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Review article

Conceptualizing sand extractivism: Deconstructing an emerging resource frontier

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ABSTRACT

Since the mid-twentieth century, the extraction and consumption of mineral aggregates (i.e., sand and gravel) has grown at a higher rate and on a larger scale than any other resource group, making it the largest mineral resource currently consumed globally. Although reliable data for extraction of mineral aggregates (referred to as sand extraction) are lacking, estimates suggest that current annual extraction is as high as 40 Gt. This has important social and ecological ramifications. The industry overall is also plagued by rampant illegality, a strong black market, and intense violence, and results in the generation of severe social and environmental injustices. Yet despite the wide-ranging impacts of sand mining, there continues to be an acute shortage of research on its extraction, impacts, and solutions for future resource governance. This article draws on the political ecology literature, utilizing the concept of the commodity frontier and the theoretical framework of extractivism whilst engaging with academic as well as non-academic, grassroots literature around sand mining, to introduce the concept of "sand frontiers". Using the sand frontier as an analytical tool, four central questions are addressed, namely: 1) What are the drivers of expansion and intensification of sand frontiers? 2) What and where are the current and potential sand frontiers? 3) How is the forward movement of sand frontiers occurring? and 4) What are the identifiable socio-ecological transformations at these frontiers? In addressing these questions, the paper bridges research gaps around solutions to unsustainable sand extraction, using the lens of post-extractivism (PE) whilst continuing to put people living at sand frontiers at the centre of proposed solutions.

1. Introduction

Mineral aggregates (sand and gravel) are estimated to be the fastest-growing material group extracted over the twentieth and twenty-first centuries and are currently the most-extracted and consumed material group worldwide (Krausmann et al., 2009; Krausmann et al., 2017, Torres et al., 2017). Although not particularly visible, aggregates are foundational to modern human society (Beiser, 2018; Peduzzi, 2014; Koehnken and Rintoul, 2018). They are embedded in the everyday lives of people by being central to the production of buildings, roads and highways, as well as products such as cell phones and laptop screens, optical glasses and glass windows. At the same time, naturally occurring aggregates provide myriad ecosystem services such as clean and filtered drinking water, support sustenance livelihood activities such as agriculture and fisheries, provide habitat for important microfauna and microflora, provide protection against floods, cyclones and coastal storms, and have aesthetic and cultural value through access to beaches and clean water bodies (Beiser, 2018; Peduzzi, 2014; Koehnken and Rintoul, 2018). As such, the massive volumetric quantities of global aggregate use mean that sand extraction[1] has important multi-dimensional negative ecological, economic, and social ramifications, both at the global level as well as locally around sites of extraction.

Although precise quantitative data on sand extraction are unavailable, volumes of extraction can be understood in terms of their representation in total global material consumption. Of the total global material consumption—which reached 89 Gt in 2015 (Krausmann et al., 2018)—close to 50% is estimated to be non-metallic minerals (Krausmann et al., 2018). Further, non-metallic minerals represent close to 84% of total mineral production (Franks, 2020). The largest component of non-metallic minerals is accounted for by construction minerals

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[1] Since aggregates (sand, gravel, pebbles, cobbles, etc.) typically occur and are extracted together (only differing in granular sizes), this process is collectively referred to as sand mining/extraction (Koehnken and Rintoul, 2018). Naturally occurring sand is a product of erosion of rocks through various mechanisms over geological timescales. Sand—regardless of its lithologic, mineralogic, or chemical composition—is characterized as a clastic fragment of individual diameter between 0.0625-2mm (Wentworth, 1922).

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(Krausmann et al., 2009). Within construction minerals, mineral aggregates (sand, gravel, and crushed stone) represent the largest component, accounting for close to 71.9% of construction minerals (Miatto et al., 2016). Given the lack of reliable quantitative data on aggregates, they are best represented in terms of data on construction minerals. Estimates suggest that between 1900 and 2005, construction minerals grew by a factor of 34, reaching 23 Gt in 2005, and this material group alone accounted for 40% of global material consumption that year (Krausmann et al., 2009).

It should be noted here that non-metallic minerals are the material group with the highest degrees of quantitative uncertainties (Krausmann et al., 2009; Fischer-Kowalski et al., 2011; Miatto et al., 2016; Steinberger et al., 2010), and all current estimates are also underestimations by large margins (Krausmann et al., 2009), indicating that actual quantities of global aggregate flows are likely to be much higher than presented here.[2]

Despite these uncertainties, lowest estimates suggest that total global sand extraction reached close to 28.6 Gt by 2010 (Krausmann et al., 2017) and 40 Gt per year by 2014 (Peduzzi, 2014; Koehnken and Rintoul, 2018; UNEP, 2019). These figures indicate that aggregates quantitatively exceed any other material group extracted (Torres et al., 2017), making it the second most used natural resource by modern human society, second only to water (Beiser, 2018; Peduzzi, 2014; Koehnken and Rintoul, 2018), and making sand extraction the largest form of mineral extraction. Given their wide geographical spread, large-scale availability, and low-capital inputs for extraction, aggregates are also estimated to account for the largest number of individual mines compared to other minerals (Beiser, 2018). Furthermore, the estimated extraction of ~40 Gt in 2014 is double the estimated total sediment (aggregate) discharge from rivers of ~20 Gt (Milliman and Syvitski, 1992), representing the unsustainability of current extraction trends. Additionally, sand extraction is characterized by a massive black market, illegal extraction and an extremely violent industry resulting in a direct threat to the lives of local people engaged in anti-extractive activism across a wide geography (Beiser 2018; Bisht and Gerber, 2017; Koehnken and Rintoul, 2018; Bisht, 2019).[3] In recent decades, the Global South has been the locus of aggregate consumption, and is the region which, in the near future, is likely to see the most important increases in aggregate use (Miatto et al., 2016), and is therefore also likely to be the locus of sand extraction and its related negative implications.

Although currently still limited, in recent years, scholarly work on sand extraction and its impacts is emerging as a growing field of research (Peduzzi, 2014; Hilson, 2016; Torres et al., 2017; Bisht and Gerber 2017; Bisht, 2019; Beiser, 2017, 2018; Marschke et al., 2020; Franks, 2020; Lamb et al., 2019; Bendixen et al., 2019; Kothari and Arnall, 2020). There is also significant work by journalists, activists, non-governmental organizations (NGOs), and grassroots organizations, and increasing conflicts around sand mining. This article draws on political ecology literature, utilizing the concept of the commodity frontier and the theoretical framework of extractivism whilst engaging with non-academic, grassroots literature around sand mining to introduce a discourse on the movement of sand frontiers and theorize sand extractivism.

A scoping review of both quantitative and qualitative studies on sand mining was conducted. It comprised three major groups of scholarly works: 1) sand mining, sand extraction and sand conflicts; 2) quantitative analysis of global trends and patterns of social metabolism, including non-metallic mineral and construction mineral extraction and use; 3) research on extractivism, specifically that related to artisanal mining, small-scale mining; and 4) other types of extraction of non-metallic minerals. Grey literature was collected using web-based online keyword searches for "sand mining", "sand crises", "sand conflicts", "sand scarcities", "sand governance", and "ecological impacts of sand mining". The literature collected was grouped as follows: journalistic reports, reports from international organizations, reports from advocacy groups and NGOs, and news articles. Details of ecological conflicts linked to sand were also extracted from the EJAtlas, a global database of ecological distribution conflicts (EDCs) and environmental injustices.

Section 2 of this paper explores the linkages between increasing social metabolism and the creation, proliferation and intensification of commodity frontiers, and introduces the concept of "sand frontiers". Section 3 elaborates on sand frontiers by addressing four research questions, namely: 1) What are the drivers of expansion and intensification of sand frontiers? 2) What and where are the current and potential sand frontiers? 3) How is the forward movement of sand frontiers occurring? and 4) What are the identifiable socio-ecological transformations at these frontiers? Based on the analysis of creation, proliferation, intensification and transformations at sand frontiers, Section 4 highlights the similarities and discusses the differences between sand extraction and other forms of mineral extractivism. It reflects on why extractivism—a framework typically used to study metal or bulk mineral extraction (Acosta, 2017; Bunker, 1985; Ye et al., 2019; Gudynas, 2013)—is an increasingly relevant and necessary theoretical framework for deeper analysis of sand extraction. Section 5 proposes solutions to the ongoing patterns of sand frontier expansion, utilizing the rich literature on post-extractivism (PE) (Acosta, 2016, 2017; Gudynas, 2013; Svampa, 2015). The lens of PE—which engages with problems around resource extraction whilst keeping socioeconomic and ecological transformations occurring at frontiers central to the design of solutions—is utilized to enhance the existing, limited, policy recommendations around sand governance to focus solutions for sand frontiers. The sixth section concludes the article.

2. Increasing social metabolism and the forward movement of commodity frontiers

The increasing rates and scale of extraction and consumption of sand resources over the twentieth and twenty-first centuries are commensurate with increasing total global social metabolism across all material groups. Given the limitation of analyses on sand extraction, it is essential to first explore, theoretically, the broader history of natural resource extraction, and resultant ecological and socioeconomic transformations at frontiers of extraction. Although metabolic interaction between human society and ecosystem has always existed, the introduction, reproduction, and ever-increasing scale of capital involved in nature-society interactions over the past two centuries has led to massive growth of metabolic demands on nature by the economy (Clark and Foster, 2010). This increasing social metabolism and global material use (Muradian et al., 2012; Haberl, 2001; Fischer-Kowalski and Haberl, 2007; Fischer-Kowalski, 1998; Schaffartzik et al., 2014) has been a product of intensification and expansion of frontiers of resource extraction—commodity frontiers (Moore, 2000; Clark and Foster, 2010, 2014).

The commodity frontier simultaneously refers to both a specific geographical place and a socio-spatial movement—typically the "forward movement of the (capitalist) system", expanding into new spaces and/or creating new socio-ecological-economic flows (Moore, 2000, p. 412). These have historically been spaces forced open by the combined agencies of capital, science and empire (Moore, 2000, 2014; Schindler and Kanai, 2018). Frontier dynamics have been theorized by Moore

[2] Since one of the largest uses of aggregates is for construction (Peduzzi, 2014), global consumption of aggregates are estimated using cement consumption data, with average cement-to-aggregate ratio of 1:6 for buildings (Steinberger, 2010), which may in itself be an underestimation. For instance, much larger quantities of aggregates are used for road construction, at bitumen-to-aggregates ratio of 1:20 (Steinberger et al., 2010).

[3] Whereas no official international database currently exists, large-scale violence is evidenced by reports in local, national and international newspapers, through NGOs, transnational activist networks, etc. The EJAtlas is one important database documenting such cases (ejatlas.org).

(2014) as nature-capital interactions which treat ecosystems as "cheap nature", and appropriate ecological surpluses from local inhabitants who are both users and stewards by dispossessing them (Schindler and Kanai, 2018), and by mobilizing "the work of uncommodified human and extra-human natures in service to advancing labour productivity within commodity production" (Moore, 2014, p. 286). The first phase of this frontier expansion, also termed as the "cheap nature strategy" of early capitalism, was first undertaken during the 15th century, with expansion of extraction into Africa and Latin America through colonialism and imperialism (Moore, 2014; Schindler and Kanai, 2018). This has extended well into the 20th century through a combination of instruments, such as recommendations of supranational organizations and state policies (Svampa, 2015; Arsel et al., 2016; Saes and Bisht, 2020). Frontier expansion has also included generations of ever-increasing new resource frontiers. This is because as new resources have been metabolized by the economy, they are absorbed into circuits of capital, thus enhancing their commodification and extraction (Schindler and Kanai, 2019).

The forward movement of commodity frontiers typically occurs in three ways: commodity widening—encroaching into new geographical spaces for extraction; commodity deepening—introducing new technologies or organizational logistics to intensify extraction at existing frontiers; and commodity-transformation—reconstituting the forms of commodity and their underpinning of socio-ecological systems (Banoub et al., 2020). These movements are transformative of local ecosystems, degrading ecosystems and generating environmental pollution, as well as socioeconomic and cultural dynamics at frontiers (Moore, 2000). Furthermore, given the self-exhaustive nature of resource extraction, frontier expansion results in generating forward movements of localized scarcities (Moore, 2000; Schindler and Kanai, 2018). The extraction of raw materials, land and labour at commodity frontiers have also been historically linked to unequal development, dispossessions, violence and power asymmetries (Moore, 2000; Harvey, 2007; Schindler and Kanai, 2018). Frontier expansion and the negative externalities it engenders eventually result in the generation of environmental injustices and often lead to ecological distribution conflicts (Temper et al., 2015).

In recognition of the large quantities of already appropriated and commodified natural resources, Moore (2014) posited that the early twenty-first century was witnessing the "end of cheap nature"—a point beyond which there are no more great global commodity frontiers that could be transgressed at rates and on scales that would enable further resource appropriation to enable the next phase of global economic growth (Moore, 2014; Schindler and Kanai, 2018). However, Schindler and Kanai (2018) posit that even if there is no longer a single "great" or global commodity frontier, "rescaled governance regimes may be able to locate localized commodity frontiers". Moreover, there is a continually growing search for new materials and energy sources (Temper et al., 2015), which is likely to continue pushing and even creating new commodity frontiers of resources newly incorporated into commodity regimes. These discussions are particularly relevant in the analysis of sand extraction because, in recent decades, sand is increasingly becoming one such "new" resource.

As is the case with all minerals, the mining of sand has seen significant growth over the last two centuries. Although historically used in construction, large-scale consumption of sand is today linked to concrete production (Beiser, 2018). The immense increase in concrete production since the late nineteenth century (Forty, 2012; Watts, 2019), which continued over the twentieth century with increasing urbanization and globalization, has culminated in concrete becoming the world's most consumed man-made material in the twenty-first century (Courland, 2011). The increase in concrete production is the most significant driver of current scales of sand extraction. Given its close linkages with economic growth, over the last century sand consumption has spatially and temporally shifted, with consumption currently being primarily located in the Global South (Miatto et al., 2016), two of the top domestic consumers being China and India (Koehnken and Rintoul, 2018). China is an especially important example here, with the country being the largest global cement producer in 2018 with an estimated production of 2.37 Gt of the total 4.1 Gt production that year, representing 58% of global production (USGS, 2019). Another important factor here is the rate of growth in construction, which is so rapid that it is estimated that total cement consumption in China (at 6.6 Gt) between 2011 and 2013 was greater than consumption in the USA between 1901 and 2000 (at 4.5 Gt), i.e., China consumed more cement in two years than the USA in a century (Smil, 2014). Rapidly increasing population and urbanization in the Global South are further expected to push demand for sand in the near future, e.g., it is estimated that if India follows a development trajectory similar to that of China, it is likely to result in quadrupling global sand demand (Koehnken and Rintoul, 2018). This ongoing consumption of sand is already leading to sand scarcities, is likely to drive prices up further in the near future (Bendixen et al., 2019), and, in line with frontier dynamics, result in further expansion and intensification of sand frontiers.

Based on a critical analysis of the frontier discourse and available qualitative and quantitative data on sand extraction, the next section of the paper elaborates on the concept of sand frontiers by presenting the drivers, locations, forward movement of, and transformations at these frontiers.

3. The emergence, expansion and intensification of sand frontiers

3.1. Major drivers of increasing social metabolism of sand resources

Sand has diverse and widespread applications, and therefore a large number of drivers of increasing social metabolism, the most significant of which are explored here. Given that sand use is dominantly utilized for construction, the two largest drivers are urbanization and transport infrastructure (Peduzzi, 2014), although exact figures used in these global projects are unavailable. Global social metabolism of construction minerals increased drastically over the 20th and 21st centuries (Krausmann et al., 2018; Miatto et al., 2016), and is closely linked to economic growth and development at national level (Steinberger et al., 2010). Urban spaces require massive quantities of sand for building construction, roads, pavements, etc., and the construction of 1 km of highway on average requires close to 30,000 tons of sand (Koehnken and Rintoul, 2018), with 80% of concrete roads and 90% of asphalt pavements being composed of aggregates (Peduzzi, 2014). Owing to a mix of increasing population pressures, global capital, and enhanced technology and engineering capabilities, this project is currently evolving to increasingly larger scales. Urbanization has expanded to the production of megacities and the creation of entire new cities, such as those in Qatar (Rizzo, 2014), Dubai and the UAE (Nassar et al., 2014; Peduzzi, 2014). In addition, infrastructure projects have expanded from the production of roads and highways to much larger-scale projects, such as national development corridors, special economic zones, transnational highways, and intra-continental transport infrastructures, including the Belt and Road Initiative (World Bank, 2018), following processes of "infrastructure-led development" (Schindler and Kanai, 2019). All these developments lead to massive increases in sand extraction.

The next major infrastructure driver of sand metabolism is land building or land reclamation. These projects are undertaken for various reasons, such as land reclamation for expansion of territorial borders, e.g., Singapore (Koehnken and Rintoul, 2018; Lamb et al., 2019), the Netherlands (Hoeksema, 2007), Nigeria (Sengupta et al., 2018), Japan (Suzuki, 2003); for luxury residential projects in countries such as Dubai/UAE (the Palm Island and The World), Nigeria's planned Eko Atlantic City built on 10 million m^2 of reclaimed land and surrounded by the protective "Great Wall of Lagos" (Ajibade, 2017); and for national development projects, such as Indonesia's planned Giant Sea Wall or National Capital Integrated Coastal Development project in Jakarta (EJAtlas, 2019); and for geopolitical reasons, e.g., China's construction

of Spratly Islands in the South China Sea (Sengupta et al., 2018; Mora et al., 2016).

Another driver of sand extraction, currently largely limited to USA, is hydraulic fracturing (fracking), which requires large quantities (each well requiring close to 10,0000 tons) of high-grade silica sand as a "propper" agent to maintain open shale fractures and ensure continuous gas flow (Biersted, 2015). Frac sand consumption in 2017 in the Permian Basin (largest fracking basin in the world) stood at 23 million tons, with estimates that demand will increase to 54 million tons by 2022 (Black Mountain Sand, 2018). High-grade silica sand—with purity grades of over 99%—is required for the production of optical lenses, microchips, and glass (for buildings, electronics, etc.). Finally, an increasingly important utility of sand is for mining of rare earth minerals and metals, such as ores of iron, ilmenite ore for titanium, garnet, zirconium, rutile, etc. (EJAtlas, 2017a, 2017c).

Moreover, ongoing and future needs for sand consumption continue to exist and even grow. For instance, necessity-based decent housing, basic public infrastructure and transport access for all is still lacking for large sections of global society. Construction of protective barriers especially in low-lying countries, high-density coastal cities, regions prone to flooding, and Small Island Developing States are likely to become increasingly important future drivers of sand use due to global sea level rise (Sengupta et al., 2018). Finally, potential growth of needs-based sand use is also likely to increase in the production of electronic devices, which will be ever more important for access to basic services in a post-COVID-9 world.

Given the increasing extraction of sand, and the geographically widespread nature of sand availability and extraction, the following section explores where sand has been and is being extracted, i.e., where sand frontiers are located.

3.2. Locating sand frontiers

Typically, commodity frontiers are spaces characterized by a combination of abundance of specific natural resources, availability of technological feasibility for large-scale extraction, and favourable political conditions. Given their widespread availability, relative ease of extraction, and lack of regulatory policies in many countries, sand frontiers are much more diversely located and widespread. Five major spatial categories which have the potential to convert into sand frontiers are identified below:

3.2.1. Riverine

Located below surfaces and along coastlines of rivers, riverine sands are clastic fragments typically composed of different minerals, and have angular individual grains, making them particularly well-suited for concrete production, hence their widespread use in construction. They are also preferred given their general proximity to urban agglomerations. Since riverine sands can be found in all rivers, tributaries and other flowing surface water bodies, and are easy to access with relatively lower-grade technological inputs, current and prospective riverine sand frontiers are constricted only by policy, e.g., in Western Europe (Koehnken and Rintoul, 2018). Given their ease of access, they are also much more likely to involve smaller-scale, local extractive actors. Frontier expansion and intensification have major negative implications for downstream flooding and drought, fishing and agriculture, and can severely affect aquatic biodiversity (Koehnken and Rintoul, 2018; Peduzzi, 2014; Gavriletea, 2017).

3.2.2. Beach/coastal

Beach sands are deposits of clastic fragments carried by rivers as they enter oceans,[4] and are composed of angular grains, thus having utility in construction, albeit to a lesser degree than riverine sands. One of the most important applications of beach sands is in land building/expansion. Beach mining has also recently begun including mining for rare earth minerals, e.g., zircon and ilmenite mining operations on the coast of Senegal (EJAtlas, 2018). Similar to riverine frontiers, many beach-sand frontiers are located in unregulated beaches in the Global South (Tweedie, 2018; EJAtlas 2017a; EJAtlas 2017c). Frontier expansion and intensification have significant implications for disappearing/reducing beaches and inland flooding, increasing climate vulnerability of coastal cities and affecting livelihoods and sustenance-based fisheries (Koehnken and Rintoul, 2018; Peduzzi, 2014; Gavriletea, 2017).

3.2.3. Lakes and creeks

Located on floor/beds of lakes, creeks, and other stagnant or semi-stagnant water bodies, such sands are deposits of riverine sands, are angular, and are largely used for construction, but require relatively large technology and energy inputs. Prominent examples of such extraction are the large-scale mechanical operations in Lake Poyang (China) (de Leeuw et al., 2010; Ye et al., 2018), and large-scale manual operations in Vasai Creek (India) (EJAtlas, 2020). Frontier expansion and intensification can lead to negative impacts on local livelihoods, especially from peasant agriculture and fisheries, and altered patterns of downstream sediment deposition has potential implications for floods and droughts.

3.2.4. Marine

Located on ocean floors, marine sands are deposits of riverine and beach sands. Although angular, they are relatively less suitable for industrial applications owing to higher extraction costs—mechanical operations involving higher capital, technology and energy inputs—and an expensive stage of salt removal (Koehnken and Rintoul, 2018; Peduzzi, 2014; Gavriletea, 2017). This results in marine-sand frontiers being relatively few but likely to be more intensive given the higher cost of operations and thus the involvement of larger extractive players. Large-scale marine-sand mining has severe negative impacts on benthic ecosystems, as they disturb or destroy habitats, especially unique ecosystems such as coral reefs and mangroves. For instance, dredging in Waa-Tiwi-Diani coral reef (Kenya) of ~800,000 m^3 in the first phase (EJAtlas, 2017b), followed by ~20Mt of sand and 400 tons of stones extraction in the second phase (Aggregates Business, 2015) resulted in severe damage to reefs, turtles and fish, and a loss of cultural commons. These operations are currently funded by the Japanese International Cooperation Agency and use the Dutch vessel Willem van Oranje (The Conversation, 2019), indicating the presence of powerful, international, larger-scale extractive players.

3.2.5. Crushed rock

In cases of limited access to other forms of sand, hills/boulders/rocks can be mechanically broken down into smaller fragments until granular sand size is obtained. This activity is capital intensive, making crushed rock sand frontiers more sparse but likely to involve larger extractive players and be more intensive. For construction, regular rock/hills/boulders are crushed to obtain angular particles (Koehnken and Rintoul, 2018; Peduzzi, 2014; Gavriletea, 2017). Other, more specific applications require specific rocks/stones, and private ownership of rocks/hills/boulders, e.g., frac sand—crushed sandstone for fracking (Black Mountain Sand, 2018)—and powder from talc rocks for cosmetics and pharmaceuticals (Jadhav et al., 2013).

Desert sand, although available in large quantities, is composed of individual spherical grains, which are currently incompatible for concrete production, thus having no large-scale applications (Zhang et al., 2006), and hence no current desert-sand frontiers.

Given the potential for sand frontier creation in multiple spaces, the following section explores how forward movement of sand frontiers is occurring and can continue to occur.

[4] Exceptions include coral, and volcanic beaches.

3.3. Forward movement of sand frontiers

The forward movement of sand frontiers can be observed to have occurred through strategies of commodity-widening—geographical and spatial expansion, and commodity-deepening—intensification of operations at existing sites. Although quantitative analysis of commodity-widening is difficult given the lack of data, because of its strong linkages to concrete, frontier movement can be expected to have progressed coterminously with increased construction, since sand is a high-volume, low-value commodity (Miatto et al., 2016) with a relatively small range of transportation. Between 1970 and 2010, non-metallic mineral consumption stabilized in North America and Europe, whereas Asia-Pacific saw an intense increase in extraction, and Latin American and Africa showed increasing extraction but remained below the world average of per capita consumption (Miatto et al., 2016). Much of this supplemented the massive built environment and infrastructure growth in the Global South, particularly in BRICS (Brazil, Russia, India and China) in the 21st century (Miatto et al., 2016). Since extracted sand is largely used within national boundaries, domestic consumption can be expected to be largely correlated with the expansion of sand commodity frontiers. In the 21st century, therefore, sand frontiers have transitioned from the Global North to the Global South, which can be traced along the temporal movement of the projects of economic growth and development. Another indication of commodity-widening in the Global South is the presence of sand-related socio-ecological conflicts, which are largely localized in the Global South.

Along with commodity-widening, processes of commodity-deepening can be observed at many sand frontiers. This applies especially to large-scale mechanical dredging operations, which can be similar to multinationally operated extractivisms in terms of inputs, processes, and outputs, with high extraction rates, resulting in large-scale, and long-term ecological degradation. Extraction in the largest single sand mine in the world—Lake Poyang in China—was estimated at 488 million tons or 236 million m^3 in 2005–2006 (de Leeuw et al., 2010), resulting in increased discharge capacity of 1.5–2 times its pre-extraction average (Lai et al., 2014), and an average annual water level decline of 0.26 0.75 m between 2000 and 2014 (Ye et al., 2018). Another example of commodity-deepening is in the Mekong river. Despite a lack of reliable data, reports from investigative journalism (Constable, 2017; Beiser, 2018), international and national NGOs and other transnational actors (Global Witness, 2010), and intergovernmental bodies (UNEP, 2019; Koehnken and Rintoul, 2018) indicate that Cambodia, Vietnam, Lao PDR and Thailand have been large exporters of sand from the Mekong, mostly for export to Singapore (Lamb et al., 2019). This implies that the Mekong has emerged as an international sand frontier for urbanization, construction and development in the more developed nations in the region. Extraction in the basin was estimated to be around 55 million tons per year in 2011 (Koehnken and Rintoul, 2018), with volumes of extraction so high as to result in the Mekong channels in Vietnam deepening by an average of 1.4 m and material bed losses of ~90 million m^3 between 1998 and 2008 (Brunier et al., 2014). Furthermore, intensity of extraction in Indonesia was so high that 24 Indonesian islands are believed to have disappeared between 2005 and 2014 as a direct result of sand extraction, and 80 islands remain under threat (Tweedie, 2018). The extractive intensity at the Mekong riverine frontier, the quantities of sand extracted and exported, its downstream ecological and livelihood effects on people (Lamb et al., 2019), and the corruption and illegalities involved,[5] were so extreme that exports to Singapore were banned by Cambodia in 2017, Indonesia in 2007, and Malaysia in 2018 (Reuters, 2020). Following these bans, to ensure sand availability, the search for resources, their commodification, extraction and export has spatially shifted to Myanmar (Reuters, 2020), in line with commodity-widening strategies.

Forward movement of commodity frontiers is both responsible for localized ecological exhaustion and provides impetus for further expansion, thus creating a cyclical loop of scarcities, commodification, and increasing extraction along its movement. Localized sand scarcities are already emerging across the world, especially in South-east and South Asia. These scarcities are likely to increase prices, further commodify sand, push sand frontiers, and increase transnational movement of sand resources. This is corroborated by a global system dynamic model of sand, gravel, crushed rock and stone, which concludes that localized sand scarcities are presently increasing demand, signalling that global trade in these materials is likely to continue growing in the near future (Svedrup et al., 2017).

The forward movement of sand frontiers, as all commodity frontiers, is associated with the continuing movement of ecological and socio-economic transformations, which are examined in detail in the following two sections.

3.4. Ecological transformations at and downstream impacts of sand frontiers

As explored in Section 2, commodity frontiers are spaces where capital-nature interactions lead to appropriation of cheap nature through exploitation of ecosystems and labour, and are characterized by profound transformations of land and ecosystems as well as labour and socioeconomic relations (Moore, 2000; Frederiksen and Himley, 2019). All these transformations can be identified at sand frontiers. Geomorphologically, frontier intensifications lead to changes in river channel morphology resulting in localized increase of river-bed slope and increased flow velocities (through channel deepening); sediment composition (through extraction of medium to coarse grains, thus reducing median-size grains); reduced river sediment load (through extraction of large volume of materials); and impacts on water quality (resulting in altered light penetration impacting algal, vegetation growth, and biotic life) (Koehnken and Rintoul, 2018). Intense riverine sand frontiers also impact deltas and coastal zones, due to insufficient sediment deposition, which is essential for production and maintenance of beaches. Coastal sand dredging heightens vulnerabilities through reduction of beaches and increased inflow and access of sea water and can damage ecosystems such as mangroves, which serve as first lines of defence against extreme weather events (Koehnken and Rintoul, 2018).

Ecological transformations at sand frontiers have severe implications since aquatic ecosystems are habitats for diverse flora and fauna, including endangered species. The Mekong is an ecological hotspot supporting over 800 species of fish, 165 long-distance migratory species and one of three largest remaining populations of freshwater Irrawaddy dolphin; Ganga supports at least 12 freshwater turtles, two crocodiles, 48 aquatic birds and two mammal species (Rao, 2001); Waa-Tiwi-Diani in Kenya (Constable, 2017) and Spartly Islands (Mora et al., 2016) are important coral reefs ecosystems, and Southern Asian countries' coastlines have protective and biodiversity-rich mangrove ecosystems, which are at serious risk of loss. Moreover, impacts can last over extended time periods, with one post-cessation evaluation study in an intense extraction site off the coast of southern England (>10 h/day dredging within a 100 m^2 block over 25 years) showing localized benthic recolonization did not recover even 6 years post-cessation of extraction (Boyd et al., 2005).

Sand frontiers also generate significant downstream transformations that extend beyond the frontier. Socioeconomically, altered river flows have serious downstream impacts affecting the livelihoods of peasant and fishing communities; for example, the Mekong supports the world's largest inland fishery providing a critical food source for 18 million people (Brunier et al., 2014), and the Ganga basin supports close to 40% of India's population (Ganga Action Plan).

[5] An investigative report comparing value of sand transfer from Cambodia to Singapore revealed a discrepancy of USD720 million, which was found to relate to illegal operations run by two Cambodian senators (Global Witness, 2010).

3.5. Socioeconomic transformations at sand frontiers

Sand frontiers also introduce new, often exploitative labour relations, livelihood precarity and risk to life. Although typically only small-scale illegal mines and artisanal small-scale mines (ASM) utilize manual labour, in cases where frontiers are located in labour surplus regions, large-scale operations can be run fully manually. One pertinent example is Vasai Creek in Mumbai, India (EJAtlas, 2020). It is estimated that operations employed over 75,000 daily wage labourers—a mix of migrants and local traditional fishing communities—with operations involving unprotected free diving up to 40–50 feet, 200–300 times a day to the creek bed to collect sand using iron buckets. Investigations revealed that miners regularly died by being swept away by undercurrents, or by burial beneath underwater sand dunes (EJAtlas, 2020; Srivastava 2017). Such manual mining labour has been described as the "new mining precariat", composed of destitute people working in unstable, insecure, exploitative, unregulated, often illegal jobs which involve high risk and no occupational protection, often in locations that are not easily accessible and are lacking in basic services (Lahiri-Dutt, 2018). Given the insecurity and danger involved in manual sand-mining operations, people employed here—as with ASMs—often belong to socioeconomically vulnerable sections of society, rural and previously agrarian peasant populations suffering from declining returns on traditional livelihoods and failure to meet basic daily needs, thus engaging in fluid or flexible low-skill work as a form of income diversification or "livelihood multiplexity" to supplement agrarian outputs (Bryceson, 2002; Lahiri-Dutt, 2018). These engagements are, however, inadequate in terms of incentivizing skilling, technical innovation, and overall improvement of people's well-being (Bryceson, 2002). As a result, in regions where manual sand mining has emerged as an alternative livelihood option, "deagrariarization" occurs both as a result and further reinforcement of the dissolution of traditional livelihoods (Bryceson, 2002; Bryceson and Jonsson, 2010), following tendencies of extractivism towards the creation of monoproductive local economic systems.

On the other hand, sand mining has historically been carried out through ASM for small-scale, individual housing or other construction applications all over the world, and is a traditional livelihood source, for instance, for the *areneros* (traditional manual sand miners) of Colombia (Hougaard and Velez-Torres, 2020). This has largely been possible due to the non-commodification, easy access and widespread availability of sand. However, the presence of larger-scale extractive players able to mobilize technology, capital and especially power (both legal and illegal) in local settings results in commodification and reduced access to sand commons for local communities. There is an important need here to draw clear distinctions between small-scale traditional sustenance operations as opposed to illegal sand extractors, e.g., the sand mafia. For instance, sand frontiers are not spaces where traditional, manual, communal, small-scale and subsistence-based sand extraction occurs, but rather where large-scale extraction, controlled and consolidated by powerful actors, for accumulation occurs.

Sand frontiers are often sites of transformed social relations through the introduction of illegal extractive actors, which results in related violence creating severe disruption to the lives of local communities (Bisht and Gerber, 2017; Bisht, 2019; Beiser, 2018; Constable, 2017). In many countries, large percentages of sand consumed are illegal (Beiser, 2017). Illegality enables a complete lack of accountability with respect to environmental or social impacts, labour conditions, or extracted quantities and has significant economic implications, ensuring that illegal sand is far cheaper, thus reducing the economic viability of legal operations. Protection and preservation of these illegal operations has resulted in intense and brutal localized violence against anti-extractive activists and citizens across the world. For instance, India has widespread "sand mafia" responsible for the intimidation, maiming and murder of activists, journalists, and police officers of all ranks (Bisht and Gerber, 2017; Bisht, 2019), Cambodia has witnessed the imprisonment of activists, an activist in Mexico was murdered in 2019, and a Kenyan police officer's body was found with his head crushed and eyes pierced (Beiser, 2017; Constable, 2017).

Sand frontiers can also introduce cultural transformations if expansion and intensification lead to the loss of or loss of access to precious aquatic ecosystems that are cultural commons, and species of inherent value or which are revered by indigenous peoples and local communities. This also extends to the loss of aesthetic ecosystem services such as beaches valued and used by broader sections of society. Given these socioeconomic and ecological transformations, the movement of sand frontiers results in altered patterns of access to natural resources, dispossessions, local power asymmetries, violence, environmental and social justice incursions, with sand extraction eventually leading to localized EDCs (Bisht, 2019; Bisht and Gerber 2017; Hougaard and Velez-Torres, 2020).

Table 1 presents a brief summary of the typologies of sand, its uses and impacts of high ratesand scales of extraction. Given these facets of sand frontier expansion and intensification, which are resulting in serious negative socioeconomic and ecological implications, it is necessary for sand extraction and sand frontier movement to be further analysed. This requires utilization of a pertinent and relevant theoretical framework which can enable a deeper examination of existing problems, as well as designing alternatives to ongoing patterns of sand extraction. In this context, the following sections explore the theoretical framework of extractivism.

4. Locating sand within the framework of mineral extractivism

As has been explored in the previous section, sand frontiers have been and still are continually intensifying and expanding. This frontier movement is associated with large-scale ecological degradation, altered patterns of access to natural resources by local communities, and the introduction of or increase in social violence at sand frontiers. Given these features of sand frontier movement and the associated socioeconomic and ecological transformations, the most pertinent theoretical framework to deconstruct, analyse and provide alternatives for transformations away from existing trends and patterns of sand extraction can be found within the rich literature on mineral extractivism. Extractivism is theorized as the process of human appropriation of natural resources at scales large enough and rates high enough to be beyond the regenerative capacities of natural systems. This appropriation is effected through structures, processes and modalities which are exploitative of local ecosystems and peoples, and which propagate an outward flow of nature from frontiers of extraction to spaces of consumption (Acosta, 2017). This includes large-scale extraction of fossil fuels and bulk minerals, but can also extend to large-scale monoculture plantations and agricultural activities or fisheries. The inherently self-depleting nature of extractivism combined with increasing global resource requirements implies that extractive expansion is inevitable, and occurs either through intensification in existing extractive locations, or movement of frontiers of extraction to new geospatial locations (Temper et al., 2015; Bunker, 1985; Ye et al., 2019), often leading to social mobilizations and generating EDCs (Bebbington et al., 2008; Temper et al., 2015). Extractivism is also characterized by the acquisition of extreme wealth by extractive agents through processes referred to as "accumulation by dispossession" (Harvey, 2007), and result in cost-shifting of externalities to local communities (Temper et al., 2015).

There are several key differences between extraction of sand and other resources: individual sand extraction operations are usually much smaller in scale than individual bulk mineral operations, they require lower capital, energy and technology inputs, extractive agents are typically not internationally powerful actors, trade and transport are limited to relatively short distances, and, unlike most other minerals, sand is available across a widespread geography (Sections 3.2 and 3.3; Beiser, 2018). However, similar to other forms of extractivisms (Bunker, 1985; Acosta, 2017; Gudynas, 2013; Harvey, 2007; Ye et al., 2019), and based on the analysis provided in the previous section, sand extraction is

Table 1
A brief overview of typologies of sand, its uses and impacts of high rates and scales of extraction.

Types of sand	Description of formation	Description of individual particles	Major uses	Major impacts
Riverine	Wind and water erosion, attrition, microbial action.	Angular	Construction industry, glass making	Livelihood impacts, river course shifts, altered access to water downstream, altered sediment deposition downstream, floods, droughts, access to water, cultural implications.
Beach	Wind and water erosion, attrition, microbial action, coral degradation, degradation of volcanic rocks.	Angular	Construction industry, Rare earth metals, land building and reclamation	Loss of beaches, inland flooding, loss of mangroves, enhanced vulnerability of coastal cities, cultural implications.
Lakes, creeks and other stagnant water bodies	Wind and water erosion, attrition, microbial action.	Angular	Construction industry	Altered drainage of water into downstream river systems, altered sediment deposition downstream, enhanced potential of flood and droughts, livelihood impacts (fisheries and agriculture), cultural impacts.
Marine	Wind and water erosion, attrition, microbial action, oceanic activity-based erosion.	Angular	Land building and reclamation	Loss of coral reefs, and other ecosystems, loss of mangroves, benthic and marine species habitat degradation and destruction, cultural impacts.
Crushed rocks	Created by manually or mechanically breaking down of rocks from hills and mountains	Angular	Construction, fracking, cosmetics and pharmaceuticals (Talc)	Loss of mountains/hills, generation of air pollution, cultural impacts.
Desert	Wind erosion	Spherical	None	None

characterized by the following extractive features. First is the presence of disproportionately powerful extractive actors. Although typically not a multinational corporation or the state, these actors hold extreme political power and economical wealth at local, regional or national level and are able to engage in processes which undermine the democratic rights, interests and values of local communities. Unlike other extractivisms where value accumulation directly feeds into multinational corporations, the state or global markets, here value is concentrated with locally powerful actors, thus reinforcing local power asymmetries (Sections 3.5 and 3.3). Second, even though individual mines are smaller and scattered, operations in a region are often widespread—along long stretches of river ecosystems or coastal zones. The cumulative scales typically result in extensive ecological degradation, negative implications of which are often cost-shifted onto local communities, frequently leading to social and environmental injustices (Sections 3.1, 3.4 and 3.5). Third, sand is largely transported away from extractive zones, essentially resulting in the export of nature to different spaces where value addition and consumption takes place, e.g., for urbanization, large-scale transport infrastructures, land building, etc. (Sections 3.1 and 3.2). The benefits of extraction through access to value-added products and the flow of monetary compensation are not accrued by local populations, and even if direct income or employment opportunities are created, they are complemented by high degrees of exploitation of the employed workforce (Sections 3.5). Fourth, large-scale and intensive operations result in the elimination or endangerment of previous livelihood generation activities, such as agriculture and fisheries, because resultant ecological degradation often renders traditional livelihoods ineffective, thus making sand extraction the most economically lucrative activity. This leads to the establishment of monocultural or monoproductive systems, which can result in local people becoming integrated with and dependent upon monoproductive, self-depleting extractive activities (Sections 3.3–3.5). Fifth, violence—against people, nature, animals, knowledge, cultures, traditions, etc.—is not only a byproduct, but a necessary precondition for extractivism (Gudynas, 2013, 2018), a feature which is especially prevalent in sand extraction (Sections 3.3 and 3.5). Finally, similar to the creation of "parastates" and "deterritorialization" observed in the case of other extractivisms (Acosta, 2017), sand extraction zones or enclaves often fall under the control of locally powerful illegal extractive agents who control flows of sand and are able to subvert the interests of communities for the benefit of extractive operations, e.g., India's sand mafias (Sections 3.3 and 3.5). As with other mineral extractivisms, each of these features flow in sync: they require, complement and compound each other.

One key divergence in the theorization of extractivism that is relevant to sand is related to international export of primary materials. Gudynas (2018) delimits the definitional ambit as only those minerals that satisfy the criteria of national volumetric export of over 50% (Gudynas, 2018), so sand is not considered a form of extractivism. In contrast, Ye et al. (2019) propose that the "essence of extractivism" is not situated in the type of resource, but rather in the control of flows, and that the key feature of extractivism is the "monopolistic control over a wide range of resources that is exerted by, and through, an operational centre" (Ye et al., 2019, p. 6), thus allowing for the potential expansion of modalities of extractivism to new resources. This movement through time and space is a critical aspect which makes extractivism "a politico-economic formation that is constantly on the move: on the one hand, it is feeding itself by ruthlessly exploiting (and depleting) the resources it controls; on the other, it is grabbing new resources in order to continue its operation" (Ye et al., 2019; p. 5). Further, as Schindler and Kanai (2018) posit, new governance regimes continually create novel forms of frontiers. Therefore, although sand differs from bulk mineral extraction in several aspects, the essence and modalities of extractivism still apply. Furthermore, lack of reliable data and research on sand transport is significant. For instance, although commonly perceived not to be internationally exported in high volumes, the case of South-east Asian countries and the strong presence of a black market suggests that the large-scale undocumented export/import of sand is ongoing and has the potential of further expansion across new territories (Section 3.3). Finally, trade dynamics are still relevant even domestically, because in most cases of unsustainable sand extraction, resources are "traded" to supply the needs of spatially dislocated, often urban agglomerations (Sections 3.1 and 3.2).

Moreover, the inclusion of the sand lens can significantly contribute towards research in the field of mineral extractivism. First, the sand lens broadens the ambit of mineral extractivism—which has largely focused on metals and bulk minerals—to also include within its framework and address issues related to non-metallic, or "minor", or "development" minerals. These consist of minerals including, but not limited to, stones, granite, marble, talc, limestone, etc., and rare earth metals (increasingly extracted from beach sands). This contributes towards analysing resources which differ from currently studied "extractivisms", but which could still result in the expansion of capitalist social relations across new territories and in significant localized negative socioeconomic transformations, downstream effects, altered access to ecosystem services, consequently affecting large numbers of people, both directly and indirectly, and generating EDCs (Sections 3.3–3.5). Second, the inclusion of the sand lens can help address gaps in and improve research on alternatives for resource governance, especially in the context of easily

accessible, widespread resources, and can also help make important and much-needed contributions around the governance of ASM operations and actors across different resources. Third, as explored above, extracted sand and its value currently suffer from high (but unknown) degrees of inequitable social distribution, e.g., for use in superfluous/luxury infrastructures and through "export" for territorial expansion or island building, rather than necessity-based applications (Section 3.1). As such, the inclusion of the sand lens can expand perspectives on the equitable distribution of increasingly scarce local resources and address intra-generational and intergenerational equity concerns. Finally, sand has a relatively recent history of being directly commodified, integrated into global trade—yet not being regulated or priced at an international or national level (developmentminerals.org, Bendixen et al., 2019)—and appropriated through extractivism. Its inclusion therefore enables the study of materials which are either currently undergoing or will in the near future undergo commodification, large-scale privatization, and extractive appropriation and will enter global commodity markets.

This conceptualization of sand frontiers and sand extractivism is essential in terms of both a critical analysis of the problems associated with sand and the design of appropriate solutions. Following on from this, the next section explores the rich literature on post-extractivism as a relevant and pertinent framework in which to conceptualize alternatives and solutions to existing problems at sand frontiers.

5. Exploring post-extractive options for sand extraction

Given the high degree of similarities in the characteristics of extractivism which can be identified with respect to the ongoing patterns of sand extraction, the substantial body of PE literature can help provide socially and ecologically relevant and desirable transformations. Although some reports propose policy recommendations for the future of sand governance, no scholarly work currently integrates post-extractivist principles and perspectives into existing policy proposals. Some of these global policy programmes for alternatives to sand governance and use can be located in Bendixen et al. (2019), UNEP (2019) and Koehnken and Rintoul, 2018. For instance, Bendixen et al. (2019) propose a 7-point policy programme to develop a global agenda for sand extraction, which includes: identification of sustainable sources; replacing, reducing and reusing extracted sand; developing an international and/or multilateral framework and set of good practices for regulation and governance; educating the broader public on sand extraction; and monitoring ongoing quantities, rates and locations of sand extraction. These proposals are discussed below, and the lens of post-extractivism used to expand on proposals for sand resource governance, specifically with respect to adaptation at sand frontiers. In broad terms, the PE lens helps in setting the agenda and introducing the foundations for a more decentralized, localized regulatory and governance framework for extraction of sand resources at frontiers. This ensures that research on sand extraction, extractivism, regulation and governance are addressed in a manner that includes people at sand frontiers, and that the benefits of these proposals are accrued by the people closest to the negative externalities of continued patterns of sand extractivism.

Founded upon critiquing processes of growth and development as the sole means to achieving enhanced social and economic progress, PE focuses on the critique of large-scale resource extraction and distribution. It centres on nation states' promotion of large-scale extraction and international trade of primary commodities with the purported objective of achieving growth, which is eventually expected to translate into increased national GDP, development, societal progress and human well-being (Hollender, 2015; Escobar, 2015; Arsel et al., 2016). However, it proposes neither complete bans, nor abrupt cessation of all extractive operations; rather, in line with sustainable degrowth (Martinez-Alier et al., 2010), it aims to build space for "substantial downsizing whereby the only ones left are those that are genuinely necessary [and] meet social and environmental conditions" (Gudynas, 2013, p. 175). It calls for the optimization of efficiencies of utilization of extracted resources to maximize social benefit, rather than a continual increase in extraction volumes (Acosta, 2017). Post-extractive proponents focus on breaking economic dependencies between peripheries/frontiers of extraction and cores where value is accumulated. These linkages are often responsible for the "underdevelopment" of frontiers, and their dissolution is envisioned as a necessary precondition for peripheries to eventually build socioeconomic structures whereby opportunities for meeting basic socioeconomic needs and supporting dignified, sustained livelihoods for local communities can be created (Bunker, 1985). It also calls for this rebuilding to enable enhanced societal well-being in ways compatible with local cultures, cosmovisions, and needs whilst eliminating environmental injustices. Rather than ceasing extraction, PE envisages transformations towards building alternative extraction regimes which enable achievement of two imperative conditions: poverty eradication and biodiversity loss prevention (Gudynas, 2013). The following sections explore some PE solutions for sand frontiers.

5.1. Assessment of needs and regulation of extraction

Increasing sand use seems inevitable in a number of locations within countries in the Global South, given the needs for appropriate housing and basic public infrastructures spaces. However, it is essential that existing, already limited sand resources be targeted towards basic needs-oriented utilities, dwellings, and community utility maximizing public built environments and protective public infrastructures, while disincentivizing superfluous, luxury and rentier-economy-oriented, and global or national capital centric or capital-oriented consumption. Along with keeping needs-based applications central to consumption, local extraction can be limited on the basis of biological carrying capacities, for instance by implementing local extraction caps. Extraction bans and limits already exist in many countries/regions. In most of Western Europe, sand extraction was banned or heavily regulated around the 1980s and 1990s (Koehnken and Rintoul, 2018), and British Columbia (Canada) limits sand extraction only for purposes of public safety or flood mitigation (Koehnken and Rintoul, 2018). In India, the National Green Tribunal has consistently banned large-scale sand mining in many cases, although without much practical success. Finally, if extraction is limited by a needs-based approach, a significant part of new sand extraction can be limited by recycling or reusing construction and demolition waste, rates of circulation of which are currently relatively low (Haas et al., 2015). This is especially relevant for the Global North, where there is a limited need for an increase in built infrastructure (Torres et al., 2017).

5.2. Documentation of social and environmental injustices

One of the most significant issues surrounding sand is the lack of reliable quantitative data around extraction, import, export, extractors, location of extraction and dispatch (Koehnken and Rintoul, 2018; UNEP, 2019; Torres et al., 2017). This makes it difficult to estimate the extent of resultant ecological, social, and economic damages, and to develop targeted, evidence-based solutions. As such, there is a need to establish monitoring systems which are transparent and recorded and make real-time data publicly available. Successes in reliable data collection have been evidenced in Zambia and Cameroon under the ACP-EU Development Minerals Programme (Franks, 2020; Hilson, 2016; developmentminerals.org). Another important indicator symptomatic of illegal and/or unsustainable extraction and any social or environmental injustice is the presence of social resistance, protests, or complaints—legally or publicly—by local citizens, civil society actors, or NGOs, etc. As such, an important part of data collection is the documentation of EDCs, the discontents and demands of anti-sand extraction movements. For instance, an analysis of mineral extractivism EDCs across India revealed that over half had resulted from sand extraction (Bisht and Gerber, 2017; Bisht, 2019). Such documentation is essential

to provide insights into locations of unsustainable extractivism.

5.3. Management of outward flow of value

Under current extraction regimes, the value of sand is typically appropriated by a small, locally powerful minority, often operating "sand enclaves". Exploring alternative resource governance options is therefore crucial. Goals of intergenerational and intragenerational equity can be accomplished by imposing and regulating resource caps, combined with empowering localized self-regulation by village cooperatives. In Telangana (India), sand extraction through a village cooperative increased local incomes and autonomy (Telangana Today, 2018) and, given the proximity of local communities, ensured prevention of over-extraction. In Colombia, *areneros*, who have traditionally mined sand sustainably, have resisted the entry of large-scale private extractors to defend their rights to sand commons, which are increasingly being threatened by privatization of sand resources; this is likely to reduce their access to sand and eliminate sustenance livelihoods, while enabling the outward flow of value to corporations or large-scale, non-local extractive actors (Hougaard and Velez-Torres, 2020). To safeguard the success of alternative governance regimes, it is also essential to provide avenues for the realization of resource value. This is especially true in the case of enclaves captured by illegal actors with no legal/formal markets for local trading. Here, building effective and efficient local markets can help provide avenues for fair income generation, thus disincentivizing illegal extraction. Finally, redistribution of value, especially by large-scale private entities is essential. One mechanism for this is the District Mineral Funds in India, which collects part of the royalties from extractive operations, eventually making funds available for local projects (Banerjee and Shalya, 2017). Although this mechanism is currently suffering from implementation problems, it still offers a model for ensuring the redistribution of value of sand commons.

5.4. Local power asymmetries: illegal operations and violence

The scale and severity of illegal operations present a complex challenge which will require many levels of community, government, and civil society engagement. One step is locating illegal activities by institutionalizing decentralized, open-access digital platforms for community-based, anonymous, and real-time reporting that are publicly accessible, to help track illegal activities and hold perpetrators accountable. One operational example of a similar idea is community-based monitoring to enhance the collection of data on environmental liabilities in Ecuadorian Amazon oil frontiers (Mena et al., 2020). Another is for the state to set up digital platforms and new institutions to monitor sand extraction, e.g., India's Sand Mining Framework 2018 proposes the use of IT for allocating, ordering, monitoring, and delivering sand.

5.5. Banning certain zones and forms of extraction

Extractivism often operates in ecologically sensitive and biodiverse zones, sacred lands of indigenous people, vulnerable and threatened megafauna corridors and habitats, and sources of important ecosystem services, e.g., rivers, lakes and aquifers, or large, ancient, native forests. Given this background, it is essential to delineate some activities and zones where sand extraction is banned for intergenerational and intragenerational equity and access, for both human and non-human ends. For instance, with respect to locations, this could include establishing no-sand extraction zones, e.g., coral reefs, mangroves, and sacred and culturally significant aquatic bodies. In addition, bans could also be extended to extraction dedicated to specific applications which are extremely harmful, e.g., hydraulic fracturing. Fracking has already resulted in EDCs with local communities in the USA (Biersted, 2015), where NGOs and community resistance has been active against frac sand operations, which threaten ecosystems and the health of local residents.

6. Conclusions

Global sand extraction has seen a sharp increase over the last two centuries. In order to analyse this increase in sand extraction, the commodity frontier provides an important analytical tool. This article proposes that this increase has resulted in the creation of localized frontiers of sand extraction spread across the world—particularly in the Global South—and introduces the concept of sand frontiers. Sand frontiers are sites of capital-nature interactions where "surplus" or cheap sand is being extracted, resulting in ecological and geomorphological transformations, which have led to multidimensional and cascading negative downstream effects. Furthermore, there is a perceptible reproduction of capitalist relations at frontiers, where new social and socioeconomic relations and often exploitative labour conditions have been introduced. The forward movement of sand frontiers can be observed to have occurred through processes of commodity widening—from the Global North to the Global South and continually expanding across new regions within the Global South—and commodity deepening, with increasingly larger scales of operations, and intensification of extraction at existing sites. The article also concludes that, given the global scale of extraction, the local intensity and patterns of sand extraction, socioeconomic dynamics at frontiers, increasing localized scarcities, growing international trade, and the local conflicts it is engendering, sand is increasingly emerging as a form of extractivism. Built on this conceptualization of sand extractivism, by utilizing critiques from literature on bulk mineral extractivisms and combining literature on post-extractive solutions, the article provides some PE-based solutions and alternatives for monitoring, governance and regulation at sand frontiers.

Existing patterns of sand extraction can have serious repercussions for intergenerational equity (limiting access to future generations), intragenerational equity (reducing access for less socioeconomically privileged sections of society), social and environmental injustices, and EDCs. Despite its significance, increasing extraction and projected scarcities, research on sand extraction is limited, making future work on sand resources both important and imminent. Given the large data and research gaps, there is an urgent need to ensure availability of reliable extraction, consumption, and trade data; to analyse linkages with larger political economic processes; to analyse and find solutions to massive illegal operations, the black market, and the violence involved; as well as to discuss and develop alternative frameworks—both theoretical and analytical—in order to understand this all-pervasive yet invisibilized resource further. Overall, there is an urgent need to regulate and limit sand extraction, and reduce the continuing forward movement of sand frontiers, in order to slow or halt the impending emergence of sand as a new frontier of global resource scarcity.

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No conflicts of interest declared.

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References

Acosta, A., 2016. Post-growth and post-extractivism: two sides of the same cultural transformation. Alternautas 3 (1), 50–71.

Acosta, A., 2017. Post-extractivism: from discourse to practice—reflections for action. Int. Dev. Policy 9 (9), 77–101.

Aggregate Business. 2015 (November 2). Kenya's major sand scramble. https://www.aggbusiness.com/ab10/feature/kenyas-major-sand-scramble (Last accessed August 18, 2020).

Ajibade, I., 2017. Can a future city enhance urban resilience and sustainability? A political ecology analysis of Eko Atlantic city, Nigeria. Int. J. Disas. Risk Reduct. 26, 85–92.

Arsel, M., Hogenboom, B., Pellegrini, L., 2016. The extractive imperative in Latin America. Extract. Ind. Soc. 3 (4), 880–887.

Banerjee, S., Shalya, C., 2017. District Mineral Foundation Status Report 2017. Centre for Science and Environment, New Delhi.

Banoub, D., Bridge, G., Bustos, B., Ertör, I., González-Hidalgo, M., de los Reyes, J.A., 2020. Industrial dynamics on the commodity frontier: managing time, space and form in mining, tree plantations and intensive aquaculture. Environ. Plann. E Nature Space.

Bebbington, A., Bebbington, D.H., Bury, J., Lingan, J., Muñoz, J.P., Scurrah, M., 2008. Mining and social movements: struggles over livelihood and rural territorial development in the Andes. World Dev. 36 (12), 2888–2905.

Beiser, V., 2017. Sand Mining: The Global Environmental Crisis You've Probably Never Heard Of. The Guardian. https://www.theguardian.com/cities/2017/feb/27/sand-mining-global-environmental-crisis-never-heard (Last accessed August 18, 2020).

Beiser, V., 2018. The World in a Grain: The Story of Sand and How it Transformed Civilization. Riverhead Books. Penguin Random House, New York.

Bendixen, M., Best, J., Hackney, C., Iversen, L.L., 2019. Time is running out for sand. Nature 571, 29–31.

Bierstedt, C., 2015. What's the fracking problem? Hydraulic fracturing, silica sand, and issues of regulation. Drake Law Rev. 63, 639.

Bisht, A., 2019. Discontent, conflict, social resistance and violence at non-metallic mining frontiers in India. Ecol. Econ. Soc. INSEE J. 2 (1), 31–42.

Bisht, A., Gerber, J.F., 2017. Ecological distribution conflicts (EDCs) over mineral extractivism in India: an overview. Extract. Ind. Soc. 4 (3), 548–563.

Black Mountain Sand, 2018. https://www.blackmountainsand.com/permian-basin-frac-sand-infographic/ (Last accessed August 18, 2020).

Boyd, S.E., Limpenny, D.S., Rees, H.L., Cooper, K.M., 2005. The effects of marine sand and gravel extraction on the macrobenthos at a commercial dredging site (results 6 years post-dredging). ICES J. Mar. Sci. 62 (2), 145–162.

Brunier, G., Anthony, E.J., Goichot, M., Provansal, M., Dussouillez, P., 2014. Recent morphological changes in the Mekong and Bassac river channels, Mekong delta: the marked impact of river-bed mining and implications for delta destabilisation. Geomorphology 224, 177–191.

Bryceson, D.F., 2002. Multiplex livelihoods in rural Africa: recasting the terms and conditions of gainful employment. J. Mod. Afr. Stud. 40 (1), 1–28.

Bryceson, D.F., Jonsson, J.B., 2010. Gold digging careers in rural East Africa: small-scale miners 'livelihood choices'. World Dev. 38 (3), 379–392.

Bunker, S.G., 1985. Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State. University of Chicago Press, Chicago.

Clark, B., Foster, J.B., 2010. The dialectic of social and ecological metabolism: marx, Mészáros, and the absolute limits of capital. Social. Democr. 24 (2), 124–138.

Constable, H. 2017 (August 11). Kenya's Sand Wars. Al Jazeera. https://interactive.aljazeera.com/aje/2017/kenya-sand-wars/index.html (Last accessed August 18, 2020).

Courland, R., 2011. Concrete Planet: The Strange and Fascinating Story of the World's Most Common Man-made Material. Prometheus Books.

de Leeuw, J., Sandman, D., Wu, G., de Boer, W.F., Burnham, J., He, Q., Yesou, H., Xiao, J., 2010. Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China. Reg. Environ. Change 10 (2), 95–102.

EJAtlas. 2017a (24 April). Beach sand mining for ilmenite, garnet and other minerals in Tamil Nadu, India. https://ejatlas.org/conflict/beach-minerals-sand-mining-in-tamil-nadu-india (Last accessed August 18, 2020).

EJAtlas. 2017b (28 December). Offshore sea sand harvest in Kwale district, south of Mombasa, Kenya. https://ejatlas.org/conflict/offshore-sea-sand-harvest-from-in-south-coast-of-the-indian-ocean-kenya (Last accessed August 18, 2020).

EJAtlas. 2017c (7 August). Iron sand mining in Watu Pecak Beach, Indonesia. https://ejatlas.org/conflict/deaths-in-iron-sand-mining-west-java-indonesia (Last accessed August 18, 2020).

EJAtlas. 2018 (24 March). Projet Grande Côte for zircon and ilmenite mining, Senegal. https://ejatlas.org/conflict/diogo-zircon-mining-niayes-senegal (Last accessed August 18, 2020).

EJAtlas. 2019. Fisherfolk against fake new islands in Jakarta Bay, Indonesia. https://ejatlas.org/conflict/fisherfolk-against-fake-new-islands-in-jakarta-bay-indonesia (Last accessed August 18, 2020).

EJAtlas. 2020 (Feb 18). Sand mining in Vasai Creek, Mumbai, India. https://www.ejatlas.org/conflict/vasai-creek-mumbai (Last accessed August 18, 2020).

Escobar, A., 2015. Degrowth, postdevelopment, and transitions: a preliminary conversation. Sustain. Sci. 10 (3), 451–462.

Fischer-Kowalski, M., 1998. Society's metabolism: the intellectual history of materials flow analysis, Part I: 1860-1970, Part II (with W. Huettler): 1970-98. J. Ind. Ecol. 2 (1) and 2(4).

Fischer-Kowalski, M., Haberl, H., 2007. Socioecological Transitions and Global Change. Trajectories of Social Metabolism and Land Use. Edward Elgar, Cheltenham.

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., Weisz, H., 2011. Methodology and indicators of economy-wide material flow accounting. J. Ind. Ecol. 15 (6), 855–876.

Forty, A., 2012. Concrete and Culture: A Material History. Reaktion Books, London.

Franks, D.M., 2020. Reclaiming the neglected minerals of development. Extract. Ind. Soc. 7 (2), 453–460.

Frederiksen, T., Himley, M., 2019. Tactics of dispossession: access, power, and subjectivity at the extractive frontier. Trans. Inst. Br. Geogr. 45 (1), 50–64.

Gavriletea, M.D., 2017. Environmental impacts of sand exploitation. Analysis of sand market. Sustainability 9 (7), 1118 (1-26).

Global Witness, 2010. Shifting Sands: How Singapore's Demand for Cambodian sand Threatens Ecosystems and Undermines Good Governance. Global Witness Limited.

Gudynas, E., 2013. Transitions to post-extractivism: directions, options, areas of action. In: Land, M., Mokrani, D. (Eds.), Beyond Development. Transnational Institute/Rosa Luxembourg, Foundation, pp. 165–188.

Gudynas, E., 2018. Extractivisms. Tendencies and consequences. In: Munck, R., Wise, R. D. (Eds.), Reframing Latin American Development. Routledge, Eds, pp. 61–76.

Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M., 2015. How circular is the global economy?: an assessment of material flows, waste production, and recycling in the European Union and the world in 2005. J. Ind. Ecol. 19 (5), 765–777.

Haberl, H., 2001. The energetic metabolism of societies, Parts I and II. J. Ind. Ecol. 5 (1), 71–88, 11-33, 5(2).

Harvey, D., 2007. A Brief History of Neoliberalism. Oxford University Press, USA.

Hilson, G., 2016. Development Minerals in Africa, the Caribbean and the Pacific: Background Study. Development Minerals in Africa, the Caribbean and the Pacific. ACP-EU Development Minerals Programme, United Nations Development Programme, Brussels.

Hoeksema, R.J., 2007. Three stages in the history of land reclamation in the Netherlands. Irrigat. Drain. J. Int. Commiss. Irrigat. Drain. 56 (S1), S113–S126.

Hollender, R., 2015. Post-growth in the global South: the emergence of alternatives to development in Latin America. Social. Democr. 29 (1), 73–101.

Hougaard, I.M., Vélez-Torres, I., 2020. Shifting sands: legal dispossession of small-scale miners in an extractivist era. Geoforum 115, 81–89.

Jadhav, N.R., Paradkar, A.R., Salunkhe, N.H., Karade, R.S., Mane, G.G. 2013. World journal of pharmacy and pharmaceutical sciences. 6 (2): 4639–4660.

Koehnken, L., Rintoul, M., 2018. Impacts of Sand Mining on Ecosystem Structure, Process and Biodiversity in Rivers. WWF.

Kothari, U., Arnall, A., 2020. Shifting sands: the rhythms and temporalities of island sandscapes. Geoforum 108, 305–314.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecol. Econ. 68 (10), 2696–2705.

Krausmann, F., Lauk, C., Haas, W., Wiedenhofer, D., 2018. From resource extraction to outflows of wastes and emissions: the socioeconomic metabolism of the global economy, 1900–2015. Global Environ. Change 52, 131–140.

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., Haberl, H., 2017. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. Proc. Natl. Acad. Sci. 114 (8), 1880–1885.

Lahiri-Dutt, K, 2018. Reframing the debate on informal mining. In: Lahiri-Dutt, K. (Ed.), Between the Plough and the Pick: Informal, Artisanal and Small-Scale Mining in the Contemporary World. ANU Press, In Ed.

Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., Jiang, J., 2014. Sand mining and increasing Poyang Lake's discharge ability: a reassessment of causes for lake decline in China. J. Hydrol. Amst. 519, 1698–1706.

Lamb, V., Marschke, M., Rigg, J., 2019. Trading sand, undermining lives: omitted livelihoods in the global trade in sand. Ann. Am. Assoc. Geogr. 109 (5), 1511–1528.

Marschke, M., Rousseau, J.-.F., Schoenberger, L., Hoffman, M., 2020. Roving Bandits and Looted Coastlines: How the Global Appetite for Sand is Fuelling a Crisis. The Conversation. https://theconversation.com/roving-bandits-and-looted-coastlines-how-the-global-appetite-for-sand-is-fuelling-a-crisis-132412 (Last accessed August 18, 2020).

Martínez-Alier, J., Pascual, U., Vivien, F.D., Zaccai, E., 2010. Sustainable de-growth: mapping the context, criticisms and future prospects of an emergent paradigm. Ecol. Econ. 69 (9), 1741–1747.

Mena, C.F., Arsel, M., Pellegrini, L., Orta-Martinez, M., Fajardo, P., Chavez, E., Guevara, A., Espín, P., 2020. Community-Based Monitoring of Oil Extraction: lessons Learned in the Ecuadorian Amazon. Soc. Nat. Resour. 33 (3), 406–417.

Miatto, A., Schandl, H., Fishman, T., Tanikawa, H., 2016. Global patterns and trends for non-metallic minerals used for construction. J. Ind. Ecol. 21 (4), 924–937.

Milliman, J.D., Syvitski, J.P., 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. J. Geol. 100 (5), 525–544.

Moore, J.W., 2000. Sugar and the expansion of the early modern world-economy: commodity frontiers, ecological transformation, and industrialization. Rev. Fernand Braudel Center 409–433.

Moore, J.W., 2014. The end of cheap nature, or, how I learned to stop worrying about 'the' environment and love the crisis of capitalism. Struct. World Polit. Econ. Future Global Confli. Cooper. 285–314.

Mora, C., Caldwell, I.R., Birkeland, C., McManus, J.W., 2016. Dredging in the Spratly Islands: gaining land but losing reefs. PLoS Biol. 14 (3) e1002422: 1-7.

Muradian, R., Walter, M., Martinez-Alier, J., 2012. Hegemonic transitions and global shifts in social metabolism: implications for resource-rich countries. Introduction to the special section. Global Environ. Change 22 (3), 559–567.

Nassar, A.K., Blackburn, G.A., Whyatt, J.D., 2014. Developing the desert: the pace and process of urban growth in Dubai. Comput. Environ. Urban Syst. 45, 50–62.

Peduzzi, P., 2014. Sand, rarer than one thinks. Environ. Dev. 11, 208–218.

Rao, R.J., 2001. Biological resources of the Ganga river, India. Hydrobiologia 458 (1–3), 159–168.
Reuters. 2020 (March 4th). As Myanmar Farmers Lose Their land, Sand Mining For Singapore is Blamed. https://www.reuters.com/article/us-myanmar-sand-singapore-insight-idUSKBN20R0C1 (Last accessed December 28, 2020).
Rizzo, A., 2014. Rapid urban development and national master planning in Arab Gulf countries. Qatar as a case study. Cities 39, 50–57.
Saes, B.M., Bisht, A., 2020. Iron ore peripheries in the extractive boom: a comparison between mining conflicts in India and Brazil. Extract. Ind. Soc. 7 (4), 1567–1578.
Sand Mining Framework, 2018. Ministry of Mines, Government of India. https://www.mines.gov.in/writereaddata/UploadFile/sandminingframework260318.pdf (Last accessed December 28, 2020).
Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N., Loy, C., Krausmann, F., 2014. The global metabolic transition: regional patterns and trends of global material flows, 1950–2010. Global Environ. Change 26, 87–97.
Schindler, S., Kanai, J.M., 2018. Producing localized commodity frontiers at the end of cheap nature: an analysis of eco-scalar carbon fixes and their consequences. Int. J. Urban Reg. Res. 42 (5), 828–844.
Schindler, S., Kanai, J.M., 2019. Getting the territory right: infrastructure-led development and the re-emergence of spatial planning strategies. Reg. Stud. 1–12.
Sengupta, D., Chen, R., Meadows, M.E., 2018. Building beyond land: an overview of coastal land reclamation in 16 global megacities. Appl. Geogr. 90, 229–238.
Smil, V., 2014. Making the Modern World: Materials and Dematerialization. Wiley.
Srivastava, R. 2017 (July 18). Drowning for sand: miners risk all for India's building boom. Reuters. https://www.reuters.com/article/us-india-slavery-sand-miners/drowning-for-sand-miners-risk-all-for-indias-building-boom-idUSKBN1A3005 (Last accessed August 18, 2020).
Steinberger, J.K., Krausmann, F., Eisenmenger, N., 2010. Global patterns of materials use: a socioeconomic and geophysical analysis. Ecol. Econ. 69 (5), 1148–1158.
Suzuki, T., 2003. Economic and geographic backgrounds of land reclamation in Japanese ports. Mar. Pollut. Bull. 47 (1–6), 226–229.
Svampa, M., 2015. Commodities consensus: neoextractivism and enclosure of the commons in Latin America. South Atlant. Q. 114 (1), 65–82.
Sverdrup, H.U., Koca, D., Schlyter, P., 2017. A simple system dynamics model for the global production rate of sand, gravel, crushed rock and stone, market prices and long-term supply embedded into the WORLD6 model. BioPhys. Econ. Resource Qual. 2 (2), 8.
Telangana Today. 2018. Tribal people chart a new path in Telangana. https://telanganatoday.com/tribal-people-chart-a-new-path-in-telangana (Last accessed August 18, 2020).
Temper, L., del Bene, D., Martinez-Alier, J., 2015. Mapping the frontiers and front lines of global environmental justice: the EJAtlas. J. Polit. Ecol. 22, 255–278.
The Conversation. 2019 Why Kenya must take control of sand harvesting off its coast. Obura, D. https://theconversation.com/why-kenya-must-take-control-of-sand-harvesting-off-its-coast-113952 (Last accessed December 28, 2020).
Torres, A., Brandt, J., Lear, K., Liu, J., 2017. A looming tragedy of the sand commons. Science 357 (6355), 970–971.
Tweedie, N., 2018. Is the World Running Out of Sand? The Truth Behind Stolen Beaches and Dredged Islands. The Guardian. https://www.theguardian.com/global/2018/jul/01/riddle-of-the-sands-the-truth-behind-stolen-beaches-and-dredged-islands (Last accessed August 18, 2020).
UNEP, 2019. Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources. GRID-Geneva, United Nations Environment Programme, Geneva, Switzerland.
USGS. United States Geological Survey, Mineral Commodity Summaries—Cement. https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-cemen_0.pdf (Last accessed August 18, 2020).
Watts, J., 2019. Concrete: The Most Destructive Material on Earth. The Guardian. https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth (Last accessed August 4, 2020).
Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30 (5), 377–392.
World Bank. 2018. Belt and Road Initiative. https://www.worldbank.org/en/topic/regional-integration/brief/belt-and-road-initiative (Last accessed August 18, 2020).
Ye, J., van der Ploeg, J.D., Schneider, S., Shanin, T., 2019. The incursions of extractivism: moving from dispersed places to global capitalism. J. Peasant Stud. 47 (1), 155–183.
Ye, X., Xu, C.Y., Zhang, Q., Yao, J., Li, X., 2018. Quantifying the human induced water level decline of China's largest freshwater lake from the changing underlying surface in the lake region. Water Resour. Manag. 32 (4), 1467–1482.
Zhang, G., Song, J., Yang, J., Liu, X., 2006. Performance of mortar and concrete made with a fine aggregate of desert sand. Build. Environ. 41 (11), 1478–1481.