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Impact of Caspian Sea-level Changes on the Ecological and Geomorphological Condition of the Lankaran–Astara Coastal Zone

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Abstract. The Caspian Sea has entered a sustained phase of water-level decline, driven mainly by an increasingly negative hydroclimatic balance and modified river inflow. This article evaluates the likely ecological and geomorphological consequences for the Lankaran-Astara coastal zone of south-eastern Azerbaijan. The coast combines low-gradient alluvial surfaces, river mouths, wetlands, sandy sectors, settlements and transport infrastructure; consequently, a basin-wide fall in water level does not produce one uniform shoreline response. General regression may expose new land and shift wetlands seaward, but local erosion, waterlogging, salinisation, temporary re-inundation and deformation-related changes may occur simultaneously. The study synthesises published research and recent local observations and proposes an integrated monitoring framework based on comparable satellite imagery, DSAS shoreline statistics, InSAR/GNSS, environmental data and field verification. Newly exposed surfaces should therefore be treated as provisional rather than automatically stable land.
Keywords: *Caspian Sea; Lankaran-Astara; shoreline change; coastal geomorphology; wetlands; remote sensing; adaptive zoning.*

Introduction. Unlike the global ocean, the Caspian Sea is a closed inland basin whose level is controlled by river discharge, precipitation, evaporation and water use within its catchment. Instrumental records show strong twentieth-century fluctuations: a major fall before 1977, a rapid rise until 1995 and renewed decline thereafter. Recent assessments associate the continuing regression with increased evaporation, changes in precipitation and wind, and alteration of river inflow, particularly from the Volga basin[1]. CMIP6-based projections indicate an increasingly negative water balance and estimate climate-driven declines of about 8 m under SSP2-4.5 and 14 m under SSP5-8.5 by 2100, although the model ranges are broad and should not be read as precise local forecasts[2].

The Lankaran-Astara coast is especially important because it links the Caspian shoreline with the humid Lankaran Lowland and the foothills of the Talysh Mountains. Short rivers, wetlands, cultivated land, transport routes, settlements and tourism areas occur within a relatively narrow coastal corridor. Its sensitivity is therefore determined not only by the vertical change in water level but also by coastal slope, sediment supply, river-mouth behaviour, wave exposure, drainage, groundwater and land deformation. The purpose of this article is to explain these interacting effects and outline a monitoring and management approach suitable for a local empirical study.

Study Area and Analytical Approach. The study area extends along Azerbaijan's southern Caspian coast from Lankaran toward Astara. Low-lying alluvial and marine-accumulative surfaces dominate much of the coastal plain, while river mouths and wetland depressions interrupt the shoreline. Sandy beaches and locally steeper or engineered sectors create additional contrasts. This setting means that equal vertical changes in sea level can produce very different horizontal shoreline movements. Low-gradient areas may experience extensive seaward migration, whereas steeper, sediment-starved or structurally constrained sectors may show limited advance or even local erosion.

The article uses a critical synthesis of basin-scale climate and ecological research, Azerbaijani coastal analogues and recent observations from Lankaran-Astara. Regional values are used only to identify mechanisms and appropriate methods. They are not transferred as local shoreline rates. Gasimov's (2021) analysis of the neighbouring Kura geomorphological sub-region demonstrates the value of multi-date Landsat imagery, NDWI-based waterline extraction and the Digital Shoreline Analysis System (DSAS), but it also shows that abrasion, accumulation, delta development and tectonic setting create strong spatial variability. A recent monitoring report from Lankaran-Astara recorded previously submerged tree stumps exposed during recession and later covered again after heavy rainfall. This local example shows why a short-lived waterline change must not be interpreted automatically as a reversal of the long-term Caspian trend [3].

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Ecological and Geomorphological Responses. The most visible geomorphological effect of falling water level is seaward displacement of the waterline. On gently sloping surfaces, even a modest vertical fall can expose a wide belt of former seabed. The new surface may pass through several stages: shallow water, saturated mudflat, saline or waterlogged ground, pioneer vegetation and, only later, a more consolidated terrestrial surface. Its apparent emergence therefore does not prove geomorphological stability or suitability for construction and agriculture. Drainage may remain poor, groundwater may stay close to the surface, salts may accumulate through evaporation, and storms or high river discharge may cause temporary re-inundation[4].

Shoreline regression also reorganises sediment pathways. River mouths may lengthen, split or become unstable as their base level falls; channels can incise while adjacent bars and spits accrete. Where sediment supply is adequate, new beaches or accumulative surfaces may develop. Elsewhere, wave concentration, a sediment deficit, coastal structures or an oblique sediment transport pattern can maintain erosion even while the regional sea retreats. Results from Azerbaijan's Kura coast confirm that accumulation and abrasion can occur in neighbouring sectors during the same sea-level phase[5]. Vertical land motion adds another control: subsidence increases relative water level and inundation risk, whereas uplift strengthens apparent regression. Consequently, shoreline position alone cannot separate climatic forcing from tectonic or anthropogenic effects.

Ecological effects are equally non-linear. Retreating shallow water can reduce nursery and feeding habitats, disconnect lagoons and wetlands, alter salinity and groundwater exchange, and force reed beds and other littoral vegetation to migrate. Newly exposed sediment may be colonised, but the resulting habitat is not necessarily equivalent to the lost aquatic or wetland system. Basin-wide modelling indicates that a 5-10 m decline would severely reduce shallow-water ecosystems and the effectiveness of fixed marine protected areas, illustrating the need for conservation boundaries that can move with habitats. The Lankaran-Astara zone may also experience local waterlogging after intense rainfall; thus drying, salinisation and temporary flooding can coexist within a short distance. These changes affect biodiversity, fisheries, agriculture, recreation and the ecological functions of coastal wetlands.

Four overlapping response types are therefore useful for mapping: accumulation-dominated sectors on low-gradient, sediment-supplied surfaces; transitional sectors that remain saline, wet, vegetating or intermittently flooded; erosion-sensitive sectors influenced by waves, sediment deficit, river-mouth instability or structures; and deformation-modified sectors where uplift or subsidence changes relative water level. These are dynamic states rather than permanent land units. A sector may shift category as vegetation, storms, river discharge, sediment supply or land deformation changes[6].

Monitoring and Management Implications. A reproducible programme should begin by dividing the coast into segments defined by slope, geomorphology, river mouths, wetlands, settlements and engineering structures. Seasonally comparable Landsat and Sentinel-2 scenes can then be processed with NDWI or MNDWI and manually verified using one consistent shoreline proxy and coordinate system. DSAS indicators, including Net Shoreline Movement, End Point Rate and Linear Regression Rate, should be reported with positional and statistical uncertainty. Sentinel-1 InSAR and GNSS can test for vertical deformation, while elevation, sea level, rainfall, river discharge, wind, storm, groundwater, salinity, vegetation and sediment observations help explain the measured change. Field verification should include GNSS points, repeat photography, beach profiles, sediment descriptions, vegetation surveys and inundation markers[7].

Each shoreline record should retain its acquisition date, sensor, season, extraction threshold, proxy, uncertainty and validation status. This is essential because waves, wind setup, wet sand, rainfall, discharge and vegetation can shift an optical waterline without representing a persistent geomorphological trend. Management priorities should be assigned where rapid change coincides with wetlands, river mouths, settlements, roads, drainage systems or subsiding ground. Newly exposed areas should remain provisional until elevation, bearing capacity, drainage, salinity, inundation recurrence and ecological value are known. Dynamic setbacks, periodic zoning review and reversible, low-regret measures are safer than permanent development based on a single recent shoreline[8].

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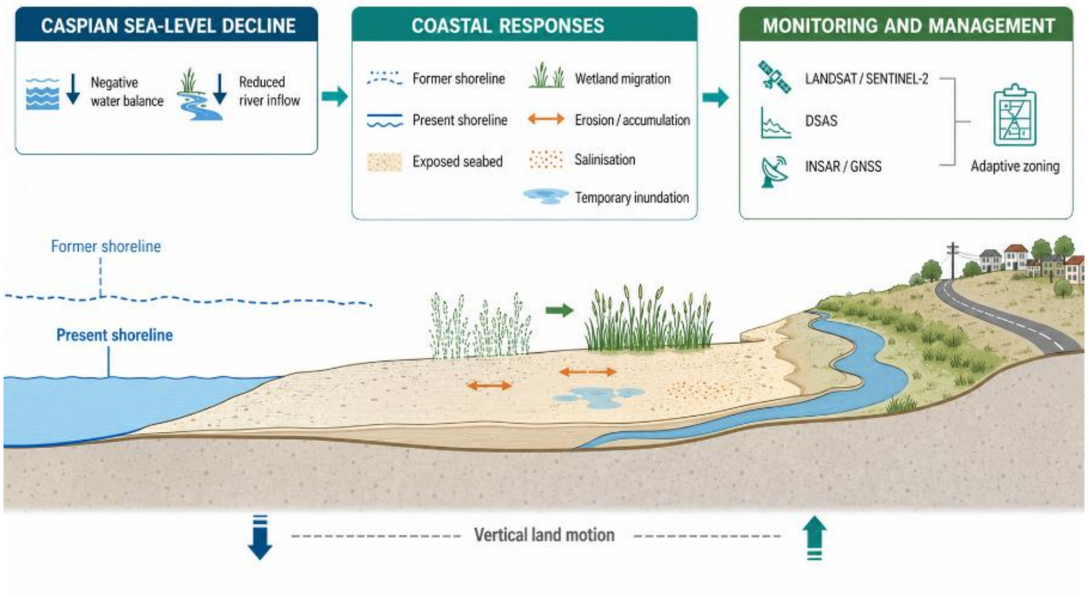

Figure 1
Conceptual Model of Ecological and Geomorphological Responses to Caspian Sea-Level Decline in the Lankaran-Astara Coastal Zone

Conclusion. Caspian Sea-level decline is likely to reshape the Lankaran-Astara coast, but it will not create a uniform or automatically stable seaward advance. The response will emerge from the interaction of regional water-balance forcing with local slope, sediment supply, river processes, wetlands, storms, groundwater and vertical land motion. Ecological loss may accompany geomorphological emergence, while local erosion and temporary flooding may coexist with basin-wide regression. Reliable assessment therefore requires segment-based, repeated monitoring that integrates satellite-derived shorelines, uncertainty analysis, deformation measurements, environmental variables and field evidence. Such an approach provides a defensible basis for adaptive zoning, wetland protection and risk-sensitive development along Azerbaijan's southern Caspian coast.

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