

PERSPECTIVES

ENVIRONMENT

A looming tragedy of the sand commons

Increasing sand extraction, trade, and consumption pose global sustainability challenges

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Between 1900 and 2010, the global volume of natural resources used in buildings and transport infrastructure increased 23-fold (1). Sand and gravel are the largest portion of these primary material inputs (79% or 28.6 gigatons per year in 2010) and are the most extracted group of materials worldwide, exceeding fossil fuels and biomass (2). In most regions, sand is a common-pool resource, i.e., a resource that is open to all because access can be limited only at high cost. Because of the difficulty in regulating their consumption, common-pool resources are prone to tragedies of the commons as people may selfishly extract them without considering long-term consequences, eventually leading to overexploitation or degradation. Even when sand mining is regulated, it is often subject to rampant illegal extraction and trade (3). As a result, sand scarcity (4) is an emerging issue with major sociopolitical, economic, and environmental implications.

Rapid urban expansion is the main driver of increasing sand appropriation, because sand is a key ingredient of concrete, asphalt, glass, and electronics. Urban development is thus putting more and more strain on limited sand deposits, causing conflicts around the world (5). Further strains on sand deposits arise from escalating transformations in the land-sea interface as a result of burgeoning coastal populations, land scarcity, and rising threats from climate change and coastal erosion (5). Even hydraulic fracturing is among the plethora

of activities that demand the use of increasing amounts of sand. In the following, we identify linkages between sand extraction and other global sustainability challenges.

ENVIRONMENTAL IMPACTS

Sand extraction from rivers, beaches, and seafloors affects ecosystem integrity through erosion, physical disturbance of benthic habitats, and suspended sediments (5). Thus, extensive mining is likely to place enormous burdens on habitats, migratory pathways, ecological communities, and food webs.

For instance, sand mining degrades corals, seaweeds, and seagrass meadows through direct removal during dredging operations, sedimentation, and reduction in light availability that compromises photosynthesis (6). As a result, it is a driver of biodiversity loss that threatens species on the verge of extinction—such as the Ganges river dolphin (7)—as well as newly discovered species, such as the São Paulo marsh antwren, found in isolated marshes of southeast Brazil that have been heavily degraded by sand mining (8). Furthermore, sand transport vessels may carry one of the most aggressive freshwater invaders, the Asian clam (9), although the role of sand transport in the spread of invasive species remains underexplored.

CASCADING EFFECTS

Such environmental impacts have cascading effects on the provisioning of ecosystem services and human well-being. For example, sand mining is a frequent cause of shoreline and river erosion and destabilization, which undermine human resilience to natural hazards such as storm surges and tsunami events, especially as sea level continues to rise (10). In Sri Lanka, extensive sand mining exacerbated the impacts of the 2004 Indian Ocean tsunami; ironically, sand demand for coastal restoration increased in the aftermath of the tsunami (11).

Extensive sand extraction also impairs water and food security. Extraction-induced erosion and degradation of riverine and coastal



systems may disrupt the productivity of both wild (e.g., fisheries) and cultivated (e.g., mariculture and croplands) food sources. In the Mekong Delta, sand mining is responsible for enhanced salt-wedge intrusion during the dry season, which damages domestic water supply and increases salinization of cultivated land in Southeast Asia's most important food-producing region (10). In Sri Lanka, saltwater intrusion due to extensive illegal sand mining has affected drinking water supply and led to severe declines in productivity of crops (e.g., coconut, rubber, and tea) (11).

Health impacts associated with sand mining remain poorly characterized, but there is evidence that the conditions created by extracting sand can facilitate the spread of infectious diseases. New standing-water pools created by extraction activities in rivers and stream beds provide potential breeding sites for malaria-transmitting mosquitoes. Hence, sand mining has been associated with the spread of malaria. For example, Soleimani-Ahmadi *et al.* (12) have shown that in Iran, the most common larval habitats for anopheline larvae of two malaria vectors (*Anopheles dthali* and *Anopheles stephensi*) are sand-mining pools. Sand mining has also been associated with increased incidence of an emerging bacterial disease, the Buruli ulcer, in West Africa (13).

The high profits generated by sand trade often lead to social and political conflicts, including violence, rampant illegal extraction and trade, and political tensions between nations. For example, in India, the “Sand Mafia” is considered one of the most powerful and violent organized crime groups, and

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Illegal sand mining on the bank of the Yamuna River in Greater Noida, India, is contributing to severe environmental degradation.

hundreds of people have been killed in “sand wars” (3). To gain land through land-reclamation projects, Singapore relies on sand imports from neighboring countries; the latter lose sand and suffer the consequences of mining, frequently leading to political tensions, accusations of illegal sand extraction, and sand export bans (5).

All these challenges have important implications for environmental justice. The degradation brought about or reinforced through sand extraction places heavy burdens on local populations, especially on farmers, fishers, and those—typically women—fetching water for households. People from these populations may become environmental refugees, as has already happened in Sri Lanka and the Mekong Delta (10, 11). Increased vulnerability of eroded areas to flooding and landslides may directly displace populations, as shown by the recent relocation of over 1200 households in Vietnam (10).

IMPLICATIONS FOR RESEARCH AND GOVERNANCE

Current development trends suggest that sand demand will increase further in the coming years. The resulting acceleration of sand extraction, trade, and consumption will have escalating effects on environmental and human systems. There is a pressing need for an effective global sand governance system.

Effective governance will require detailed knowledge of how much sand is used locally as well as globally and how much of this sand is replenished through natural processes. Several characteristics of sand contribute to the impression that it is an abundant or re-

newable resource. Sand is scattered all over Earth’s crust and, in some deposits, is continually replenished by sediment transport. Furthermore, it is relatively inexpensive to extract, and as in the case of many mined substances, the negative consequences of mining are not felt at the point of consumption, but rather in the poorer regions where mining occurs. But is this perception of sand as an abundant and renewable resource a delusion? Sand is a scarce resource in many parts of the world, but it is unclear if, globally, sand demand exceeds supply. We urgently need to move beyond estimating past and future sand demand and toward disentangling the global sand budget.

To illuminate complex interlinkages between sand demand, mining, trade, transport, and consumption, researchers must use interdisciplinary approaches. Systems integration frameworks and methods have been useful in addressing management challenges of other resources such as water and carbon (14). Considering all systems, from extractive areas to consumption points, in a holistic and systematic way will help to elucidate the hidden impacts of sand extraction and trade.

For instance, applying the framework of telecoupling—long-distance interactions between socioeconomic and environmental systems (14)—to this issue would allow capturing complex relationships and global consequences across three intertwined systems: the sending systems where sand is mined; the receiving systems, such as urban areas, where sand is consumed; and spillover systems—that is, areas through which the sand is transported or that are affected

by its extraction and consumption. Use of this approach would help to unravel interconnections between distant places such as importing and exporting countries, clarify responsibilities of local and remote extraction of sand, address spillover effects such as invasive species or carbon emissions, guide policies across scales and boundaries, and anticipate cascading effects such as those described above.

On the governance side, efforts to increase efficiency of sand use and trade should include recycling policies and avoiding waste along the supply chain. However, although recycling helps alleviate pressures on sand resources, there are currently no alternatives to satisfying skyrocketing global demand without drastic innovation. Achieving responsible consumption will require fostering coordination among multiple national and international policies; establishing controls on planning, permission, prospecting, extraction, and monitoring for the mining industry; developing payments for environmental and social damage; and building capacity for the sustainability of sand appropriation. Simultaneously, regulations should be crafted for local contexts (15) and must be accompanied by effective enforcement and monitoring. With increased attention to the complex linkages of sand scarcity, our global community can begin to understand how to use sand more sustainably and avert a tragedy of the sand commons. ■

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