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Assessing Eutrophication Drivers and Water Quality Degradation in Gorgan Bay: A Catchment-Scale Nutrient Export Analysis

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Gorgan Bay, situated in the southeastern Caspian Sea, is an ecologically significant wetland and a critical habitat for wildlife, migratory birds, and fisheries. However, the bay's ecological and economic importance is increasingly threatened by eutrophication, driven by substantial nutrient inflows, particularly nitrogen (N) and phosphorus (P), originating from its upstream catchment. This study aims to quantify nutrient loads, identify their sources, and evaluate their impacts on water quality using land-use analysis, export coefficient modeling (ECM), and the Carlson Trophic State Index (CTSI). Over the past two decades, nutrient loads have risen steadily, with phosphorus and nitrogen inputs each increasing by approximately 3.6% due to agricultural intensification, urbanization, and untreated wastewater discharge. Concurrently, the annual discharge of freshwater into Gorgan Bay has shown a significant declining trend, despite minimal changes in monthly flows. The Qarasu River, contributing approximately 50% of the total inflow, and the Baghou River, accounting for 14%, play crucial roles in the bay’s hydrological balance. The declining water inflows, coupled with high evaporation rates and no significant replenishment since 2015, have led to a persistent decrease in the bay’s water storage. Notably, in 2017, the water loss exceeded 2 million cubic meters. These changes have resulted in reduced water quantity, which directly affects water quality and intensifies eutrophication in the bay. Land-use changes have further exacerbated nutrient export. Analysis indicates a 10% increase in agricultural land, often linked to intensive fertilizer use, and a 7% reduction in forested areas, which has diminished the natural capacity for nutrient filtration. The CTSI analysis reveals that while some areas of Gorgan Bay are mesotrophic, most central and eastern regions are classified as eutrophic, reflecting significant seasonal and spatial variations in water quality, algal productivity, and light penetration. These changes have resulted in severe ecological consequences, including algal blooms, reduced water clarity, and hypoxic conditions, which pose substantial threats to aquatic biodiversity and ecosystem stability. Furthermore, the socio-economic ramifications for fisheries and local communities reliant on the bay's resources are profound. To address these challenges, this study recommends adopting integrated management strategies. Key measures include controlling point-source phosphorus pollution through advanced wastewater treatment, promoting sustainable agricultural practices to optimize nitrogen and phosphorus use, and restoring riparian vegetation to enhance natural nutrient buffering. Additionally, increasing environmental awareness and fostering stakeholder engagement at the catchment scale are crucial for achieving long-term conservation goals. Implementing these strategies can help mitigate eutrophication impacts, improve water quality, and preserve the ecological and economic

significance of Gorgan Bay for future generations.