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Sustainable Mining Zones: A Multi-Criteria Framework for Balancing Sand Extraction and River Integrity in the Mekong Delta

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Unregulated sand mining has become a major global sustainability challenge, yet managers still lack clear tools to determine where sand can be extracted and how much can be removed without damaging river systems. This study presents a new, practical framework called Sustainable Mining Zones (SMZ) that combines high-resolution sediment mapping with ecological and geomorphic sensitivity analysis to support science-based sand mining decisions. The Vietnamese Mekong Delta, one of the world's most intensively mined river systems, is used as a test case. Using a high-resolution Delft3D-FM model initialized with a 2017 riverbed survey and validated against 2020 observations, we simulated hydrodynamics, sediment transport, salinity intrusion, and riverbed evolution from 2017–2021. Results indicate a cumulative sediment loss of approximately 250 Mm³, with severe reach-scale deficits reaching ~−79.5 Mm³ yr□¹ in the Tien River and a median incision rate of ~0.30 m yr□¹, strongly coinciding with observed dredging hotspots. Although the delta contains substantial sediment resources (~10.59 Bm³ above a conservative thickness threshold), sustainability screening reduces the effective resource to ~4.91 Bm³ once geomorphic stability and ecological constraints are applied through the Suitability-Weighted Reserve (SWR). Scenario simulations show that an equilibrium extraction benchmark of approximately ~4.9 Mm³ per year produces minimal morphological impact, while a practical upper operational limit of about 9.8-9.9 Mm³ per year can meet moderate construction demand if extraction is confined to high-suitability mid-channel and point-bar zones. The SMZ framework provides a transferable, map-based tool for regulators to balance development needs with long-term river resilience in sediment-stressed river basins worldwide.

Keywords: Sand mining; Mekong Delta; sediment dynamics; sustainable management; river morphology; decision support