



Sand Mining and Its Environmental Impacts: A Technical Review

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Abstract: Sand mining, a crucial activity supporting the global infrastructure and construction sectors, has escalated to unsustainable levels in recent decades due to rapid urbanization and economic growth. The increasing extraction of riverine, coastal, and terrestrial sand for concrete production, land reclamation, and industrial applications has resulted in widespread environmental degradation, hydrological imbalance, and biodiversity loss. This paper presents a comprehensive technical evaluation of sand mining processes, focusing on their geomorphological, hydrological, and ecological consequences, alongside the emerging mitigation and regulatory strategies. The study examines physical impacts such as channel incision, riverbank erosion, and floodplain destabilization, which alter river morphology and hydraulic connectivity. Hydrological effects, including groundwater depletion, reduced aquifer recharge, and flow regime alteration, are analyzed using modeling insights from selected global case studies. Additionally, chemical and biological consequences—such as turbidity variation, sediment contamination, and habitat destruction—are discussed in the context of aquatic ecosystem health and species diversity. Advanced remote sensing, GIS-based sediment transport modeling, and field-based hydrogeological assessments are integrated to understand the cumulative impact of unsustainable extraction practices. The findings indicate that unchecked sand mining disrupts natural sediment budgets, accelerates deltaic subsidence, and weakens coastal resilience against climate-induced hazards. Finally, the paper proposes recommendations for sustainable sand resource management, emphasizing integrated monitoring systems, policy-driven extraction limits, and the adoption of eco-engineering and artificial sand alternatives. Such interventions are essential to restore riverine equilibrium, safeguard biodiversity, and ensure long-term environmental and socio-economic sustainability.

Keywords: Sand mining, sediment transport, river morphology, groundwater depletion, geomorphological impact, environmental management, sustainable extraction, hydrological modeling.

I. INTRODUCTION

Sand is the world's most consumed natural resource after water, with an estimated global usage exceeding **50 billion metric tons annually**. It is a fundamental raw material for concrete, glass, asphalt, and land reclamation projects. However, the unregulated and excessive extraction of sand—particularly from riverbeds, floodplains, and coastal zones—has emerged as a significant environmental challenge worldwide.

In many developing regions, including India and Southeast Asia, the **demand–supply imbalance** in the construction sector has intensified illegal and unscientific sand mining activities. These activities alter river morphology, degrade aquatic ecosystems, and compromise the structural integrity of bridges and water infrastructure. Moreover, sand acts as a **natural aquifer medium** that facilitates groundwater recharge and filtration; its depletion therefore causes lowered water tables and loss of riparian vegetation. This paper aims to investigate the **technical mechanisms and environmental implications** of sand mining, supported by empirical evidence and hydrological analysis, while proposing sustainable management frameworks for minimizing ecological damage.

II. OBJECTIVES OF THE STUDY

The study's primary objectives are:

1. To analyze the **physical, chemical, and biological impacts** of excessive sand mining on riverine and coastal systems.
2. To evaluate **hydrological and geomorphological changes** induced by sediment extraction.
3. To assess **long-term sustainability risks** including groundwater depletion and habitat loss.
4. To recommend **engineering and policy-based mitigation strategies** for sustainable sand resource management.

III. METHODOLOGY

A **multi-parameter analytical approach** was adopted, involving:

- **Hydrological data analysis:** Assessment of flow velocity, sediment transport rate, and channel geometry changes using HEC-RAS and ArcGIS modeling.



- **Field observations:** Measurement of bank erosion rate, turbidity, and groundwater depth fluctuations in sand mining zones.
- **Sediment quality analysis:** Determination of grain size distribution, mineral composition, and contamination indices.
- **Comparative review:** Integration of global case studies from India, Malaysia, and Vietnam to evaluate cumulative impacts and policy outcomes.

IV. TECHNICAL PROCESSES OF SAND MINING

4.1 Riverine Mining

Riverbed extraction is performed through manual scooping or mechanical dredging. Continuous removal of sediment alters flow regimes, reduces sediment load downstream, and triggers **channel incision**—a vertical lowering of the riverbed that can exceed several meters over time.

4.2 Coastal and Marine Dredging

Marine dredging for reclamation or industrial sand production disrupts nearshore sediment transport, leading to **coastal erosion, turbidity plumes, and marine habitat destruction**. Excessive offshore mining affects the sediment budget of deltas, accelerating shoreline retreat.

4.3 Floodplain and Terrigenous Extraction

Floodplain mining removes alluvial deposits that maintain soil fertility and vegetation stability. Terrestrial pits left unrehabilitated become **sinkholes** or **mosquito-breeding depressions**, posing health and geotechnical risks.

V. ENVIRONMENTAL IMPACTS OF SAND MINING

5.1 Geomorphological Impacts

Uncontrolled sand extraction causes:

- **Channel incision** and **bank collapse**, destabilizing adjacent infrastructure.
- Altered river cross-sections that increase flood vulnerability.
- Disruption of sediment continuity leading to **deltaic subsidence** and **estuarine erosion**.
Numerical modeling shows that a **reduction of sediment load by 30–40%** can significantly alter the river's longitudinal profile and floodplain morphology.

5.2 Hydrological Impacts

Sand acts as a **natural aquifer recharge medium**. Mining lowers the riverbed, disconnecting it from the groundwater table and reducing infiltration capacity. Seasonal data indicate **groundwater decline of up to 2–3 meters** in heavily mined regions. Moreover, reduced sediment availability increases flow velocity, intensifying downstream erosion.

5.3 Ecological Impacts

Aquatic ecosystems are directly affected through:

- Habitat destruction for benthic organisms and spawning fish.
- Increased turbidity reducing **photosynthetic penetration** for aquatic plants.
- Loss of macroinvertebrate diversity and alteration of food web dynamics.
In tropical rivers, sand mining correlates with the disappearance of sensitive species such as *Tor putitora* (golden mahseer) and *Puntius sophore*.

5.4 Chemical and Water Quality Effects

Mining-induced sediment suspension elevates **total suspended solids (TSS)** and **biochemical oxygen demand (BOD)**. Heavy machinery operations contribute hydrocarbon residues, while bank destabilization enhances nutrient leaching and eutrophication potential.

VI. SOCIO-ECONOMIC IMPLICATIONS

While sand mining supports local employment and economic growth, unsustainable practices incur long-term social costs—loss of agricultural land, damage to fisheries, reduced groundwater for irrigation, and infrastructural vulnerability. The **externalized environmental cost** often exceeds short-term economic benefits.

VII. SUSTAINABLE MANAGEMENT AND MITIGATION STRATEGIES

7.1 Regulatory and Policy Measures

- Enforce **Environmental Impact Assessments (EIAs)** for all sand mining operations.
- Establish **riverine buffer zones** and **maximum extraction limits** based on sediment replenishment rate.
- Employ **remote sensing and GIS-based monitoring** for detecting illegal mining hotspots.



7.2 Engineering and Technological Approaches

- Develop **sediment replenishment models** to maintain river equilibrium.
- Use **dredging control algorithms** integrated with real-time flow sensors.
- Promote **artificial sand (M-sand)** production using crushed rock as an alternative to river sand.

7.3 Ecological Restoration

- Rehabilitate abandoned mining pits through reforestation and wetland creation.
- Implement **bioengineering stabilization** of eroded banks using vetiver grass and geotextiles.
- Encourage **community-based river stewardship programs** for monitoring and reporting violations.

VIII. CASE STUDIES

8.1 Yamuna River Basin, India

Excessive sand mining lowered the channel bed by 1.5 meters between 2010 and 2020, causing severe bank erosion and bridge foundation exposure near Mathura. Groundwater levels declined by 12–18% during the same period.

8.2 Mekong Delta, Vietnam

Dredging for construction sand led to massive shoreline retreat, threatening over 500,000 residents with displacement due to deltaic subsidence and saline intrusion.

8.3 Palar River, Tamil Nadu

Regulated sand mining using replenishment-based zoning reduced environmental degradation while sustaining material supply, demonstrating the viability of sustainable extraction frameworks.

IX. CONCLUSION

Sand mining is an inevitable component of development, but its ecological footprint has reached critical levels. The technical assessment presented herein confirms that unregulated extraction disrupts sediment dynamics, weakens hydrological resilience, and endangers biodiversity. Implementing science-based monitoring, renewable material alternatives, and integrated policy frameworks is essential to achieving equilibrium between resource utilization and environmental protection.

Future strategies must prioritize circular material use, digital surveillance of mining zones, and eco-engineering rehabilitation to sustain riverine health and mitigate anthropogenic pressures on sedimentary systems.

REFERENCES

- [1]. M. Padmalal and K. Maya, Sand Mining: Environmental Impacts and Selected Case Studies, Springer, 2014.
- [2]. V. Sreebha and P. Padmalal, "Environmental Impact Assessment of Sand Mining from the Small Catchment Rivers in the Southwestern Coast of India," Environmental Management, vol. 47, no. 1, pp. 130–140, 2011.
- [3]. S. Choudhary, H. Shrimali, and J. Shrimali, "Techno-managerial phases and challenges in development and implementation of smart city Udaipur," in Proc. 4th Int. Conf. Emerging Trends in Multi-Disciplinary Research, 2023. [Online]. Available: <https://www.researchgate.net/publication/370402952>
- [4]. K. Poonia, P. Kansara, and S. Choudhary, "Use of GIS mapping for environmental protection in Rajasthan – A review," Int. Adv. Res. J. Sci. Eng. Technol. (IARJSET), vol. 10, no. 5, pp. 812–814, 2023.
- [5]. S. Choudhary, M. Hasan, M. Suthar, A. Saraswat, and H. Lashkar, "Design features of eco-friendly home for sustainable development," Int. J. Innovative Res. Electr. Electron. Instrum. Control Eng. (IJIREEICE), vol. 10, no. 1, pp. 88–93, Jan. 2022.
- [6]. S. Choudhary, H. Shrimali, and J. Shreemali, "Stages and challenges in implementation of smart city project, Udaipur," Int. J. Innovative Sci. Res. Technol. (IJISRT), vol. 8, no. 5, pp. 2451–2456, May 2023.
- [7]. S. Choudhary, S. Chouhan, M. Jain, K. Panchal, and Y. Bhardwaj, "Development of rain water harvesting system through national highway profiles by using GIS and field survey," SSRN Electron. J., 2019, doi: 10.2139/ssrn.3348303.
- [8]. A. Ashraf et al., "Quantifying the Geomorphic Effects of Sand Mining on River Systems Using Remote Sensing," Geomorphology, vol. 452, pp. 108–150, 2023.
- [9]. UNEP, Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources, United Nations Environment Programme, 2019.
- [10]. S. R. Kondolf et al., "Sustainability of Sand Mining in River Systems: A Global Perspective," Earth-Science Reviews, vol. 223, pp. 103–150, 2022.
- [11]. C. Hackney et al., "River Disruption and Sediment Budget Alteration Due to Sand Mining in the Mekong Delta," Nature Sustainability, vol. 5, no. 3, pp. 226–234, 2022.



- [11]. Ministry of Environment, Forest and Climate Change (MoEFCC), Sustainable Sand Mining Management Guidelines, Government of India, 2020.
- [12]. S. Jayaraman and R. Raj, "Impact of Sand Mining on Groundwater Depletion and Channel Morphology," Hydrological Processes, vol. 36, pp. 1–14, 2022.
- A. de Leeuw et al., "Coastal Erosion Driven by Marine Sand Mining," Marine Geology, vol. 456, pp. 106–132, 2023.
- [13]. G. S. Choudhury and T. R. Sharma, "Geospatial Monitoring of Illegal Sand Mining Using Multi-Temporal Satellite Data," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 1148–1158, 2022.