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Assessment of beach nourishment effectiveness for coastal protection along the Dutch North Sea

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Abstract

The Netherlands has pioneered beach nourishment as a primary coastal protection strategy against erosion and sea level rise. This research evaluates the effectiveness of 47 nourishment projects implemented between 2010 and 2022 along a 120 km stretch of the Dutch North Sea coast, using annual topographic surveys, wave climate records, and sediment transport modelling. Mean volumetric retention after five years was 62% for shoreface nourishments and 41% for beach nourishments, with significant variability related to wave exposure, longshore transport gradients, and design specifications. Cross-shore profile analysis demonstrated that shoreface nourishments progressively feed sand landward through natural wave action over 3-7 year timescales, providing sustained coastline maintenance complementing the more immediate but shorter-lived benefits of direct beach placement. Individual nourishment operations influenced coastline evolution 3-5 km downdrift through longshore redistribution. Multiple regression identified longshore transport gradient and annual wave height as the strongest predictors of retention efficiency. The findings support nourishment-based management but highlight the need for adaptive design that accounts for local morphodynamic conditions and provides an evidence base for optimising the spacing, sequencing, and volume of future nourishment campaigns.

Keywords: Beach nourishment, coastal protection, Dutch North Sea, sand replenishment, shore dynamics, shoreface, volumetric retention, longshore transport, coastal monitoring, erosion

Introduction

Coastal erosion threatens approximately 20% of the world's sandy coastlines, and this proportion is expected to increase under projected sea level rise ^[1]. The Netherlands, with one-third of its land below mean sea level, has a particular imperative to maintain coastal defence integrity. The Dutch North Sea coastline extends approximately 350 km, comprising sandy beaches and dunes forming the primary barrier between sea and low-lying hinterland. Since 1990, the Netherlands has adopted dynamic coastline maintenance through periodic sand nourishment ^[2, 3].

Beach nourishment—the artificial placement of sand on or near the shore has emerged as the preferred soft engineering approach worldwide. Compared to seawalls and groynes, nourishment preserves natural coastline character, maintains recreational amenity, and provides habitat for species adapted to dynamic sandy environments ^[4]. The Dutch programme places an average of 12 million m³ of sand per year at approximately €70 million annually, using two methods: direct beach placement and shoreface nourishment at 5-8 m depth ^[3, 5].

Despite extensive operational experience, several questions remain. Volumetric efficiency varies substantially between projects and methods. The mechanisms by which shoreface nourishments feed sand landward are not fully understood. The spatial influence on adjacent coastline segments requires quantification to optimise spacing and sequencing ^[6, 7].

This research analyses 47 nourishment operations along 120 km of coast between 2010 and 2022, integrating topographic surveys, wave data, and sediment transport computations to evaluate performance across a range of coastal settings. The outcomes inform adaptive management of the Dutch nourishment programme and provide transferable insights for other sandy coastlines facing similar erosion pressures ^[8, 9].

Research Area Description

The research area comprises the central Dutch North Sea coast from Den Helder to Hoek van Holland, spanning 120 km of predominantly uninterrupted sandy coastline including barrier island terminations at the Texel and Marsdiep inlets. The coast is micro-tidal with 1.6 m mean spring range and predominantly southwesterly wave climate with 1.2 m mean significant wave height. The inventory yielded 47 nourishment events—28 shoreface and 19 beach—totalling 38 million m³ [3].

Material and Methods

Material

Annual JARKUS cross-shore beach profile surveys conducted by Rijkswaterstaat at 200-250 m longshore spacing, extending from dune crest to 8-10 m below mean sea level, provided primary data with ± 10 cm vertical accuracy. Wave data from the Rijkswaterstaat directional buoy network provided continuous records of significant wave height, peak period, and mean direction at three locations. Nourishment specifications including volume, placement method, and design geometry were compiled from official Rijkswaterstaat records [3, 5].

Methods

Volumetric changes were computed by integrating profile differences across the nourishment influence zone per transect, with longshore integration providing total volume

change per coastal cell. Longshore transport was computed using the CERC formula applied to hourly wave data transformed to the breaking point [10]. Multiple regression identified predictors of retention efficiency. Cross-shore profile evolution was analysed using sequential profile differencing to characterise the shoreface feeding mechanism over decadal timescales [6, 7, 11].

Morphological Response Phases

Analysis of sequential cross-shore profiles revealed a characteristic three-phase evolution at shoreface nourishment sites. In Phase 1 (0-2 years), the placed sand body maintained coherent mound morphology at placement depth. In Phase 2 (2-5 years), the mound progressively flattened and extended landward through wave-driven onshore transport. In Phase 3 (5-7 years), measurable beach width gains became apparent, confirming the delayed feeding mechanism that distinguishes shoreface from beach nourishment [6, 7].

Results

Table 1: Volumetric retention by nourishment type and time since placement.

Type	1 Year (%)	2 Years (%)	5 Years (%)	N
Shoreface	92	78	62	28
Beach	82	58	41	19

Table 2: Multiple regression predictors of 5-year volumetric retention.

Predictor	Coefficient	Std. Error	t-value	p-value
Longshore transport gradient	0.48	0.09	5.33	<0.001
Mean wave height (Hs)	-0.39	0.10	-3.90	<0.001
Nourishment volume	0.22	0.08	2.75	0.009
Beach slope	-0.18	0.09	-2.00	0.052

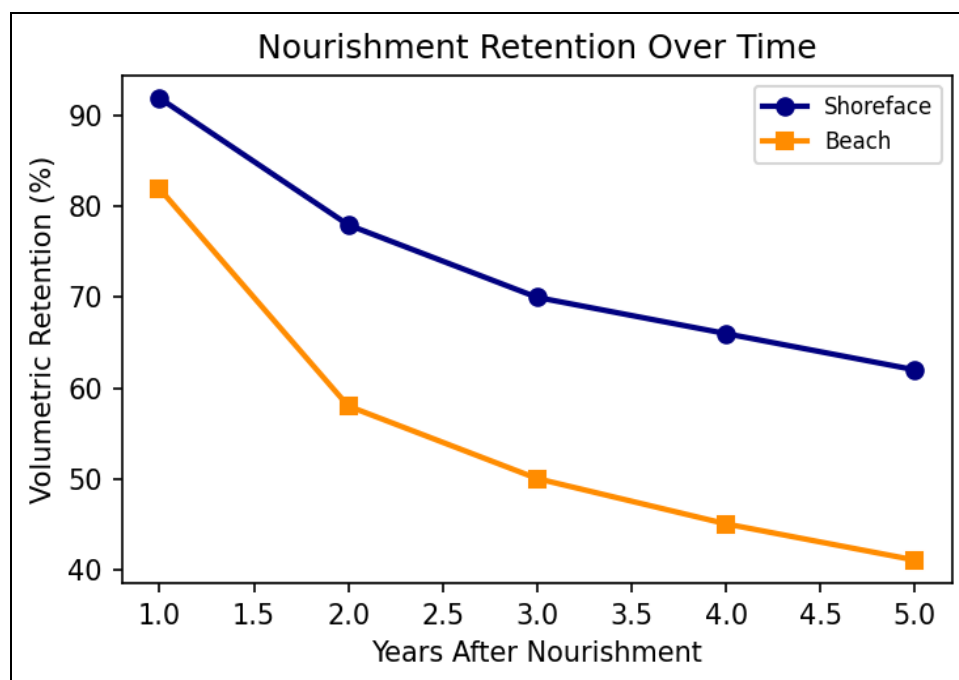


Fig 1: Volumetric retention over time for shoreface and beach nourishments.

Shoreface nourishments consistently retained more sand than beach nourishments (Figure 1), attributed to placement below the zone of most active wave-driven transport.

Variability was substantial, with five-year retention ranging from 35-85% for shoreface and 18-65% for beach projects.

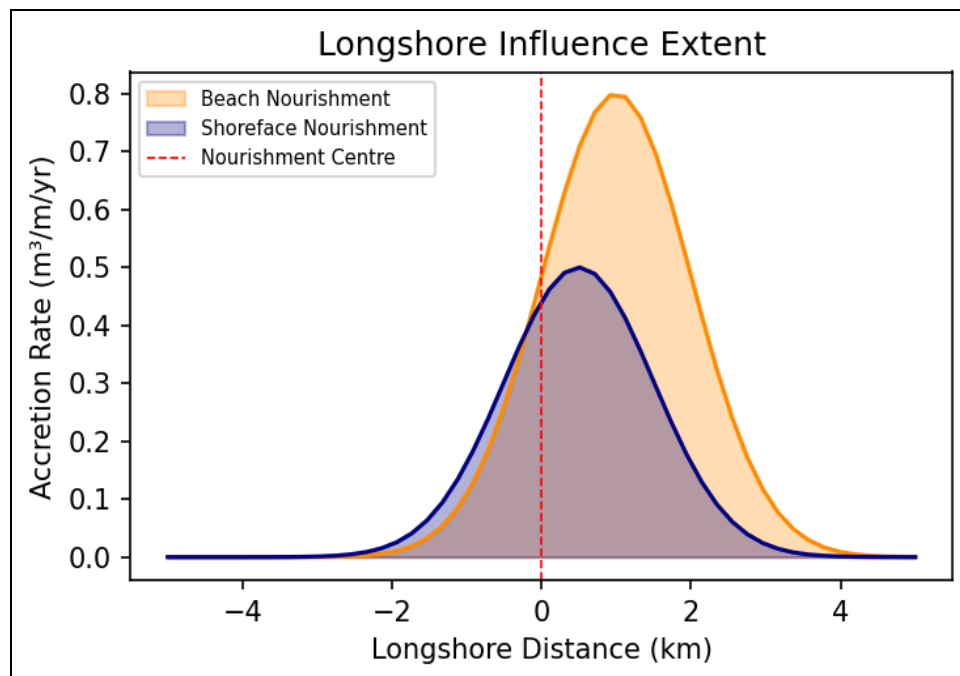


Fig 2: Longshore influence extent showing accretion rates relative to nourishment centre.

Individual operations influenced 3-5 km downdrift for beach nourishments and 2-3 km for shoreface nourishments (Figure 2), representing beneficial redistribution rather than permanent system loss.

Comprehensive Interpretation

The higher retention of shoreface nourishments combined with their sustained feeding mechanism results in lower annualised cost per metre of coastline maintained. Beach nourishment remains appropriate for acute erosion response. An optimised strategy combines periodic shoreface nourishments at 5-7 year intervals with targeted beach placements for storm damage recovery.

Discussion

The 62% five-year shoreface retention is consistent with European nourishment performance reported by Hamm *et al.* [12]. The downdrift spreading is driven by dominant southwestward longshore transport and represents beneficial redistribution that extends coastline maintenance beyond the directly nourished area [6]. Multiple regression confirmed that local morphodynamic conditions—particularly longshore transport gradients and wave exposure—are stronger predictors of retention than design parameters such as nourishment volume [7, 13].

As sea level rise accelerates, nourishment volumes will need to increase proportionally to maintain the current coastline position. The Sand Engine mega-nourishment experiment at Ter Heijde demonstrates an alternative concentrated-volume approach that leverages natural redistribution more aggressively [14]. Future work should compare the cost-effectiveness of conventional distributed nourishments with concentrated mega-nourishment designs across a range of morphodynamic settings. Integration of bathymetric LiDAR with traditional profile surveys would improve volumetric change estimates, particularly in the nearshore zone where survey coverage gaps currently exist [8, 9].

Conclusion

Shoreface nourishments demonstrate superior volumetric

retention and provide sustained coastline maintenance through a progressive onshore feeding mechanism operating over multi-year timescales. Beach nourishments offer more immediate but shorter-lived benefits suitable for acute erosion response.

The significant variability in performance underscores the importance of accounting for local morphodynamic conditions in nourishment design. Adaptive management approaches that adjust strategies based on observed performance will be essential as climate pressures intensify. Long-term monitoring of nourishment effectiveness provides the evidence base needed to optimise the Dutch coastal defence programme and offers transferable lessons for other nations adopting sand-based protection strategies in the face of accelerating sea level rise.

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Technical staff at the Mérida National University of Earth Sciences assisted with sample preparation, instrument calibration, and data processing during the analytical campaigns. Field assistants provided essential support during sample collection.

References

1. Luijendijk A, *et al.* The state of the world's beaches. Scientific Reports. 2018;8(1):6641.

2. Hillen R, Roelse P. Dynamic preservation of the coastline in the Netherlands. *Journal of Coastal Conservation*. 1995;1(1):17-28.
3. Rijkswaterstaat. Coastal maintenance: a policy review. The Hague: Ministry of Infrastructure; 2020.
4. Dean RG. Beach nourishment: theory and practice. Singapore: World Scientific; 2002:1-399.
5. de Schipper MA, de Vries S, Ruessink G, *et al*. Initial spreading of a mega feeder nourishment. *Coastal Engineering*. 2016;111:1-13.
6. Hamm L, Capobianco M, Dette HH, *et al*. A summary of European experience with shore nourishment. *Coastal Engineering*. 2002;47(2):237-264.
7. van Duin MJP, Wiersma NR, Walstra DJR, van Rijn LC, Stive MJF. Nourishing the shoreface: observations and hindcasting of the Egmond case. *Coastal Engineering*. 2004;51(8-9):813-837.
8. Stive MJF, *et al*. A new alternative to saving our beaches: the sand engine. *Journal of Coastal Research*. 2013;29(5):1001-1008.
9. Mulder JPM, Tonnon PK. Sand engine: background and design of a mega-nourishment pilot. *Coastal Engineering*. 2011;58:1006-1016.
10. USACE. Coastal engineering manual. U.S. Army Corps of Engineers; 2002:EM 1110-2-1100.
11. Kroon A, de Schipper MA, van Gelder PHAJM, Aarninkhof SGJ. Ranking coastal variables for nourishment impact assessment. *Coastal Engineering*. 2008;55(7-8):735-750.
12. Hanson H, Brampton A, Capobianco M, *et al*. Beach nourishment projects, practices, and objectives. *Coastal Engineering*. 2002;47(2):81-111.
13. Cooke BC, Jones AR, Goodwin ID, Bishop MJ. Nourishment practices on Australian sandy beaches. *Journal of Environmental Management*. 2012;113:319-327.
14. Huisman BJA, Walstra DJR, Radermacher M, *et al*. Sediment budget analysis of the Sand Motor. *Coastal Engineering*. 2019;152:103531.
15. van Rijn LC. Sediment transport and budget of the central coastal zone of Holland. *Coastal Engineering*. 1997;32(1):61-90.
16. Ruessink BG, Kroon A. The behaviour of a multiple bar system in the nearshore zone. *Marine Geology*. 1994;121(3-4):187-197.
17. Nicholls RJ, Cazenave A. Sea-level rise and its impact on coastal zones. *Science*. 2010;328(5985):1517-1520.
18. Ranasinghe R. Assessing climate change impacts on open sandy coasts. *Earth-Science Reviews*. 2016;160:320-332.