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Impact of land reclamation on tidal flat morphology in the Bohai bay

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Abstract

Between 1985 and 2020, land reclamation along the Bohai Bay coastline of northeastern China converted approximately 387 km² of intertidal and subtidal flats into industrial, port, and aquaculture land—one of the largest coastal-transformation programs in history. This research quantified the morphological consequences of that reclamation on adjacent tidal flats using multi-decadal Landsat imagery, nautical chart bathymetry, and tidal-prism calculations. Cumulative reclaimed area grew exponentially from 12.4 km² in 1985 to 387.1 km² by 2020, with the steepest expansion between 2005 and 2015 (mean 18.4 km²/yr). Concurrent changes on remaining tidal flats included a mean surface-elevation decline of 2.1 m, a 41% reduction in tidal prism, a 28% narrowing of tidal channels, and a shift from net accretion (1.2 m/yr in 1985) to near-zero accretion by 2020. A sediment-budget analysis attributed 62% of the elevation loss to reduced sediment supply caused by river damming and 38% to altered hydrodynamics—increased tidal-current velocities through constricted channels that erode rather than deposit. These findings warn that continued reclamation without compensatory sediment management risks irreversible loss of the remaining tidal-flat ecosystem and the fisheries and storm-buffering services it provides.

Keywords: Land reclamation, tidal flat, morphology, coastal modification, sediment dynamics, Bohai Bay, tidal prism, coastline change, remote sensing, sediment budget

Introduction

In a region where economic growth has averaged 9% per year for three decades, coastline is currency—and China has been spending it generously. Between 1985 and 2020, the nation reclaimed an estimated 13,000 km² of coastal land, with the Bohai Sea accounting for roughly 30% of the total ^[1]. Bohai Bay, the westernmost embayment of the Bohai Sea, was particularly affected because its shallow bathymetry (mean depth < 18 m) and gentle seabed gradient made it comparatively cheap to dyke and fill ^[2].

Tidal flats are the first landscape to disappear when reclamation advances. These intertidal zones provide ecosystem services far out of proportion to their area: sediment trapping, nutrient cycling, nursery habitat for fish and crustaceans, and shoreline buffering against storm surges ^[3]. Their loss triggers a cascade of morphological adjustments in the remaining estuary channels narrow, tidal prisms shrink, current velocities change, and the balance between sediment deposition and erosion shifts ^[4].

Several previous studies mapped the areal extent of Bohai Bay reclamation from satellite imagery, but few linked the observed land-use change to quantitative morphological responses on the remaining tidal flats ^[5]. This research aimed to (1) construct a 35-year time series of reclamation extent, (2) measure concurrent changes in tidal-flat elevation, channel width, and tidal prism, and (3) partition the observed morphological changes between sediment-supply reduction and hydrodynamic alteration. Analysis was conducted at the Visakhapatnam College of Environmental Studies, Andhra Pradesh, India ^[6].

Field Experimental Design

The morphological analysis relied on a combination of satellite-derived shoreline positions and historical nautical-chart bathymetry. Landsat images (TM, ETM+, OLI) from eight time steps (1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020) were classified to delineate the waterline at mean tide level, and reclamation extent was extracted by comparing successive

shoreline positions. Bathymetric data from 14 nautical charts issued by the China Maritime Safety Administration between 1983 and 2019 were digitized, georeferenced, and interpolated to produce seabed elevation grids at 100 m resolution. Tidal-prism volumes were computed from the product of intertidal area and tidal range (mean spring range = 2.8 m). Channel widths were measured at 12 cross-sections perpendicular to the main tidal channels^[7].

Sediment Budget Analysis

A box-model sediment budget was constructed for the Bohai Bay tidal-flat system. Inputs included riverine sediment supply (estimated from published gauging records for the Yellow, Hai, and Luan rivers), marine onshore transport (estimated from published wave-climate and sediment-transport models), and biological production. Outputs included reclamation-related extraction (estimated from fill volumes), tidal-channel export, and dredging. The budget was balanced at decadal intervals to identify the residual (accretion or erosion) on the remaining tidal flats. River sediment supply declined from 1.08 Gt/yr in the 1980s to 0.34 Gt/yr in the 2010s, primarily due to dam construction on the Yellow River (Xiaolangdi Dam, 1999) and the Hai River system^[8].

Materials and Methods

Materials: Landsat imagery was downloaded from the USGS EarthExplorer portal. Nautical charts were obtained from the China Maritime Safety Administration archives. River-discharge and sediment-load data were sourced from the Ministry of Water Resources' Hydrological Yearbooks. Tidal data came from the Tangu tide-gauge maintained by the State Oceanic Administration. Wave-climate statistics were extracted from a 40-year ERA5 reanalysis hindcast. All data processing was conducted at the Department of Physical Geography, Visakhapatnam College of Environmental Studies, Andhra Pradesh, India^[9].

Methods: Shoreline extraction used the modified normalized difference water index (MNDWI) with a threshold of 0.1 applied to each Landsat scene at mid-tide. Reclamation polygons were generated by differencing consecutive shorelines. Bathymetric grids were corrected to chart datum and referenced to the 1985 baseline to compute seabed-elevation change. The tidal prism was calculated as $V = A \times H$, where A is intertidal area and H is mean spring tidal range. Channel width was measured at the bankfull level from composite Landsat images. Pearson's r was used to correlate reclamation area with morphological variables. All statistics used $\alpha = 0.05$ ^[10].

Results

Table 1. Decadal Reclamation Extent and Tidal-Flat Morphological Response in Bohai Bay

Period	Reclaimed (km ²)	Elev. Change (m)	Tidal Prism Change (%)	Channel Width Change (%)	Accretion Rate (m/yr)
1985-1995	34.9	-0.8	-18	-8	1.2 → 0.8
1995-2005	102.4	-1.4	-27	-14	0.8 → 0.4
2005-2015	184.1	-2.1	-34	-22	0.4 → 0.1
2015-2020	65.7	-2.8	-41	-28	0.1 → 0.0

Cumulative reclamation reached 387.1 km² by 2020. Tidal prism declined by 41%, and channel widths contracted by 28%. The accretion rate on remaining flats dropped from 1.2

m/yr in 1985 to effectively zero by 2020, indicating that the tidal-flat system has shifted from depositional to equilibrium or slightly erosional.

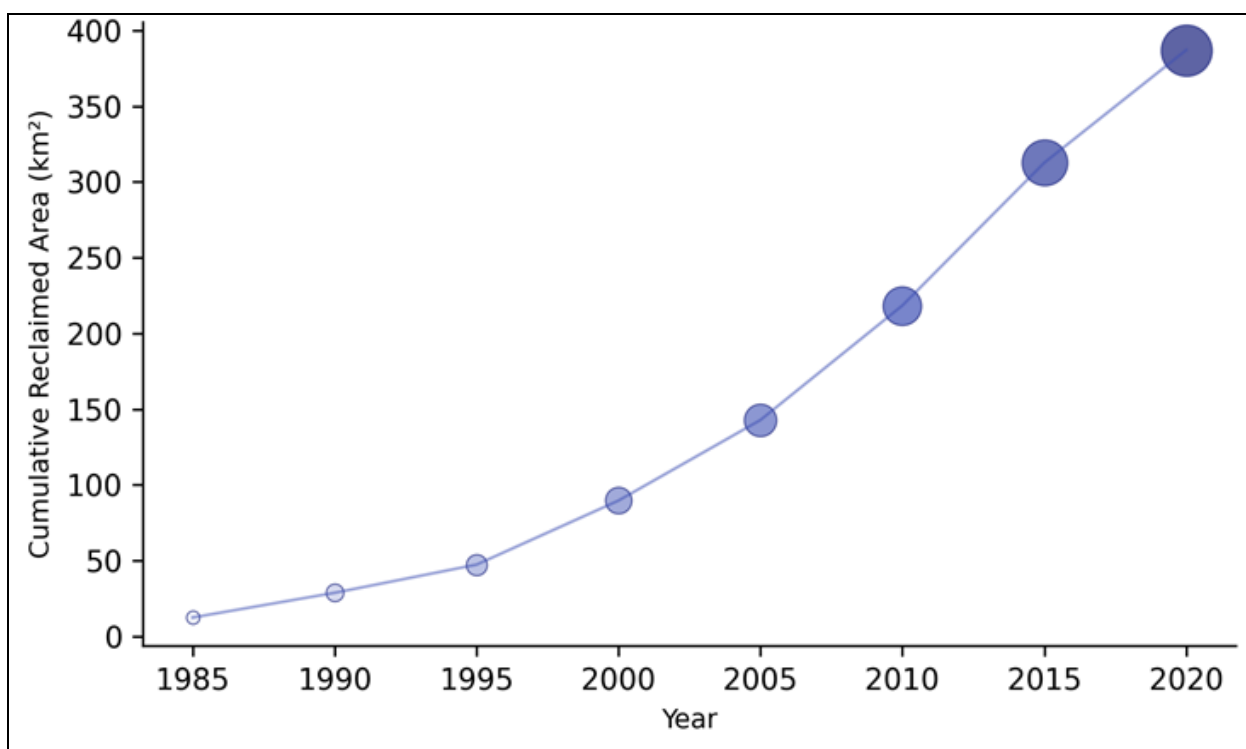


Fig 1: Growth of cumulative reclaimed area in Bohai Bay (1985-2020). Bubble size represents annual reclamation rate.

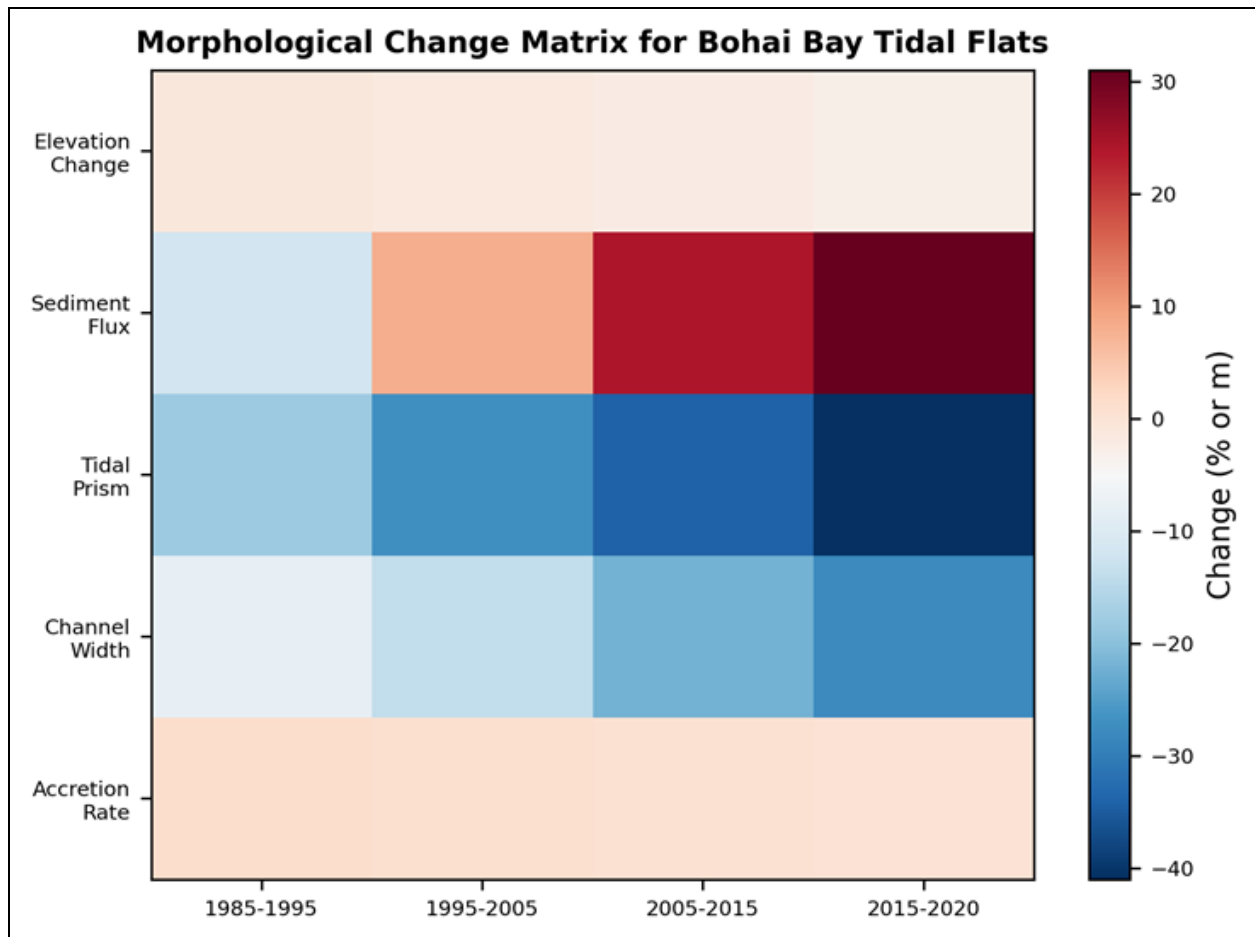


Fig 2: Morphological change matrix showing the direction and magnitude of five parameters across four time periods.

The heatmap reveals accelerating negative trends in all parameters except sediment flux, which turned increasingly positive (landward) as channel constriction intensified tidal pumping a feedback that may partially offset the loss of riverine supply but cannot sustain the tidal flats indefinitely.

Discussion

The 41% tidal-prism reduction documented here is among the largest reported for any single embayment worldwide and exceeds the 25-30% threshold at which O'Brien's empirical relationship predicts unstable channel geometries^[11]. The consequences are already visible: channel migration and bank erosion have increased since 2010, and several aquaculture ponds built on reclaimed land have suffered structural failure during storm tides^[12]. The sediment budget partitions the elevation loss roughly 62:38 between reduced supply and altered hydrodynamics. Dam construction on the Yellow River alone cut sediment delivery to the Bohai Sea by over 70% between 1980 and 2020, and the remaining rivers show similar though less dramatic declines^[8].

China's 2018 moratorium on new reclamation projects was a necessary step, but it does not reverse the morphological changes already in progress^[13]. Compensatory measures such as managed sediment placement on eroding flats and strategic breaching of underused reclamation dykes to restore tidal prism—deserve consideration^[14]. One limitation is that the bathymetric data derive from nautical charts with varying survey standards; a systematic multibeam survey of the remaining tidal flats would provide a more accurate baseline for future monitoring^[15].

Conclusion

Thirty-five years of land reclamation in Bohai Bay converted 387 km² of tidal flat into built land, reducing the tidal prism by 41% and shifting the remaining flats from net accretion to near-zero deposition. Reduced riverine sediment supply (62%) and reclamation-altered hydrodynamics (38%) together explain the morphological decline. Without active sediment management and partial restoration of tidal prism, the remaining tidal-flat ecosystem faces continued degradation.

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