependent coherence and phase relationships between groundwater depth and tidal forcing, providing insights into aquifer–tide interactions (Labat, 2005; Torrence & Compo, 1998).

2.3.2. Statistical Analysis

Given the nonnormal distribution of the hydrological, water quality, and vegetation morphology data, Mann-Whitney U tests ($\alpha = 0.05$) were used to assess differences between variables inside and outside the seawall. Spearman correlation analyses were conducted to examine relationships between cumulative precipitation and hydrological and water quality variables (Mann & Whitney, 1947; Wissler, 1905).

3. Results

3.1. Periodic Fluctuations of Groundwater Depths

Groundwater depth (GWD) fluctuated markedly at both monitoring wells, inside (D1) and outside (D2) the seawall (Figure 2a). Inside the seawall, GWD ranged from 0.20 to 1.17 m with a mean of 0.72 ± 0.28 m and a fluctuation amplitude of 0.49 m. Outside the seawall, GWD was shallower and more stable, ranging from 0.12 to 0.92 m with a mean of 0.62 ± 0.21 m and a smaller fluctuation amplitude of 0.40 m. GWD fluctuations also exhibited temporal asymmetry. During the observation period, four episodes of rapid GWD rise occurred around March 3, 11, 26, and April 11, associated with intense rainfall events. In these episodes, GWD exhibited an

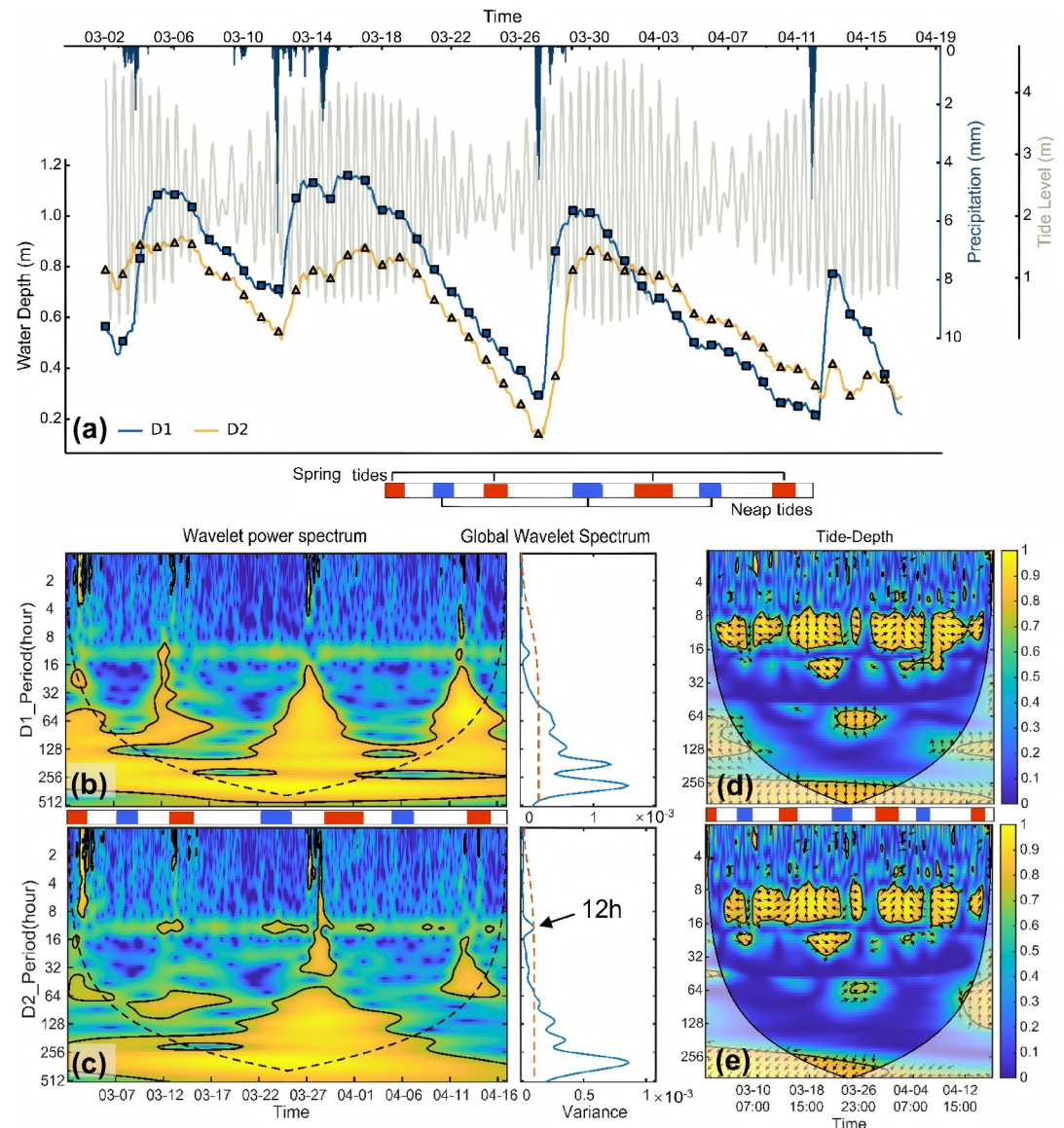


Figure 2. Time series and wavelet analyses of groundwater depth (GWD) inside (D1) and outside (D2) the seawall. (a) GWD time series (b, c) Wavelet power spectra at D1 and D2. (d, e) Wavelet coherence between GWD and tidal forcing at D1 and D2. Red and blue blocks represent spring and neap tide phases, respectively. Arrows indicate phase relationships (→: in phase; ←: anti-phase; ↑/↓: tidal forcing leads/lags GWD).

average rising rate of 0.017 m/hr inside the seawall, more than twice the 0.007 m/hr observed outside, indicating a faster response inside the seawall (Figure 2a). In contrast, the recession phase was slower, with declining rates below 0.004 m hr^{-1} . Notably, high water levels persisted longer outside the seawall, with levels inside the seawall beginning to decline around 16 March and those outside around 19 March (Figure 2a).

Despite dominant long-term trends, GWD also varied at hourly to daily timescales. CWT revealed a non-stationary 12 hr signal at both sites, corresponding to the semi-diurnal (M2) tidal cycle (Figures 2b and 2c). Intermittent wavelet ridges exceeding the global significance level appeared outside the seawall during late March and early April, whereas the corresponding power inside the seawall was weaker and generally below the significance level (Figure 2b). At longer periods (128–256 hr), both sites exhibited persistent cycles, with relatively stronger and more evenly distributed wavelet power inside the seawall, indicating more persistent low-frequency (long-term) variability (Figures 2b and 2c).

To further examine the temporal coupling between the two sites, WTC analysis was performed. Strong coherence between GWD inside and outside the seawall was observed at short periods (2–64 hr) (Figure S2 in Supporting Information S1). At longer periods (64–256 hr), GWD inside the seawall lagged behind that outside the seawall by approximately 1/8 of a cycle (Figure S2 in Supporting Information S1). During rainfall events, GWD increased more markedly inside the seawall, while short-period coherence between the two sites weakened (Figure S2 in Supporting Information S1). Significant coherence between GWD and tidal level was observed at the 12 hr period (Figures 2d and 2e). GWD initially lagged the tide during the early neap-to-spring transition and gradually approached an in-phase response. Around the spring tidal peak, the phase shift between GWD and the tidal signal became smaller, before increasing again toward neap tide as coherence weakened (Figures 2d and 2e).

3.2. Changes in Groundwater Quality

Groundwater quality differed sharply between the landward and seaward sides of the seawall, with higher salinity seaward and higher CHL, TOC, and COD landward (Figure 3). Time-series analysis showed a general decreasing trend in salinity at both sites (Figure 3a). However, salinity at the seaward site remained higher than at the landward site, with median values of 14.96 and 1.14, respectively. Salinity variability was also markedly greater seaward (IQR = 0.40) than landward (IQR = 0.01) (Figure 3b). Similar patterns of greater variability in the seaward zone were observed for CHL, TOC, and COD (Figures 3c–3e). In contrast, their concentrations were consistently higher in the landward zone (Figure 3a). Median values of CHL, TOC, and COD were consistently higher at the landward site (4.11 $\mu\text{g/L}$, 70.64 mg/L, and 28.17 mg/L) than at the seaward site (1.82 $\mu\text{g/L}$, 20.65 mg/L, and 8.16 mg/L) (Figures 3c–3e).

Groundwater quality exhibited short-term fluctuations around four heavy rainfall events (defined here as events with a peak hourly precipitation rate exceeding 1 mm hr^{-1} within a 24 hr period) on 3 March, 11 March, 26 March, and 11 April (Figure 3a). Salinity at both sites generally decreased during these periods. CHL declined by approximately 4% at the landward site, whereas no clear change was observed at the seaward site. In contrast, COD and TOC at both sites generally increased and subsequently declined. At the landward site, COD and TOC increased within approximately one day before decreasing, whereas at the seaward site they briefly stabilized before declining after 1–3 days. Additionally, a distinct short-term increase in salinity and CHL occurred at the seaward site around 28 March, coinciding with a storm-surge event; salinity increased from approximately 14.90 to 15.39 and CHL rose from 1.72 to 2.34 (Figure 3a). No comparable fluctuation was observed at the landward site. Spearman analysis revealed significant negative relationships between salinity and cumulative precipitation at both sites (Text S3 in Supporting Information S1). GWD and CHL showed stronger negative correlations with precipitation at the landward site, whereas COD and TOC exhibited weaker and more variable relationships (Text S3 in Supporting Information S1).

3.3. Vegetation Characteristics Across the Seawall

Sampling plots adjacent to the groundwater monitoring sites were used to characterize *Phragmites australis* morphology inside (D1) and outside (D2) the seawall. Although reed density was comparable, plant morphology differed markedly between the two areas (Table S2 in Supporting Information S1). *P. australis* outside the seawall exhibited greater plant height and culm diameter than those inside the seawall. Mean plant height outside the seawall was 104.25 ± 26.53 cm, with a culm diameter of 0.46 ± 0.11 cm. Inside the seawall, the corresponding values were 78.25 ± 12.20 cm and 0.33 ± 0.09 cm, respectively (Table 1). Both differences were statistically significant ($p < 0.001$ for both). Leaf number was also higher outside the seawall (8–9 leaves per plant) than inside (6–8 leaves per plant) (Table 1). Multiple terrestrial herbaceous species co-occurred with *P. australis* inside the seawall, where *Phragmites* dominance was lower than outside (Figure 1c).

4. Discussion

4.1. Seawall Impacts

In tide-dominated coastal wetlands, water-depth dynamics are primarily controlled by tidal forcing (Buschman et al., 2009). Seawalls can alter tidal propagation and hydrodynamic connectivity, generating hydrogeochemical contrasts across the structure (Duan et al., 2025). In CMD, semi-diurnal tides produce a 12 hr periodicity (Figure S3 in Supporting Information S1), with groundwater influenced by both freshwater runoff and tidal flow

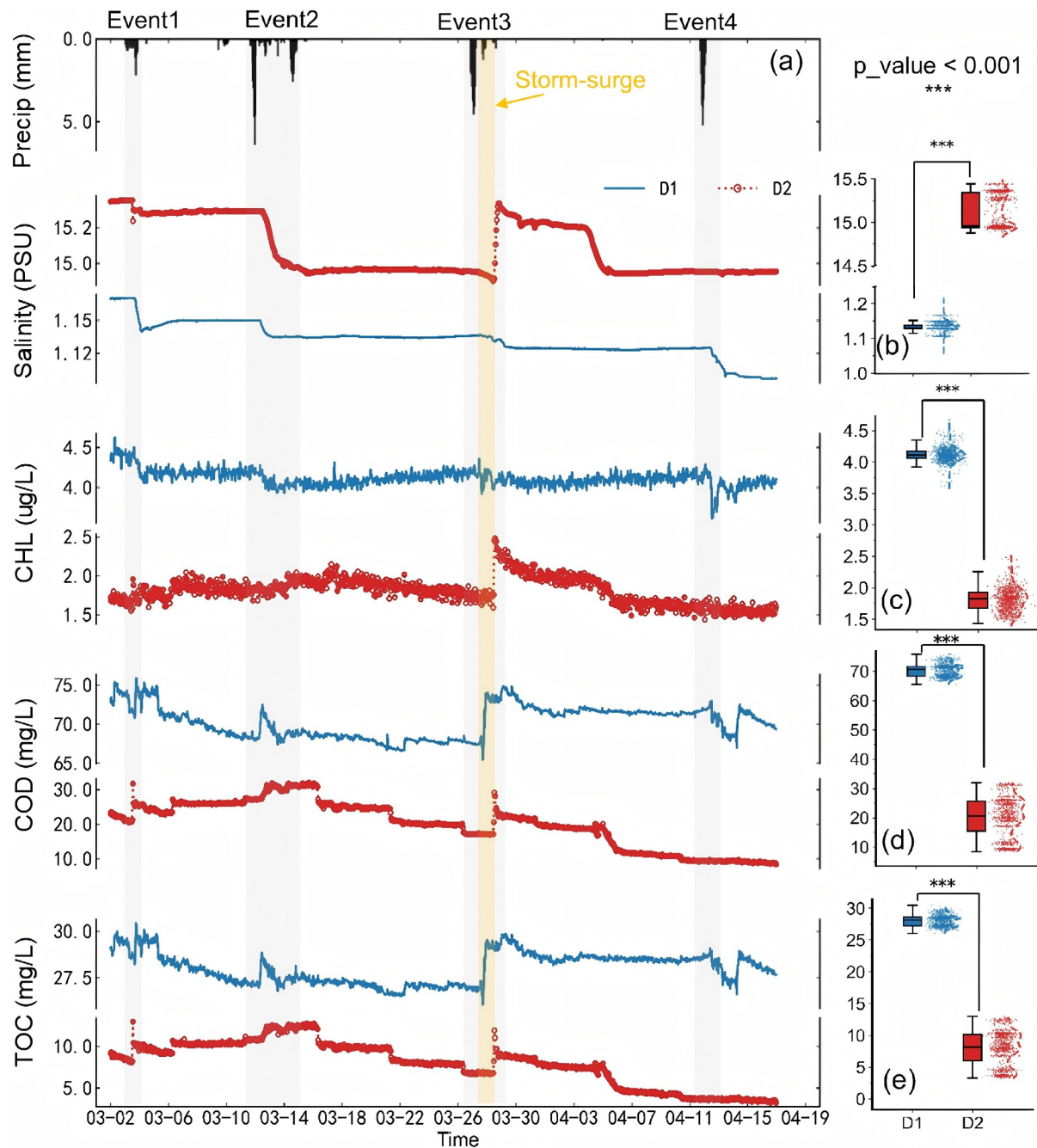


Figure 3. Groundwater quality inside (D1) and outside (D2) the seawalls. ***Indicated significance at the 0.001 level. (a) Time series of groundwater quality parameters and precipitation; gray and yellow shading indicate precipitation events and storm surges, respectively (b–e) Boxplots of (b) salinity, (c) CHL, (d) COD, and (e) TOC.

(Figure 4). However, the contrasting hydrodynamic responses between the two nearby monitoring sites indicate reduced land–sea hydrological interaction landward of the seawall (Figures 2 and 3).

The seawall affects groundwater in two main ways. First, groundwater inside the seawall showed weaker responses to tidal forcing and delayed long-term fluctuations (Figure 2). Tidal fluctuations were also dampened landward from spring to neap tides (Figure S4 in Supporting Information S1). Outside the seawall, continued tidal backwater enhances tidal influence on groundwater, resulting in prolonged high stands during spring tides and more stable GWD fluctuations (Figures 2a and S4 in Supporting Information S1). At longer periods, GWD inside the seawall lags >6 hr behind that outside (Figure S2 in Supporting Information S1). This lag suggests a transition

Table 1
Vegetation Characteristics in Quadrats Inside and Outside the Seawall

Plant parameters	D1 (inside)	D2 (outside)	p-value
Number of plants	90	106	—
Leaves per plant	6–8	8–9	—
Height (cm)	78.25 ± 12.20	104.25 ± 26.53	<0.001 ***
Culm diameter (cm)	0.33 ± 0.09	0.46 ± 0.11	<0.001 ***

Note. Values are presented as mean ± SD. p-values were calculated using the Mann–Whitney U test. *** indicates $p < 0.001$.

from a tide-driven regime seaward to a weakly tide-coupled regime landward, with suppressed high-frequency tidal signals (Figure 4a). However, the seawall primarily dampened groundwater response amplitude rather than dominant tidal periodicity. The observed tidal-GWD phase shift may reflect an asymmetric groundwater response to the weakening and strengthening of tidal forcing during the spring–neap cycle. During the spring-to-neap transition, aquifer storage may buffer weakening tidal forcing, allowing groundwater levels to retain part of their preceding response and causing a changing delay as wavelet coherence decreases (Figure 2).

Second, reduced hydrological exchange behind the seawall alters groundwater environmental conditions. Inside the seawall, salinity remains consistently low and insensitive to tidal fluctuations, indicating limited tidal influence and stronger freshwater influence (Figures 3b and S4 in Supporting Information S1). Restricted exchange may reduce flushing and favor organic matter accumulation, consistent with the higher CHL, COD, and TOC concentrations observed landward of the seawall (He et al., 2020; Figure 3). In contrast, the seaward area shows greater salinity variability, with extreme spring tides (during the 28 March storm-surge event) causing abrupt increases in salinity, CHL, COD, and TOC during surface inundation (Figure S5 in Supporting Information S1). Stronger tidal flushing promotes water renewal and maintains active hydrological connectivity with coastal waters (Figure 3; Mitchell et al., 2017).

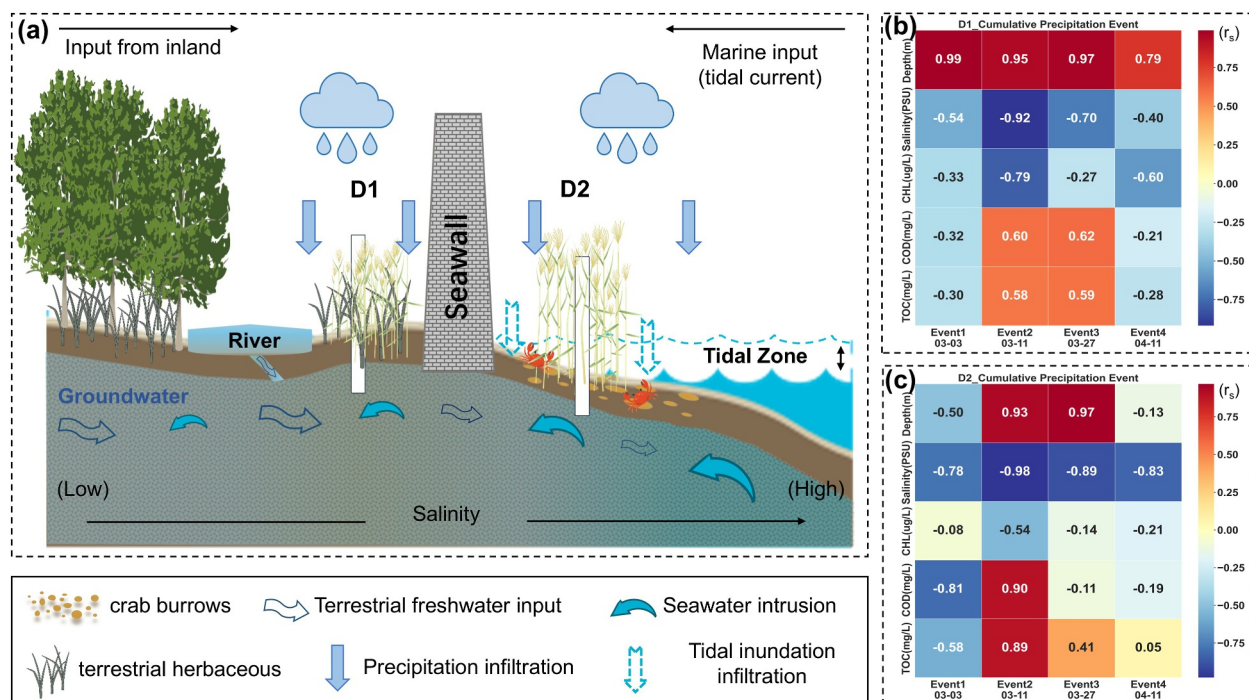


Figure 4. (a) Conceptual framework of hydrological inputs and precipitation-driven responses inside and outside the seawall; (b,c) Spearman correlation coefficients (r_s) between hydro-environmental variables and cumulative precipitation.

4.2. Impacts From Episode Precipitation Events

Coastal shallow groundwater systems are highly sensitive to hydrological recharge and atmospheric forcing, responding rapidly to precipitation and short-term weather variability (Pratt et al., 2025; J. Xu et al., 2025). In our study, precipitation temporarily overrode tidal forcing during heavy rainfall events. Through recharge-induced changes in groundwater dynamics, precipitation weakened the coupling between groundwater levels and tidal oscillations, resulting in a temporary masking of tidal signals at the event scale (Figure 2). Salinity generally declined following rainfall events, suggesting that freshwater recharge was the primary driver of short-term groundwater responses (Figures 4b and 4c). Stronger precipitation responses inside the seawall suggest altered hydrological connectivity, whereas tidal forcing and groundwater-seawater exchange likely dampen precipitation signals outside the seawall (Figures 4b and 4c). Brief increases in TOC and COD were observed in both inside- and outside-seawall groundwater during intense rainfall events, potentially reflecting pulse-like inputs of terrestrial organic matter. However, these responses were short-lived, suggesting rapid dilution and transport within the groundwater system, thereby limiting cumulative responses to precipitation.

4.3. Ecological Responses to Seawall-Induced Hydrodynamic Buffering

Seawalls can alter hydrological conditions and potentially influence vegetation structure (Bi et al., 2014; Yang et al., 2017). Crab burrows were widely observed outside the seawall (Figure 1c), and previous studies show that they can enhance groundwater-surface water exchange and tidal connectivity (X. Xu et al., 2025). Greater exchange outside the seawall may maintain more dynamic conditions, whereas restricted exchange inside may reduce flushing and influence salinity and water quality (Figures 2 and 3). These contrasting hydro-environmental conditions coincided with differences in vegetation structure, with *Phragmites australis* outside the seawall exhibiting greater plant height and larger stem diameter (Table 1). Inside the seawall, weaker *P. australis* growth and the presence of terrestrial plant species were observed, potentially indicating reduced dominance of *P. australis* (Figure 1c).

Together, these findings suggest that seawall-associated hydrological isolation and reduced tidal flushing can influence coastal hydrology and ecological structure (Figure 4). These processes may also occur in other coastal settings where seawalls and other hard infrastructure modify tidal-wetland connectivity, potentially contributing to wetland fragmentation and associated ecological impacts (Bulleri & Chapman, 2010). This trend increases ecological risks, including water quality degradation, reduced ecosystem resilience to sea-level rise and extreme events, and loss of tidal wetlands (Angnuureng et al., 2025; Leo et al., 2019). Future research should assess the cumulative hydro-ecological effects of seawalls and develop integrated coastal protection strategies combining structural and ecosystem-based approaches (Dai et al., 2026; Y. Xu et al., 2021). Such strategies can help safeguard wetland integrity and enhance coastal ecosystem resilience globally.

4.4. Limitations and Future Directions

Our observations reveal contrasting groundwater and biogeochemical conditions across the seawall, but several limitations remain. First, groundwater was monitored at one site inside and one outside the seawall. Their similar distances from the seawall and broadly comparable sedimentary settings improve site comparability. However, the lack of spatial replication and distance gradients limits quantitative separation of seawall effects from variations in hydrogeological properties and direct quantification of groundwater exchange. Second, the asynchronous timing of hydrological and vegetation observations limits direct linkage between vegetation morphology and specific hydrological states. In this study, vegetation traits reflect cumulative environmental influences and spatial contrasts between sites rather than short-term hydrological responses. Future studies combining denser observations with tracer-based approaches and hydrological modeling could better quantify groundwater exchange and its spatial and temporal dynamics under seawall modification.

5. Conclusions

This study reveals the hydro-ecological impacts of seawalls on coastal wetlands in Chongming Island, Changjiang estuary, China. Our key conclusions are as follows:

1. Seawall isolation limits tidal influence on groundwater. Water inside the seawall exhibits lower salinity variability and weaker tidal signals than outside, where semi-diurnal tidal cycles dominate, suggesting reduced hydrological exchange. Reduced flushing may contribute to altered groundwater quality.
2. Precipitation drives rapid changes in groundwater and water quality. These responses are stronger inside the seawall, whereas outside, tidal forcing masks rainfall effects on groundwater dynamics and chemistry.
3. Seawall-induced hydrological alterations may contribute to vegetation differentiation. Higher salinity and improved water quality outside the seawall coincide with greater *Phragmites australis* dominance. Limited exchange and lower salinity inside correspond with lower *Phragmites australis* dominance and the coexistence of terrestrial herbaceous species.

Although seawalls protect against storm surges, they inevitably alter coastal wetland hydro-ecology. Integrating ecological considerations into seawall design and management can reconcile infrastructure safety with ecosystem conservation, supporting resilient and sustainable coastal landscapes.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

The main statistical and analytical data supporting this study are available from the Zenodo repository (<https://doi.org/10.5281/zenodo.21023659>; Zhao et al., 2026) including groundwater observations during representative neap, medium, and spring tides, summary water-quality statistics, and vegetation quadrat measurements collected. Precipitation data were obtained from the ERA5 hourly data on single levels provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) through the Copernicus Climate Change Service (C3S) Climate Data Store (CDS) (<https://doi.org/10.24381/cds.adbb2d47>; Hersbach et al., 2023).

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References

- Angnuureng, D. B., Charuka, B., Almar, R., Dada, O. A., Asumadu, R., Agboli, N. A., & Ofosu, G. T. (2025). Challenges and lessons learned from global coastal erosion protection strategies. *iScience*, 28(4), 112055. <https://doi.org/10.1016/j.isci.2025.112055>
- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169–193. <https://doi.org/10.1890/10-1510.1>
- Bi, X., Wen, X., Yi, H., Wu, X., & Gao, M. (2014). Succession in soil and vegetation caused by coastal embankment in southern Laizhou Bay, China-Flourish or degradation? *Ocean & Coastal Management*, 88, 1–7. <https://doi.org/10.1016/j.ocecoaman.2013.11.013>
- Bishop, M. J., Mayer-Pinto, M., Airoldi, L., Firth, L. B., Morris, R. L., Loke, L. H. L., et al. (2017). Effects of ocean sprawl on ecological connectivity: Impacts and solutions. *Journal of Experimental Marine Biology and Ecology*, 492, 7–30. <https://doi.org/10.1016/j.jembe.2017.01.021>
- Boyer, J. N., Kelble, C. R., Ortner, P. B., & Rudnick, D. T. (2009). Phytoplankton bloom status: Chlorophyll a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA. *Ecological Indicators*, 9(6), S56–S67. <https://doi.org/10.1016/j.ecolind.2008.11.013>
- Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, 47(1), 26–35. <https://doi.org/10.1111/j.1365-2664.2009.01751.x>
- Bushman, F. A., Houtink, A. J. F., van der Vegt, M., & Hoekstra, P. (2009). Subtidal water level variation controlled by river flow and tides. *Water Resources Research*, 45(10). <https://doi.org/10.1029/2009WR008167>
- Byun, D. S., Wang, X. H., & Holloway, P. E. (2004). Tidal characteristic adjustment due to dyke and seawall construction in the Mokpo Coastal Zone, Korea. *Estuarine, Coastal and Shelf Science*, 59(2), 185–196. <https://doi.org/10.1016/j.ecss.2003.08.007>
- Chen, C., Liu, Y., Dokohely, M. E., Liu, J., & Hu, B. (2024). Assessing the ecological response plant and soil to the seawalls in the Laizhou bay coastal wetland, China. *Marine Environmental Research*, 201, 106678. <https://doi.org/10.1016/j.marenvres.2024.106678>
- Cousins, L. J., Cousins, M. S., Gardiner, T., & Underwood, G. J. C. (2017). Factors influencing the initial establishment of salt marsh vegetation on engineered sea wall terraces in south east England. *Ocean & Coastal Management*, 143, 96–104. <https://doi.org/10.1016/j.ocecoaman.2016.11.010>
- Dai, Z., Du, J., Tang, Z., Ou, S., Brody, S., Mei, X., et al. (2019). Detection of linkage between solar and lunar cycles and runoff of the world's large Rivers. *Earth and Space Science*, 6(6), 914–930. <https://doi.org/10.1029/2018EA000541>
- Dai, Z., Zhang, M., & Darby, S. E. (2026). Effectiveness of ecosystem-based coastal defenses against flooding. *Earth's Future*, 14(3), e2025EF006234. <https://doi.org/10.1029/2025EF006234>
- Duan, X., Yin, P., He, X., Chen, B., Cao, K., & Tong, G. (2025). Unraveling nonlinear interactions: A DPSIR-Based conceptual model for synergistic impacts of climate change and human activities on coastal blue carbon ecosystems. *Global Change Biology*, 31(8), e70432. <https://doi.org/10.1111/gcb.70432>
- Gittman, R. K., Scyphers, S. B., Smith, C. S., Neylan, I. P., & Grabowski, J. H. (2016). Ecological consequences of shoreline hardening: A meta-analysis. *BioScience*, 66(9), 763–773. <https://doi.org/10.1093/biosci/biw091>
- He, Y., Wang, P., Sheng, H., Wang, D., Huang, M., & Cao, C. (2020). Sustainability of riparian zones for non-point source pollution control in Chongming Island: Status, challenges, and perspectives. *Journal of Cleaner Production*, 244, 118804. <https://doi.org/10.1016/j.jclepro.2019.118804>

- Heiss, J. W., & Michael, H. A. (2014). Saltwater-freshwater mixing dynamics in a sandy beach aquifer over tidal, spring-neap, and seasonal cycles. *Water Resources Research*, 50(8), 6747–6766. <https://doi.org/10.1002/2014WR015574>
- Henderson, R. D., Day-Lewis, F. D., & Harvey, C. F. (2009). Investigation of aquifer-estuary interaction using wavelet analysis of fiber-optic temperature data. *Geophysical Research Letters*, 36(6). <https://doi.org/10.1029/2008GL036926>
- Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., et al. (2023). ERA5 hourly data on single levels from 1940 to present [Dataset]. *Copernicus Climate Change Service (C3S) Climate Data Store (CDS)*. <https://doi.org/10.24381/cds.adbb2d47>
- Labat, D. (2005). Recent advances in wavelet analyses: Part I. A review of concepts. *Journal of Hydrology*, 314(1), 275–288. <https://doi.org/10.1016/j.jhydrol.2005.04.003>
- Lee, E. I. H., & Nepf, H. (2024). Marsh restoration in front of seawalls is an economically justified nature-based solution for coastal protection. *Communications Earth & Environment*, 5(1), 605. <https://doi.org/10.1038/s43247-024-01753-5>
- Leo, K. L., Gillies, C. L., Fitzsimons, J. A., Hale, L. Z., & Beck, M. W. (2019). Coastal habitat squeeze: A review of adaptation solutions for saltmarsh, mangrove and beach habitats. *Ocean & Coastal Management*, 175, 180–190. <https://doi.org/10.1016/j.ocecoaman.2019.03.019>
- LeRoux, N. K., Frey, S. K., Lapen, D. R., Guimond, J. A., & Kurylyk, B. L. (2023). Mega-tidal and surface flooding controls on coastal groundwater and saltwater intrusion within agricultural dikedlands. *Water Resources Research*, 59(11), e2023WR035054. <https://doi.org/10.1029/2023WR035054>
- Li, Y., Xu, J., Wright, A., Qiu, C., Wang, C., & Liu, H. (2021). Integrating two aspects analysis of hydrological connectivity based on structure and process to support muddy coastal restoration. *Ecological Indicators*, 133, 108416. <https://doi.org/10.1016/j.ecolind.2021.108416>
- Ma, Z., Melville, D. S., Liu, J., Chen, Y., Yang, H., Ren, W., et al. (2014). Rethinking China's new great wall. *Science*, 346(6212), 912–914. <https://doi.org/10.1126/science.1257258>
- Mann, H. B., & Whitney, D. R. (1947). On a Test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, 18(1), 50–60. <https://doi.org/10.1214/aoms/1177730491>
- Mitchell, S., Boateng, I., & Couceiro, F. (2017). Influence of flushing and other characteristics of coastal lagoons using data from Ghana. *Ocean & Coastal Management*, 143, 26–37. <https://doi.org/10.1016/j.ocecoaman.2016.10.002>
- Morlet, J., Arens, G., Fourgeau, E., & Giard, D. (1982). Wave propagation and sampling theory: Part I, Complex signal and scattering in multilayered media. *Geophysics*, 47(2), 203–221. <https://doi.org/10.1190/1.1441328>
- Morris, R. L., Konlechner, T. M., Ghisalberti, M., & Swearer, S. E. (2018). From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. *Global Change Biology*, 24(5), 1827–1842. <https://doi.org/10.1111/gcb.14063>
- National Marine Data and Information Service. (2024). *China Coastal tidal tables: Shanghai port and Hangzhou Bay*. China Navigation Publications Press.
- Nordio, G., & Fagherazzi, S. (2022). Storm surge and tidal dissipation in deltaic wetlands bordering a main channel. *Journal of Geophysical Research: Oceans*, 127(3), e2021JC017655. <https://doi.org/10.1029/2021jc017655>
- Park, J. W., Kim, S. Y., Noh, J. H., Bae, Y. H., Lee, J. W., & Maeng, S. K. (2022). A shift from chemical oxygen demand to total organic carbon for stringent industrial wastewater regulations: Utilization of organic matter characteristics. *Journal of Environmental Management*, 305, 114412. <https://doi.org/10.1016/j.jenvman.2021.114412>
- Plant Science Data Center. (2022). Vegetation Quadrat Survey data standard [online]. Beijing: Plant science data Center. Retrieved from <https://www.plantplus.cn/cn/standards/10>
- Pratt, D., Guimond, J. A., Bacmeister, E. S., Fagherazzi, S., & Michael, H. A. (2025). Terrestrial groundwater drives coastal ecosystem shifts. *Geophysical Research Letters*, 52(14), e2025GL116251. <https://doi.org/10.1029/2025GL116251>
- Sadat-Noori, M., Andersen, M. S., Rutledge, H., & Glamore, W. (2025). Coastal wetland restoration effects on carbon dynamics: A groundwater perspective. *Reviews of Geophysics*, 63(3), e2025RG000895. <https://doi.org/10.1029/2025RG000895>
- Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*, 79(1), 61–78. [https://doi.org/10.1175/1520-0477\(1998\)079<0061:APGTWA>2.0.CO;2](https://doi.org/10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2)
- Welch, B. A., Davis, C. B., & Gates, R. J. (2006). Dominant environmental factors in wetland plant communities invaded by *Phragmites australis* in East Harbor, Ohio, USA. *Wetlands Ecology and Management*, 14(6), 511–525. <https://doi.org/10.1007/s11273-006-9004-8>
- White, E., & Kaplan, D. (2017). Restore or retreat? Saltwater intrusion and water management in coastal wetlands. *Ecosystem Health and Sustainability*, 3(1), e01258. <https://doi.org/10.1002/ehs2.1258>
- Wissler, C. (1905). The spearman correlation formula. *Science*, 22(558), 309–311. <https://doi.org/10.1126/science.22.558.309>
- Xin, P., Wilson, A., Shen, C., Ge, Z., Moffett, K. B., Santos, I. R., et al. (2022). Surface water and groundwater interactions in salt marshes and their impact on plant ecology and coastal biogeochemistry. *Reviews of Geophysics*, 60(1), e2021RG000740. <https://doi.org/10.1029/2021RG000740>
- Xu, J., Wei, J., Hou, M., Fu, X., Yang, Z., Zhang, T., et al. (2025). Groundwater dynamics and renewal responses in the plain section of the Yongding River, exemplified by extreme precipitation events. *Groundwater for Sustainable Development*, 31, 101522. <https://doi.org/10.1016/j.gsd.2025.101522>
- Xu, X., Yu, X., Wu, J., Xiao, K., & Xin, P. (2025). Tidal influences on temperature dynamics and heat exchange in coastal wetlands. *Water Resources Research*, 61(2), e2024WR038374. <https://doi.org/10.1029/2024WR038374>
- Xu, Y., Cai, Y., Sun, T., Yin, X., Tan, Q., Sun, J., & Peng, J. (2021). Ecological preservation based multi-objective optimization of coastal seawall engineering structures. *Journal of Cleaner Production*, 296, 126515. <https://doi.org/10.1016/j.jclepro.2021.126515>
- Yang, W., Qiao, Y., Li, N., Zhao, H., Yang, R., Leng, X., et al. (2017). Seawall construction alters soil carbon and nitrogen dynamics and soil microbial biomass in an invasive *Spartina alterniflora* salt marsh in eastern China. *Applied Soil Ecology*, 110, 1–11. <https://doi.org/10.1016/j.apsoil.2016.11.007>
- Zhang, J., Zhang, X., Niu, J., Hu, B. X., Soltanian, M. R., Qiu, H., & Yang, L. (2019). Prediction of groundwater level in seashore reclaimed land using wavelet and artificial neural network-based hybrid model. *Journal of Hydrology*, 577, 123948. <https://doi.org/10.1016/j.jhydrol.2019.12.3948>
- Zhang, W., Zeng, J., Ge, Z.-M., Yun, P., Zhu, K.-H., Zhou, K., et al. (2023). Dike risk evaluation incorporating the contribution of coastal wetlands: A case study on Chongming Island, China. *Ocean & Coastal Management*, 245, 106874. <https://doi.org/10.1016/j.ocecoaman.2023.106874>
- Zhang, X., Xiao, X., Wang, X., Xu, X., Qiu, S., Pan, L., et al. (2023). Continual expansion of *Spartina alterniflora* in the temperate and subtropical coastal zones of China during 1985–2020. *International Journal of Applied Earth Observation and Geoinformation*, 117, 103192. <https://doi.org/10.1016/j.jag.2023.103192>
- Zhao, B., Dai, Z., Liang, X., Zhang, W., Xu, F., Mei, X., & Fagherazzi, S. (2026). Data for “Seawall-induced isolation drives hydrological-biogeochemical shifts in coastal wetlands” [Dataset]. *Zenodo*. <https://doi.org/10.5281/zenodo.21023659>

References From the Supporting Information

- Domingues, M. O., Mendes, O., & da Costa, A. M. (2005). On wavelet techniques in atmospheric sciences. *Advances in Space Research*, 35(5), 831–842. <https://doi.org/10.1016/j.asr.2005.02.097>
- Fan, J., Li, J., Xie, Y., Zhang, H., & Jiang, X. (2025). Synchronous responses to tidal restriction by seawall construction across fish and plankton communities in Yangtze River Estuary. *Marine Environmental Research*, 210, 107312. <https://doi.org/10.1016/j.marenvres.2025.107312>
- Grinsted, A., Moore, J. C., & Jevrejeva, S. (2004). Application of the cross wavelet transform and wavelet coherence to geophysical time series. *Nonlinear Processes in Geophysics*, 11(5/6), 561–566. <https://doi.org/10.5194/npg-11-561-2004>
- Jevrejeva, S., Moore, J. C., & Grinsted, A. (2003). Influence of the Arctic Oscillation and El Niño–Southern Oscillation (ENSO) on ice conditions in the Baltic Sea: The wavelet approach. *Journal of Geophysical Research*, 108(D21). <https://doi.org/10.1029/2003jd003417>
- Kumar, P., & Foufoula-Georgiou, E. (1997). Wavelet analysis for geophysical applications. *Reviews of Geophysics*, 35(4), 385–412. <https://doi.org/10.1029/97RG00427>
- Li, H., Mao, D., Wang, Z., Huang, X., Li, L., & Jia, M. (2022). Invasion of *Spartina alterniflora* in the coastal zone of mainland China: Control achievements from 2015 to 2020 towards the Sustainable Development Goals. *Journal of Environmental Management*, 323, 116242. <https://doi.org/10.1016/j.jenvman.2022.116242>
- Li, X., Ren, L., Liu, Y., Craft, C., Mander, Ü., & Yang, S. (2014). The impact of the change in vegetation structure on the ecological functions of salt marshes: The example of the Yangtze estuary. *Regional Environmental Change*, 14(2), 623–632. <https://doi.org/10.1007/s10113-013-0520-9>
- Meng, W., Feagin, R. A., Innocenti, R. A., Hu, B., He, M., & Li, H. (2020). Invasion and ecological effects of exotic smooth cordgrass *Spartina alterniflora* in China. *Ecological Engineering*, 143, 105670. <https://doi.org/10.1016/j.ecoleng.2019.105670>
- Peng, J., Qiao, R., Liu, Y., Blaschke, T., Li, S., Wu, J., et al. (2020). A wavelet coherence approach to prioritizing influencing factors of land surface temperature and associated research scales. *Remote Sensing of Environment*, 246, 111866. <https://doi.org/10.1016/j.rse.2020.111866>
- Torrence, C., & Webster, P. J. (1999). Interdecadal changes in the ENSO–monsoon system. *Journal of Climate*, 12(8), 2679–2690. [https://doi.org/10.1175/1520-0442\(1999\)012<2679:ICITEM>2.0.CO;2](https://doi.org/10.1175/1520-0442(1999)012<2679:ICITEM>2.0.CO;2)
- Wu, S., Chen, R., & Meadows, M. E. (2019). Evolution of an estuarine Island in the Anthropocene: Complex dynamics of Chongming Island, Shanghai, P.R. China. *Sustainability*, 11(24), 6921. <https://doi.org/10.3390/su11246921>
- Wu, X. (2014). Seawall structure design of Chongming Dongtan ecological restoration project. *China Water Transport (Second Half Month)*, 14(12), 176–177+180. (in Chinese).
- Zhuo, W., Wu, N., Shi, R., Cui, Y., Zhang, C., Liu, S., et al. (2025). Assessing the impacts of reclamation and invasion on ecological dynamics of coastal wetland vegetation in the Yangtze Estuary from 1985 to 2019: A case study of Chongming Island, China. *Journal of Environmental Management*, 376, 124505. <https://doi.org/10.1016/j.jenvman.2025.124505>