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Hydraulic engineering overrides climatic control of eutrophication and nutrient burial in a semi-arid shallow lake over the past 150 years

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Shallow lakes in semi-arid regions are highly sensitive to climatic variability and human disturbance; however, centennial-scale quantification of when dominance shifts from climatic forcing to distinct human activities and how this transition regulates nutrient burial remains limited. Here, we analyzed a high-resolution, ^{210}Pb-dated sediment core from Chagan Lake (Northeast China) by integrating long-term water quality data, elemental geochemistry, and organic-geochemical proxies. Statistical modeling and attribution analyses were applied to reconstruct lake evolution over the past ~150 years and quantify the relative contributions of major drivers to nutrient burial. Before 1900, lake evolution was primarily climate-dominated, with precipitation controlling lake level and redox conditions, thereby regulating material cycling. Between 1900 and 1980, agricultural expansion became the dominant driver (≈94%), intensifying catchment erosion and increasing external inputs of nutrients. Since 1980, hydraulic engineering, including water diversion and enhanced river–lake connectivity, has exerted the strongest influence (≈53%), surpassing agriculture (≈40%), by restructuring inflow sources, hydrodynamics, and near-bottom conditions. Sustained external loading overwhelmed the dilution effect associated with sediment coarsening, leading to nutrient enrichment even in coarse particles. Although hydraulic operations reduced sedimentary total phosphorus burial by approximately 50%, a high potential for internal nutrient release remains. Under future warming and intensified disturbances, effective management should integrate external load reduction with hydrodynamic regulation, rather than relying solely on concentration-based targets. This study clarifies centennial-scale controls on nutrient burial and provides guidance for the restoration of regulated lakes in semi-arid regions.

