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Modern Dynamics of the Lankaran–Astara Shoreline Under Caspian Sea-Level Decline

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Abstract. The continuing decline of the Caspian Sea level is increasingly reshaping the coastal zone of Azerbaijan. This paper examines the modern dynamics of the Lankaran–Astara shoreline, with emphasis on the geomorphological response of the southern coastal sector to sea-level fall. The study is designed as an analytical synthesis rather than a presentation of newly measured shoreline distances. Recent peer-reviewed studies, remote-sensing research from the Azerbaijani Caspian coast, current field-monitoring information, and preliminary space-geodetic evidence are integrated to identify the dominant processes controlling shoreline migration. Basin-wide studies show that the Caspian Sea has been in a persistent declining phase since the mid-1990s, while recent work demonstrates that reduced river inflow and increasing evaporative losses act together in the contemporary negative water balance. For the Lankaran–Astara coast, the expected first-order response is seaward migration of the land-water boundary and exposure of former shallow-water surfaces, especially where coastal gradients are low. However, the response is spatially heterogeneous: accumulation can intensify in some sectors, whereas local erosion may persist where wave action, sediment deficit, river-mouth instability, engineering structures, or vertical land motion modify the general regression trend. The paper proposes an integrated monitoring framework combining Landsat/Sentinel-2 shoreline extraction, DSAS statistics, Sentinel-1 InSAR, digital elevation data, hydrometeorological observations, and field verification. This framework can support future quantitative assessment and coastal management in the Lankaran–Astara region.

Keywords: *Caspian Sea; Lankaran; Astara; shoreline change; sea-level decline; coastal geomorphology; remote sensing; erosion; accumulation; InSAR.*

Introduction. The Caspian Sea is the world's largest enclosed inland water body and one of the most dynamic terminal basins in terms of historical water-level variability. Because it has no natural outlet to the global ocean, changes in river inflow, precipitation, evaporation, atmospheric circulation, and human water use are directly reflected in its water balance. The coastline therefore responds to basin-scale hydroclimatic variability much more rapidly than many open-ocean coasts. After the high-water phase that culminated in the mid-1990s, the Caspian entered a prolonged period of decline. Samant and Prange (2023) estimated an average fall of about 7 cm yr−1 for 1996–2015 and around 10 cm yr−1 for 2006–2021. Their CMIP6-based projections further indicate that continued warming may sustain a strongly negative water balance during the twenty-first century, although the magnitude of long-term decline remains scenario- and model-dependent [1].

The most recent basin-scale evidence has strengthened the view that current shrinkage reflects interacting climatic and anthropogenic pressures rather than a single mechanism. Duku et al. (2026), integrating satellite observations, in situ hydrological records, and reanalysis data, reported a decline of roughly 2 m since 1996 and a substantial reduction in the surface area of the Caspian Sea. Their analysis points to declining total river inflow, particularly from the Volga, together with modestly increasing evaporation, as major contemporary drivers. Safarov et al. (2025) likewise showed that changes in the regional wind regime are relevant because wind conditions influence evaporation and the transport of moisture away from the sea surface. Thus, the modern falling-level phase is embedded in a broader hydroclimatic shift[2-4].

For coastal geomorphology, a vertical water-level change is converted into horizontal shoreline displacement according to the gradient and morphology of the nearshore surface. A small vertical fall can generate a large horizontal retreat of the waterline across very shallow coastal plains, while steeper segments may exhibit limited positional change. The resulting transformation includes the emergence of former seabed, reorganization of beach profiles, changes in wave breaking, redistribution of sediments, and modification of river-mouth and lagoon environments. Therefore, sea-level decline should not be interpreted simply as a uniform seaward shift of the coast; it is a driver that interacts with local geological, hydrodynamic, and anthropogenic conditions.

The Lankaran–Astara sector is of particular interest because it occupies the humid southern part of Azerbaijan's Caspian coast and includes low-lying coastal surfaces, beaches, river mouths, settlement areas, transport corridors, and ecologically sensitive zones. Current monitoring by the Institute of Geography of Azerbaijan has already documented visible effects of sea retreat in this region: during a 2026 monitoring expedition, previously submerged tree stumps became exposed as the waterline moved seaward; after heavy rainfall, these surfaces were temporarily inundated again. This observation is important because it demonstrates the coexistence of a long-term regression trend with short-term hydrometeorological fluctuations (Institute of Geography, 2026).The aim of this paper is to analyse the principal directions of contemporary shoreline transformation in the Lankaran-Astara coastal zone under Caspian Sea-level decline and to propose a methodological framework for future quantitative monitoring. The paper focuses on four questions: (1) how the basin-wide decline is expected to affect the southern Azerbaijani shoreline; (2) why accumulation and erosion can coexist during a regression phase; (3) how vertical land motion may alter relative shoreline change; and (4) which remote-sensing and geodetic indicators should be combined in a robust monitoring programme[5].

2. Study Area, Methodology and Research Novelty. The Lankaran-Astara coast, located in the southwestern part of the South Caspian Basin, is characterized by low-gradient coastal plains, river-mouth systems, and diverse shoreline forms that respond differently to Caspian Sea-level changes. This study synthesizes recent literature, remote-sensing research, and local monitoring data to assess shoreline transformation without assigning unsupported site-specific displacement rates. Future quantitative analysis should combine Landsat and Sentinel-2 imagery, NDWI/MNDWI-based shoreline extraction, DSAS indicators such as NSM, EPR, and LRR, and InSAR or GNSS data on vertical land motion. The novelty of the study lies in interpreting shoreline change as the combined result of sea-level decline, sediment dynamics, erosion-accumulation processes, river activity, and local crustal deformation rather than as a uniform response to Caspian regression alone [6].

3.Results and Discussion. The available evidence consistently indicates that the Caspian Sea is in a significant declining phase, while also showing that the coastal response is highly spatially variable. Table 1 summarizes the principal studies used in the analysis and their relevance to the Lankaran-Astara problem.

Table 1

Selected evidence used to interpret modern shoreline dynamics in the Lankaran-Astara sector

Source	Period / data	Key finding	Relevance to Lankaran-Astara
Samant & Prange (2023)	1996-2021; CMIP6	Persistent decline; about 7 cm yr-1 (1996-2015) and ~10 cm yr-1 (2006-2021); strong future decline under warming scenarios.	Establishes the basin-scale forcing that drives regression of the southern Azerbaijani shoreline.
Gasimov (2021)	1976-2019; Landsat, NDWI, DSAS	Sea-level rise intensified abrasion; the 1996-2019 decline strengthened accumulation in many shallow Azerbaijani sectors.	Provides a regional remote-sensing analogue and a tested GIS methodology.
Court et al. (2025)	Caspian-wide geospatial assessment	A further 5-10 m decline would cause major ecosystem and infrastructure disruption around the basin.	Shows that shoreline change has ecological and planning consequences, not only geomorphological effects.
Duku et al. (2026)	Satellite + hydrological + reanalysis data	About 2 m level loss since 1996; reduced river inflow and increasing evaporation contribute to shrinkage.	Provides the newest peer-reviewed synthesis of contemporary water-balance drivers.

Ahadov et al. (2026)	Sentinel-1 InSAR, 2014-2025	Preliminary results show localized uplift and subsidence along Neftchala-Lankaran, potentially comparable to sea-level decline rates.	Requires relative shoreline change to be interpreted together with vertical land motion.

The ongoing decline of the Caspian Sea level is causing a general seaward migration of the Lankaran-Astara shoreline and the exposure of former shallow-water surfaces, particularly in low-gradient coastal areas. However, shoreline regression does not imply uniform accumulation, as local erosion may continue under the influence of longshore sediment transport, river-mouth migration, storms, and coastal structures. Recent InSAR observations also indicate that localized uplift and subsidence can modify relative shoreline change, making it necessary to combine satellite shoreline mapping with vertical land-motion data. These geomorphological changes have important environmental and planning implications, since newly exposed areas may remain unstable, saline, periodically flooded, or vulnerable to future re-inundation. Therefore, coastal management should be based on continuous monitoring and the identification of zones with different levels of geomorphological stability

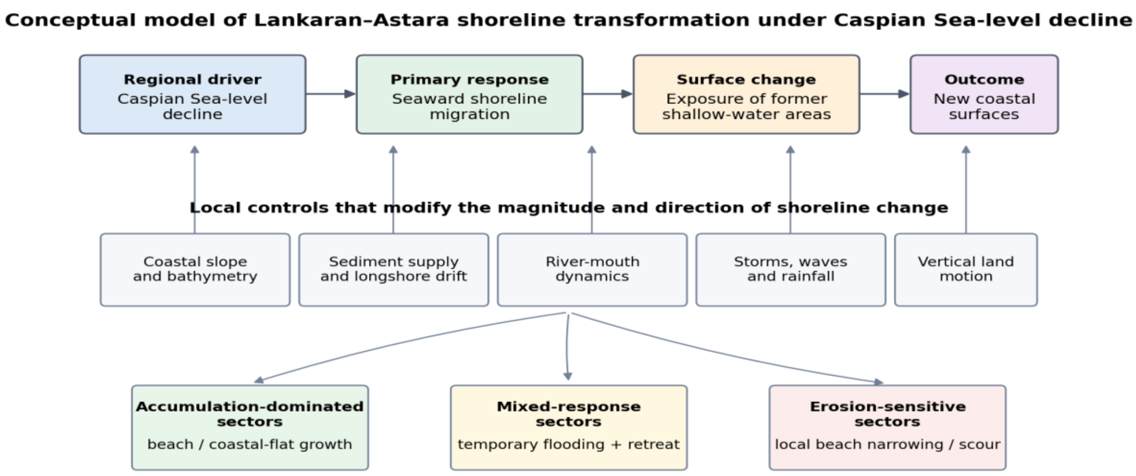

Figure 1. **Conceptual model of shoreline transformation in the Lankaran-Astara sector under Caspian Sea-level decline.**

Proposed GIS and Geodetic Monitoring Framework. A practical GIS and geodetic monitoring framework for the Lankaran–Astara coast should combine multi-date Landsat and Sentinel-2 imagery, NDWI/MNDWI-based shoreline extraction, DSAS analysis, and Sentinel-1 InSAR data on vertical land motion. The analysis should also integrate sea-level records, rainfall, wind, river discharge, storm events, and field observations to explain the main drivers of shoreline change. For a master's thesis, comparing several cloud-free images from the last two decades using consistent methods would allow the coast to be classified into sectors of rapid seaward migration, relative stability, and local erosion[7].

Conclusion. The modern decline of the Caspian Sea is a major driver of contemporary shoreline transformation along the Lankaran–Astara coast. The first-order geomorphological response is seaward displacement of the waterline and exposure of former shallow-water surfaces, particularly in low-gradient sectors. Current local monitoring confirms that this process is already visible in the region. At the same time, the response is not spatially uniform. Accumulation may dominate in some segments, while local erosion persists where sediment supply, wave energy, river-mouth behaviour, coastal structures, or short-term hydrometeorological events modify the regional regression trend.

Recent space-geodetic evidence adds an important dimension: vertical land motion can alter relative shoreline change and should be considered together with absolute water-level decline. Therefore, the most reliable future assessment of the Lankaran–Astara coastline should integrate optical remote sensing, DSAS statistics, InSAR/GNSS deformation data, digital elevation models, hydrometeorological observations, and field verification. Such an approach would provide the quantitative basis needed to identify vulnerable coastal sectors, distinguish stable from transitional newly exposed land, and support adaptive coastal planning under continued Caspian Sea-level decline.

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