The New Source to Sink: Opportunities for Geoscientists in Sand and Gravel Mining

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MOTIVATION

Sand and gravel mining, transport, and consumption in the global construction industry is arguably the world's largest "source-to-sink" (S2S) sediment dispersal system. Construction aggregates are the world's most extracted solid material resource (OECD, 2019) with 30–50 billion tons currently mined annually, largely used in concrete (UNEP, 2019). Total global sediment flux to oceans is around 19 billion tons annually, of which ~1.5 billion tons is bedload material (Syvitski et al., 2005). While crushed rock is increasingly important in construction aggregates (Torres et al., 2021), natural sand and gravel deposits are still the primary mining targets globally (Torres et al., 2021; UNEP, 2019). Given the fact that construction aggregates are generally coarser than fine sand, the most direct comparison between these two global S2S systems is bedload estimates versus construction aggregates. This makes the global construction S2S system an order of magnitude larger than all the world's natural coarse-grained S2S systems combined. Because coarse sediment is something that many geoscientists think about daily, this fact presents new opportunities for societally relevant research directions.

Defining the Components and Drivers of the New Source-to-Sink System

Construction S2S systems (Fig. 1A) begin at the mining site (source; Fig. 1B); continue through transport via trucks, trains, or barges and subsequent processing, usually mixing into concrete (transfer zones; Fig. 1C); and final use, generally pouring concrete at a construction site (sink). This S2S system has quantifiable drivers that control its evolution (Torres et al., 2021). Whereas climate and tectonics drive natural systems, economic and social forces drive the construction S2S system (Gavriletea, 2017; Torres et al., 2021). Any time a city, region, or country wants to expand infrastructure, given current concrete-centric building practices, there must be a resultant increase in sand and gravel extraction, transport, and consumption.

IMPLICATIONS AND OPPORTUNITIES

Understanding the Resource and Implications of Extraction

Natural sand and gravel can be extracted from one of two sources: old deposits or active systems (UNEP, 2019). Mining from older deposits represents a self-contained system with largely localized environmental impacts. From an S2S perspective, such networks are important to understand in terms of available resources, particularly to replace supply from more environmentally deleterious active sources. "Resource exploration" is relatively simple for sand and gravel because most economic deposits are evident at the surface. However, detailed surface mapping is not available in many places around the world. Moreover, even where surface deposits are mapped in detail, subsurface architecture and grain size distributions may be poorly known. This provides opportunity to help define the most sand- and gravel-rich locations to target to minimize even local environmental impacts.

Most sand and gravel pits are in unconsolidated Quaternary deposits, meaning an improved understanding of the history of

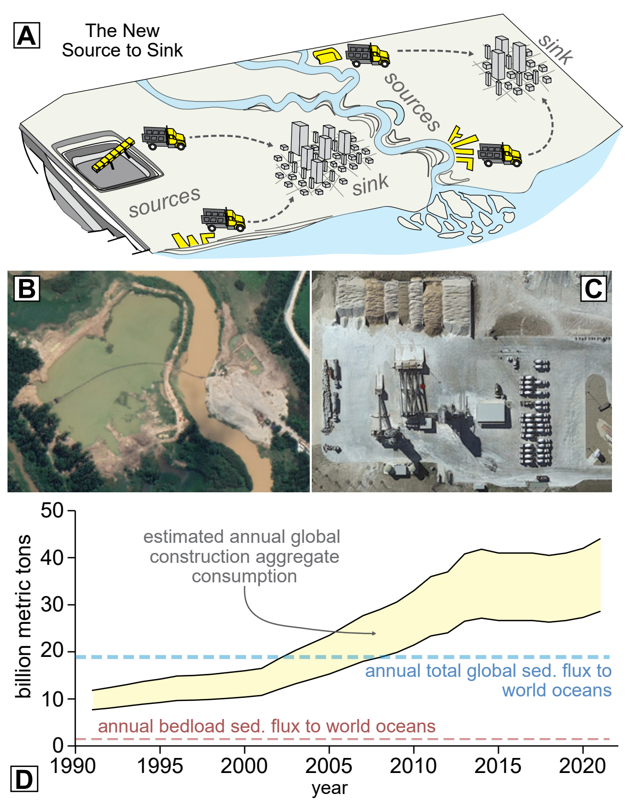

Figure 1. (A) Cartoon schematic of the new construction sand source-to-sink system. (B) Example of a river sand mine in Malaysia. (C) Example of a typical concrete batch plant. Note stockpiles of sand in upper left awaiting mixing into concrete. (D) Summary of global consumption of construction aggregates. Uncertainty envelope is estimated using the conventional proxy of 6.5–10× cement consumption (Peduzzi, 2014; UNEP, 2019). Sed.—sediment.

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recent coarse sediment flux through any given system is useful in predicting the best pit locations. Developing relationships with mining companies motivated by such resource evaluation can lead to access to sedimentary records that would otherwise be lost to science. Marine extraction is also increasingly considered as an economic source for construction sand and gravel (Torres et al., 2021)—motivating new efforts to better characterize seafloor sand deposits and understand marine coarse sediment transport. While resource evaluation in older deposits is important, in many places, studying extraction from active systems is a more pressing sustainability concern.

Although known to be unsustainable, and often illegal, mining from active systems is generally the quickest and cheapest way to meet local demand. Such deposits are usually clean, unvegetated, and can even be mined by hand. In terms of research contributions, while accurate natural bedload fluxes are notoriously difficult to estimate, they are often the biggest hurdle in evaluating mining impacts in active systems (Bendixen et al., 2019). Extracted volume/tonnage is also often difficult to estimate. Reporting systems are not common globally, and mining activity is often informal. More innovative solutions like using machine learning analysis of satellite images to track sand barges (Hackney et al., 2020) are needed to address this problem. Beyond quantifying natural supply and human extraction, we also need a better understanding of how natural systems respond to the removal of large volumes of coarse sediment.

The root cause of geomorphic change due to sand mining is an induced deficit in sediment supply that the system re-equilibrates by cannibalizing older deposits. As summarized by Koehnken et al. (2020) in their review of recent case studies, this can cause channel widening or deepening in fluvial systems, even leading to alluvial streams stripped to bedrock, and increased beach erosion and retreat in littoral systems. Other ecological impacts include destruction of aquatic habitats, increased suspended sediment, and bed coarsening (Koehnken et al., 2020). Improving our understanding of how individual local perturbations might integrate at the system scale remains an open opportunity to aid resource management and guide environmental recovery.

Traceable Supply Networks: From Where, to Where?

Construction S2S systems can be surprisingly opaque. While most consumption occurs near extraction sites (<100 km), there are often multiple options for mining within that radius. Moreover, increasing demand in areas without their own domestic supply, like Singapore and Hong Kong, leads to longer transport, with some supply chains operated by full-fledged illicit networks (Magliocca et al., 2021). Traceable sourcing is the cornerstone of sustainability policy, yet in sand and gravel mining there are currently no reliable, scalable monitoring methods beyond self-reporting and direct observation. My research group is working on novel approaches to employ sand provenance analysis in tracing supply networks (Sickmann et al., 2022), but more innovation is required in this area.

Understanding Drivers and Predicting Areas of Concern

Without alternative building materials and methods, demand for construction aggregates is projected to double by 2060 (OECD, 2019). Identifying existing areas of environmental impact and predicting future areas of concern are crucial for understanding long-term sand and gravel exploitation sustainability. This offers the opportunity for geoscientists to work with economists, urban planners, and policymakers to evaluate the best deposits for meeting demand. Sand in the concrete of a new skyscraper will never end up back in the river from which it was taken. If we, as geoscientists, can proactively help predict areas that need to be protected and better identify acceptable resource targets, we can further demonstrate direct applications of our knowledge and skillsets to the sustainability challenges of the present and future.

CONCLUSIONS

Increasing awareness of sand and gravel mining in geoscience research and curriculum is a way to expand the influence of geoscientists in planning a more sustainable future and for motivating new ways to advance fundamental earth-systems science.

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