

Coastal sand mining of heavy mineral sands: Contestations, resistance, and ecological distribution conflicts at HMS extraction frontiers across the world

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Abstract

Coastal sand mining for metals involves extraction of heavy mineral sands (HMS), which are sedimentary deposits of dense minerals that accumulate in coastal environments. HMS are localized concentrations of ores such as ilmenite, rutile, leucoxene, and iron, which are sources of metals such as titanium, zircon, iron, sillimanite/kyanite, staurolite, monazite, and garnet. The applications of these metals range from everyday products such as ceramics, paint, and pigments, as well as technologically advanced applications in the airline, shipbuilding, medicine, and defense industries. HMS extraction implies strip mining of coastal areas, which are often unique biodiversity ecosystems, or fragile ecosystems built up on sandy soils or dunes. The loss of such spaces has impacts such as loss of biodiversity and habitats, salt-water intrusion into agricultural lands and increased exposure to sea level rise. As a result of the serious ecological and socioeconomic transformations at such extraction frontiers, these operations cause resistance movements across the world. This article identifies and documents 24 cases of resistance against such operations. It presents the first comprehensive database and analysis of HMS related ecological distribution conflicts.

KEYWORDS

beach sand mining, ecological distribution conflicts, Environmental Justice Atlas, ilmenite, industrial ecology, rutile, zircon

1 | INTRODUCTION

The ever-increasing material needs of global society have resulted in massive quantities of resource extraction over the past century (Krausmann et al., 2018; Schaffartzik et al., 2014; Schandl et al., 2018). The negative socioeconomic, ecological, and cultural impacts of large-scale resource extraction are often cost-shifted onto local communities residing at spaces of resource and lead to environmental injustices. These environmental injustices are sometimes expressed in the form of social mobilizations against expanding extractivism and can be identified by the presence of an analytical category of conflicts referred to as ecological distribution conflicts (EDCs)¹ (Martinez-Alier, 1995, 2002; Temper et al., 2018, 2020). In recent decades, cases of environmental injustices and EDCs have been continually increasing across the world (Scheidel et al., 2020; Temper et al., 2020). EDCs represent and bring forth serious contestations and discontents of large numbers of marginalized people across the world (Bisht &

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Gerber, 2017; Martinez-Alier, 2021a; Saes & Bisht, 2020, 2021b). As such, any meaningful analysis of the diverse environmental and social impacts of the stocks and flows of resources in production and consumption in society necessarily requires the inclusion of perspectives of communities living at spaces of resource extraction. The recognition of local and indigenous perspectives, and inclusion of aspects of environmental, ecological, and social justice are an essential precondition for ensuring equitable, just, and peaceful transitions toward sustainability (Menton et al., 2020).

We posit that the analysis of EDCs offers an important tool which can lead to a more meaningful engagement of industrial ecology (IE) with the socioeconomic and environmental implications of extraction of industrial minerals. This is because EDCs provide important insights into the diverse contestations, discontents, and injustices, which need to be accounted for and resolved, at the beginning of commodity chains of any industrial mineral. This paper brings perspectives from ecological economics, social metabolism, political ecology, and IE to present a comparative analysis of 24 EDCs around heavy mineral sand (HMS) mining across the world.² We offer a pathway for integration of political ecological analysis into IE, as well as foreground conflicts around an under-researched form of sand mining—coastal sand mining of HMS.

The most extensive type of mineral usage across the world is that of sand resources (Bendixen et al., 2019; Bisht, 2021, 2022; Franks, 2020; Torres et al., 2017). Sand mining³ implies extraction of sand, gravel, cobbles, etc., for applications, among others, in the infrastructure building and construction industry—typically high-volume, non-metallic minerals, or “development minerals” (Franks, 2020). However, there are other applications of low-volume minerals obtained from sand extraction, for example, in the fracking industry, beauty and cosmetic industry, titanium production, and in nuclear reactors (Bisht, 2021). One such form of low-volume and metallic sand extraction is that of coastal sand mining of HMS. Despite the relatively low tonnage extracted⁴ compared to sand mining for the construction industry,⁵ HMS mining has given rise to strong contestations between local communities and mining companies on spaces used for HSM operations across the world (Healy, 2022; Huff & Orengo, 2020; Seagle, 2012; Yanuady, 2012). Compared to sand mining for the building industry, both HMS mining and conflicts around HMS mining have received much less scrutiny from academic scholarship. For instance, there is currently no study that documents HMS related conflicts or presents a comparative analysis of HMS conflicts across the world.

This article addresses these research gaps around HMS extraction. Drawing on the Environmental Justice Atlas (EJAtlas, ejatlas.org)⁶ and other sources it identifies, documents, and analyses 24 HMS related EDCs across the world. It presents a small but global database, as well as the first comprehensive analysis of HMS mining conflicts. This database includes publicly known and contested social resistance movements around HMS extraction across the world. The database is then analyzed to understand the dynamics of HSM operations, the contestations between extractive operators and mobilizing communities, the values in dispute between local communities, mining companies, and the State; and the scale and severity of socio-ecological transformations at HSM frontiers. Overall, the article contributes to the understanding of HMS extraction by exploring the broader dynamics of nature–capital–society interactions at these extractive frontiers.

The article addresses three major research questions: Where are noticeable cases of HMS extraction conflicts located? What are the major socio-ecological transformations and resultant contestations occurring at HMS extraction frontiers? What are the diverse languages of resistance utilized by protesting actors?

The paper is organized as follows: the second section introduces the theoretical framework. The third section provides a background of HMSs, followed by the methodology. The fifth section presents the database and analysis of the 24 HSM-EDCs, followed by discussions and conclusions.

2 | RESOURCE FRONTIERS, EDCS, ENVIRONMENTAL JUSTICE, AND INDUSTRIAL ECOLOGY

Over the last few decades, the field of industrial ecology (IE) has made great strides in quantitative assessments and technical analysis of industrial systems, for example, on improving technical efficiencies of production systems, closing material loops, and quantitative empirics of resource inputs and outputs in industrial systems. However, since its inception as a field of study, there have been discussions on the scope and contribution of IE beyond quantitative methodologies and analysis (Ehrenfeld, 1997; O'Rourke et al., 1996; Wells & Zapata, 2012).

In his 1997 paper “Industrial ecology: A framework and process design,” Ehrenfeld discusses the role of IE in offering a paradigm shift from the “more established modern, economic, capitalistic... ideals on which advanced Western societies rest” (Ehrenfeld, 1997, p. 88). He states that one of the key ideas for “improving positive knowledge about the socio-technical-natural system” through an IE framework would be “to connect the natural world more directly to social thinking and action, the links that, are weak or missing... would need to be replaced by inward-leading flows to the action-producing social structures” (Ehrenfeld, 1997, p. 88). In “Industrial ecology: A critical review,” O'Rourke et al., 1996, point out to the need for IE to “move beyond purely technical questions, or even beyond closing material cycles for specific industries, broader analyses of the social implications and impediments to IE” (O'Rourke et al., 1996, p. 106). These reflections and attempts toward the expansion of the scope of IE analysis continue to be found in recent contributions to IE. This includes, for example, discussions on integrating perspectives from qualitative research and critical perspectives into IE analysis (Wells & Zapata, 2012); and research on expanding on the scope of life cycle analysis (LCA) of materials by factoring into the analysis issues of social and environmental injustices and protecting cultural heritage at sites of resource extraction (Agusdinata et al., 2018, 2022).

This paper further expands the scope of IE analysis of mineral extraction by engaging with the lens of political ecology to explore cases of environmental injustices at resource frontiers. It provides a dimension of critical scholarship in engagement with the multi-dimensional impacts of resource extraction at frontiers. By foregrounding EDCs in the analysis, it also provides an approach to enhance the flow of information between the social, cultural, ecological, and economic spheres to improve the quality of production dynamics of industrial minerals. Specifically, the goal is to include perspectives from marginalized, socioeconomically and politically non-dominant, and directly affected communities residing at resource frontiers, into decision-making and policymaking regarding extraction and governance of resources.

The ever-increasing scale of metabolic demands of human society on nature have resulted in increasing intensification and expansion of frontiers of commodity extraction (Clark & Foster, 2010; Hanacek et al. 2022; Moore, 2000, 2014). This has also included the incorporation of new materials into circuits of commodification (Temper et al., 2015; Ye et al., 2019). Commodity frontier expansion is operationalized through investments reaching new geographies of extraction, resulting in ecological degradation, as well as altering patterns of access of ecosystem services, and often, dispossessions and displacements of local communities. Two processes of growth and changes in the socio-metabolism are associated with increasing extraction frontiers (Banoub et al, 2020). The first implies the spatial extension (commodity widening) of nature appropriation via territorial claims to the control and use of natural resources and associated acts of dispossession. The second implies the intensification of exploitation at existing sites, through socio-technical innovation and new investments in the same location (commodity deepening). Sand mining for metals implies a search for “new” commodities (ilmenite, rutile, zircon) which are collected in new places, and incorporated into new structures with energy-intensive machinery.

Given that metal extraction often occurs at ecologically and biodiversity rich regions (Luckeneder et al., 2021), it results in massive ecological transformations and burdens. These negative ecological impacts and loss of livelihoods are often cost-shifted onto local communities (Bebbington et al., 2008; Temper et al., 2015, 2018). Destroyed local ecosystems also often have intrinsic values (aesthetic values, sacredness, or other cultural significance), which cannot be easily amended or compensated for through waged jobs or money indemnities (Martinez-Alier, 2002; Scheidel et al., 2020). Moreover, the damage is often asymmetrically distributed even within affected communities, particularly with respect to gender, with women bearing disproportionately larger burdens (Cielo & Coba, 2018). All these processes result in reinforcing societal inequities and injustices.

As a result of environmental injustices, people at extractive frontiers can engage in defensive resistance through organizing social movements—such movements are called EDCs. EDCs arise not only out of inequalities within the economic sphere, but also due to inequities extending to the ecological and cultural spheres, with both conflicting interests and social values playing important roles (Escobar, 2006; Martinez-Alier, 1995, 2002). There is wide and rich literature documenting and analyzing EDCs across a wide variety of geographies and materials (Martinez-Alier, 2021a; Temper et al., 2018). However, till date no study has documented and/or conducted a comparative analysis of EDCs around HMS extraction across the world.

This paper fills the research gap on HMS-EDC documentation and analysis. It also presents the case of one form of mineral extraction as an example of the wide range of issues leading to injustices, discontents, conflicts, and deprivations which need to be integrated into the framework of IE scholarship in studying industrial minerals.

3 | HEAVY MINERAL SANDS: GEOLOGY, HISTORY, AND INDUSTRIAL APPLICATIONS

HMS are sedimentary deposits of dense minerals accumulating in coastal environments along with sand, silt, clay, etc., forming localized concentrations of dense or heavy minerals (Van Gosen et al., 2014, 2018). Individual HSM bodies are typically deposits in the range of 1 km width to 5 km length, with many HMS rich regions containing multiple individual deposits spread over ancient or modern coastlines (Van Gosen et al., 2014). HMS deposits can be sedimentary deposits found on paleoshorelines and marine placer deposits (concentrated along beaches), aeolian deposits concentrated by wind and forming dunes, or alluvial deposits concentrated by non-marine or riverine water (Mudd and Jovitt, 2016). Waves, tides, and coastal currents enable a natural process of sorting of grains by density size and shape thus resulting in economically exploitable concentrations along coastal environments (Van Gosen, 2014, 2018). Most HMS mining operations generally exploit ancient or modern coastlines and marine placer deposits (Mudd and Jovitt, 2016), although there are also several operations on dune systems. The largest component of HMS is typically titanium dioxide. As such HMS are divided into three categories based on the content of titanium dioxide present: rutile (90%–100% TiO_2), leucoxene (65%–90% TiO_2), and ilmenite (45%–65% TiO_2) (Base Resources Mineral Sands Factsheet).

Large-scale coastal sand mining operations of HMS began around the late 1930s (Morley, 1981). The first applications of HMS-derived metals in the defense industry were important, with the second world war being a major driver of growth in the mineral sands extraction industry in Australia (Morley, 1981). The industry in Australia—which continues to be one of the largest global producers of mineral sands, saw a massive boom in production, entry of new entrepreneurs, and start-up of new extractive companies around 1939. This was a direct response to the war effort, with concentrate exports largely being shipped to the United States and the United Kingdom. The Australian mineral sands industry witnessed the next boom in 1951 with the start of the Korean war in 1950. By late 1951, the price of rutile increased to 140\$ per tonne, as compared to 47\$ in 1950, which led to a doubling of production from 18,606 tonnes in 1950 to 35,754 tonnes in 1952 (Morley, 1981). In 2020, the global production of titanium concentrates ilmenite and rutile (rounded figures) increased to 8200 thousand metric tons (Figure 1) (USGS, MCS, 2021).

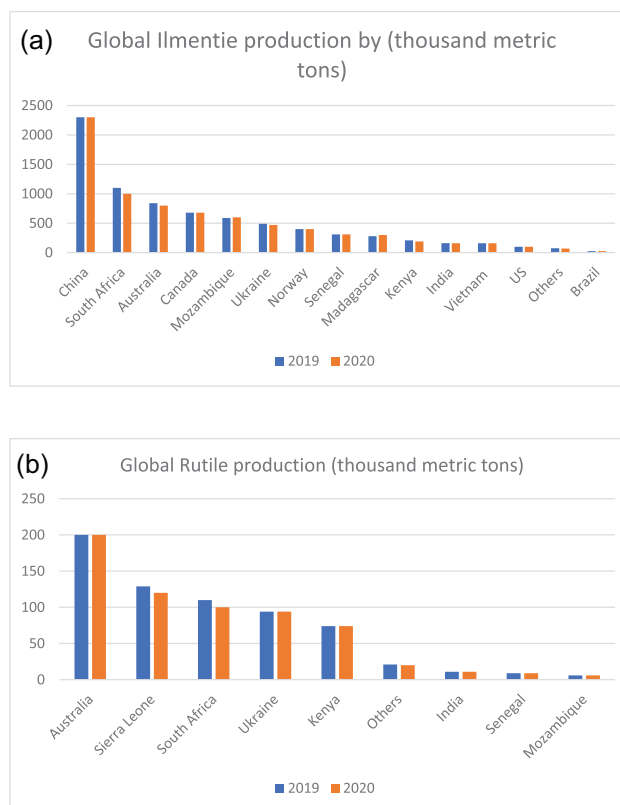


FIGURE 1 (a) Total global Ilmenite production in 2019 and 2020. (b) Total global rutile production in 2019 and 2020. Source: United States Geological Survey, Mineral Commodity Summaries, Titanium Mineral Concentrates, 2021. Underlying data for this figure can be found in the Supporting Information

HMS mining operations require strip mining of coastal areas with economically exploitable concentrations. Beaches, dunes, and sand bars provide many important ecosystem services such as food provisions, aesthetic, and recreational services, being habitats for intrinsic biodiversity, and providing protection against coastal flooding (Hanley et al., 2014). As such, mining in these spaces can have serious ecological and economic implications. The mining process involves removal of soil up to a depth of 30 m or more, with the topsoil being removed prior to mining, and then in theory is filled back by the tailings from mining operations (Farjana et al., 2018). The separation and purification process involves wet dredging operations in fragile coastal areas, and can result in groundwater pollution, and air or dust pollution due to mineral transport with heavy vehicles (Farjana et al., 2018; Huff & Orenge, 2020; Seagle, 2012). The secondary processing of minerals requires the use of reagents such as chlorides, which increase the radio-nuclide emission in mining sites, which can lead to pollution of local groundwater with high radioactive minerals (Farjana et al., 2018). The co-production of minerals with elevated radiation levels, such as thorium-bearing monazite, results in additional hazards of these operations (Farjana et al., 2018; Van Gosen, 2014).

HMS deposits are sources of two major economically important products: titanium and zircon. Titanium dioxide (TiO_2) is often the primary material of interest, and zircon is an important by-product. TiO_2 has high refractive index, opacity, resistance to chalking, chemical inertness, non-toxicity, brightness, ease of dispersion, and hiding power. These characteristics make it key to production of white pigment color (Morley, 1981; Base Resources Mineral Sands Factsheet). As such, TiO_2 is largely used to produce the durable white color, which is used in the production of white paint, paper, plastics, etc., as well as consumer goods such as toothpaste and sun creams. Titanium metal and titanium alloys have high strength-to-weight ratio and are corrosion resistant. These characteristics makes them key materials for high-tech applications in the aerospace industry (for production of jet engines and aircraft frames), space industry, defense industry (for production of missiles and welding rod coatings), shipbuilding industry, medical industry (for production of devices such as heart valves, artificial joints, and prosthetics), for geothermal applications, and for chemical processing plants and large steam power units (Morley, 1981; Woodruff et al., 2017; Base Resources Mineral Sands Factsheet). Zircon is also highly resistant to both heat and corrosion. Its largest use is in the ceramics industry, with ceramics accounting for consumption of close to 50% of global zircon production (Base Resources Mineral Sands Factsheet). Zircon also has applications in the nuclear, chemical, and medicine industries and is used in furnaces, refractories, fiber-optic components, for production of sarcophagi for nuclear waste, catalytic fuel converters, and in water and air purification systems (Jones et al., 2017).

HMS mining produces several other co-products such as sillimanite/kyanite, staurolite, monazite (a source of rare earth elements and thorium which has applications in thorium-based nuclear power), and garnet (Van Gosen et al., 2014). Another category of coastal sand mining for metals is

of iron sands—which have heavy concentration of iron ores. Iron sands have diverse industrial applications some of which are in steel manufacturing, absorbents for removing heavy metals such as arsenic from water, in the pigment industry, as magnetic sensors, and magnetic fluids (Satria et al., 2021).

4 | METHODS

This article involved first, the construction of a database of EDCs against coastal sand mining for HMS across the world, and then the analysis of the database using qualitative research methods. This methodology allows us to compare conflicts spanning different geographies, temporalities, nation states, communities, ecosystems, and companies to identify, document and understand interconnected themes and contestations.

EDCs were collected in two ways: first, from the EJAtlas; and second, from a combination of peer-reviewed academic articles, journalistic reports, reports from international organizations, reports from advocacy groups and NGOs, community blogs, and news articles. The EJAtlas was searched using the following filters: (1) Category; (2) Mineral Ores and Building Material Extraction; and (3) word search for the following phrases: “sand mining for metals,” “coastal sand mining,” “beach sand,” “titanium,” and “ilmenite.” The details of each EDC were extracted from the EJAtlas and filled into Table 1. Each of these cases filled or updated in the EJAtlas, as per the methodology described by Temper et al. (2015, 2018), include the description of the case, coded variables of projects behind the conflicts, impacts, affected population, actors mobilizing, and conflict outcomes, among others. The datasheets of the EJAtlas also provide the sources for each case which were further cross-checked using online search for confirmation of data. The non-EJAtlas cases were obtained by web-based online keyword searches for the following phrases: “beach sand mining,” “coastal sand mining,” “conflicts around heavy sand mining,” “protests around heavy sand/beach/coastal sand mining,” “mineral sands conflicts,” “mineral sands protests,” “protests against ilmenite mining,” “black sands mining,” “iron sands mining,” and “mineral sands extraction.” Each EDC thus identified was then searched in further detail by cross-checking at least five sources. In order to supplement the qualitative data on EDCs, quantitative information on HSM operations, area of operations, and volumes extracted were also obtained from webpages or reports from mining companies. Country-wide data, although only an approximation of the total HSM extraction, was obtained from the USGS mineral commodity summaries database on Titanium Mineral Concentrates.

The collected EDCs were analyzed following the methodology of comparative statistical political ecology following the framework of large sample qualitative analysis of EDCs (Navas et al., 2022; Scheidel et al., 2020; Temper et al., 2018, 2020). The cases were examined across five selected themes: mining companies involved, area of operations, resisting actors or parties, contestations, imposition of violence against people. The resisting parties were further categorized by the presence of environmental and conservation groups; local activists, scientists, journalists, and members of civil society; local communities and indigenous communities. The contestations were further assessed in terms of socioeconomic and livelihood contestations, cultural and aesthetic contestations, ecological and/or environmental contestations, civic contestations. The presence of violence involved recording threats and arrests of activists, protesters, or resisting communities; physical violence and/or murder; dispossession and displacement of local communities; and the threat of local war or armed conflicts. The multiple or overlapping resisting parties, contestations, and violence are distinctly identified in the table.

5 | ANALYZING THE CONFLICTS AND CONTESTATIONS AT HMS FRONTIERS

This section presents the geographical locations (Figure 2), the most significant ecological and socioeconomic transformations, and the related livelihood, social, and cultural impacts of extraction at HSM frontiers.

5.1 | Ecological degradation and ecosystem transformations

Our analysis shows that HSM mining operations have been found to result in severe ecological degradation and lead to significant ecosystem transformations. HSMs—by virtue of their formation and accumulation, are located in coastal regions (Van Gosen et al., 2014, 2018), which are already areas of high vulnerability to effects of climate change, for example, sea level rise and extreme precipitation events. In coastal regions, beaches, sand bars or dunes can either provide protection against tsunamis or climate change induced extreme weather events, or provide protection against incursion of saline sea water (Hanley et al., 2014). As such, where these ecosystems are also HSM deposits, their destruction can lead to exposure of communities to climate-change-based vulnerabilities. Moreover, in many cases these regions are unique ecosystems which are rich in biodiversity

TABLE 1 A comprehensive database and analysis of HMS related EDCs across the world

EDC number	Country	Name of case	Material	Location (state/ district/ province, etc.)	Mining area/ potentially affected areas	Resisting parties					Contestations					Period of EDC	References
						Companies involved	Conservation groups, environmental groups and NGOs	Local activists, scientists, journalists	Local communities/ indigenous peoples or communities	Socioeconomic or livelihood losses/ displacement and dispossession*	Cultural/ Aesthetic ecological disasters*	Civil/Illegal operations*	Violence/ Death/ Threat of War**				
1	Australia	Cable Sands project; Ludlow Titanium Minerals Mine	Titanium	Ludlow Forest, near Busselton, Southwestern Australia	147 ha	Cable Sands, Benmax Resources; Mineral Commodities	X	X	X/X*	X*	X	X	X	X	2003–2004	Lumley, 2005; EPA, Government of Australia, 2003	
2	Brazil	Projeto Retiro	Titanium and zircon	São José do Norte, Rio Grande do Sul	1.5 km by 30 km stretch	Rio Grande Mineração			X	X					2014–2019	EJAtlas, 2020a	
3	Chile		Lithium, titanium, vanadium, and iron	Putu Dunes, Constitución municipality	1200 ha	Inversiones Aconcagua S.A.; South American Iron & Steel	X	X	X						2009–2014	EJAtlas, 2020b	
4	Greenland	Dundas Titanium Project; formerly Pituffik Titanium	Ilmenite, titanium	Municipality of Avanaata	6000 ha	Dundas Titanium; Bluejay Mining Plc.; Rio Tinto Iron; Titanium Canada Inc	X				X				2020–ongoing	EJAtlas, 2021c	
5	India		Ilmenite, rutile, zircon, monazite, leucosene	Tirunelveli, Tamil Nadu		V.V. Minerals and others	X	X	X	X	X	X	X	X	1995–2016–2019	Scroll, 2017; The Hindu, 2013; The Hindu, 2017, Down to Earth, 2019; Frontline, 2021	
6	India		Ilmenite, rutile, zircon, and monazite	Chavara deposits, Alappad/Alappuzha, Kollam Kerala	8950 ha	Rare Earth Limited (IREL) and Kerala Minerals and Metals Limited (KMML)	X	X	X/X*	X/X*	X/X*	X	X	X	1992–ongoing	EJAtlas, 2020c; Land Conflict Watch, 2021; Scrollin, 2018	
7	Indonesia	Kulon Progo's Iron sand project	"Black gold" iron sands; titanomagnetite and others	Yogajarta, Kulonprogo, Java	1.8 km by 22 km	Australia's Indo Mines Limited and Indonesia's Jogja Magasa Mining	X		X	X/X*		X	X	X	2007–2021	EJAtlas, 2019; Mongabay, 2021	
8	Indonesia		Iron sands	Watu Pecak Beach, Selok Awar-Awar Village, Pasirian District, East Java	Each company holds approximately 5000 ha lease	13 companies granted license	X		X	X					2015–ongoing	EJAtlas, 2109c	
9	Kenya	Kwale Base Resources	Ilmenite, rutile, and zircon	Central Dune ore body in late 2013; South Dune orebody in June 2019.	Prospecting licenses of over 80 km ² valid till May 2021; operations in 56 km ²	Base Resources, Australia (2013); pTomin resources Inc. Canada; Jinchuan China (2013).			X/X*	X/X*		X	X	X	2013; expansion planned for 2023	EJAtlas, 2019j	

(Continues)

TABLE 1 (Continued)

EDC number	Country	Name of case	Material	Location (state/ district/ province, etc.)	Mining area/ potentially affected areas	Resisting parties					Contestations					Period of EDC	References
						Companies involved	Conservation groups, environmental groups and NGOs	Local activists, scientists, journalists	Local communities/ indigenous peoples or communities	Socioeconomic losses/ displacement and dispossession*	Cultural/ Aesthetic	Ecological and Environmental- tal/tailings spills/ ecological/disasters*	Civil/Illegal operations*	Violence/ Death/ Threat of War**			
10	Madagascar	Toliara Project	Mineral sands project	Ranobe, Toliara, South-Western Madagascar		Base Resources	X	X	X/X*	X/X*	X*			X	2014–2021	EAtlas, 2019 ^a ;	
11	Madagascar		Ilmenite, titanium, zircon, uranium, and thorium	Taolagnaro, Southwestern Madagascar	2000 to 8000 ha for 750,000 tonnes pa	Rio Tinto/QMM	X	X	X	X/X*	X*				2005–2021	EAtlas, 2019 ^a	
12	Mozambique		Ilmenite, titanium, zircon	Nagonha village, Angoche district, Nampula province	2 mining concessions. Sangage concession of 904.28 hectares, and Nagonha/Morrua concession of 5051.76 hectares	Haiyu Mozambique Mining Co.Ltd, a subsidiary of Haihan Haiyu Mining Co. Ltd., China	X	X	X	X/X*	X	X/X*	X		2011–2018	Amnesty International, 2018; Shivanmu & Matsinhe, 2018	
13	New Zealand		Iron sands, titanium, and other minerals	South Taranaki/Bight	66 km ²	Trans-Tasman Resources Limited (TTR)	X	X	X/X*	X	X*				2013–2017–2021	EAtlas, 2016 ^a ;	
14	Philippines		Magnetite	MacArthur Town, Leyte province, Northern Luzon region	Two permits of 776.89 ha and 523.57 ha	Nicua Mining Company, China (2012); Leyte Iron sand Mining Company, Philippines	X	X	X	X	X	X	X*		2010-2012; resumed operations with other companies	EAtlas, 2019 ^d	
15	Senegal	The Niarang Project	Zircon and ilmenite	Casamance	397 km ² over a 75 km area	Carnegie Ltd; Astron Corporation Limited	X	X	X	X	X	X	X	X/X*X**	2011–2021	EAtlas, 2019 ^a ;	
16	Senegal	Grand Côte Project	Zircon, ilmenite, rutile, and leucosene	The Niayes, Thiès region	445 km ²	TIZir Limited	X	X	X/X*	X/X*	X*		X	X	2013–2021	EAtlas, 2019 ^a g	
17	South Africa	Richards bay minerals	Ilmenite, rutile, and zircon	North Richards Bay, KwaZulu-Natal Province	Approximately 17 km long and 2 km wide strip	Rio Tinto				X	X*	X	X/X*		1976-2018 (operations halted due to protests); 2019–2021	EAtlas, 2019 ^a ;	
18	South Africa	Fairbreeze Project	Titanium, ilmenite, and zircon	Mtunzini	4143 ha	Exaro KZN Sands; New Tronox group, Australia; Kerr-McGee				X	X	X	X	X		EAtlas, 2019 ^a ;	

(Continues)

TABLE 1 (Continued)

EDC number	Country	Name of case	Material	Location (state/district/province, etc.)	Mining area/potentially affected areas	Companies involved	Resisting parties							Contestations				Violence/Death/Threat of War**	Period of EDC	References
							Conservation groups, environmental groups and NGOs	Local activists, scientists, journalists	Local indigenous peoples or communities	Socioeconomic or livelihood losses/displacement and dispossession*	Cultural/Aesthetic ecological disasters*	Ecological and environmental failings/spills	Civil/illegal operations*							
19	South Africa	Xolobeni titanium mining project	Ilmenite, rutile, and zircon	Pondoland on the Wild Coast	Approximately 40 km long by 3 km wide area; proposed mining in a 20 km stretch	Mineral Commodities Ltd. (MRC), Transworld Energy and Minerals (TEM)				X/X*	X	X	X	X	X	X	X	X	2003–2018	EJAtlas, 2021a; Healy, 2022; The Guardian, 2018
20	Sri Lanka	Mannar Mineral Extraction Project	Mannar Island	Ilmenite, leucosene	Approximately 2 km long Titanium Sands; and 8 km wide	Srinel Holdings Ltd.	X	X	X	X		X	X	X	X	X	X	X	2015–ongoing	Tamil Guardian, 2020; Roar Media, 2020; ABC, 2020; MENAFN, 2021; Daily Mirror, 2020.
21	The Gambia		Ilmenite, zircon, rutile	Kartung, Brufut, Kombo South District		Carnegie Corporations, Australia and Astron, China				X	X	X	X	X	X	X	X	X		EJAtlas, 2019b
22	The Gambia		Zircon, "black sands"	Sanyang and Batokunku, Kombo South		Gambia Angola China (GACH) Mining Company	X	X	X	X		X	X	X	X	X	X	X	2018–2021	EJAtlas, 2021b; Malagen, 2020; Mining Africa, 2021
23	Vietnam		Titanium	Tuan nam district, Ninh Thuan province	83.7 ha in 2012; reduced to 19.23 ha in 2013	Quang Thuan One-Member company		X		X		X	X	X	X	X	X	X	2012–2014; 2017/2021	EJAtlas, 2019k
24	Vietnam		Binh Thuan province	Titanium	19,339 ha of land and 25 extraction projects	25 extraction projects			X	X		X/X*	X/X*	X	X	X	X	X	2013–2019–2021; Halted operations; 2018; illegal mining continues	Viet Nam News, 2020; Vietnam Net, 2018; VIR, 2021; Viet Nam News, 2017; Viet Nam News, 2014



FIGURE 2 The geography of ecological distribution conflicts against heavy minerals sand extractivism across the world. Data source (see section 3 on Methodology); Map constructed using: Google My Maps.

such as mangroves (e.g., EDC20), wetlands, and coastal forests and have important ecological functions, as well as beautiful landscapes (e.g., EDC6, 11, 13), often with endemic species (EDC20, EDC19; Healy 2022), and great aesthetic values (e.g., EDC1). Large-scale mining operations in such regions has resulted in degradation of both marine and coastal ecosystems (e.g., EDC6; EDC7); destabilizing of dunes can result in increased sea water incursion and exposure to extreme weather events (e.g., EDC12); and biodiversity loss as a result of ecological degradation or changes can have significant negative livelihood impacts on local ecosystem-dependent populations (e.g., EDC19). Of the 24 EDCs analyzed, the presence of serious ecological degradation and ecosystem transformations as one main cause of contestations can be identified in not less than 20 cases.

In the case of the Rio Tinto/QMM mine in Madagascar (EDC11), operations resulted in large-scale ecological degradation due to the destruction of almost 6000 ha of dense forests, with a small section being “conserved” for the purpose of “ecotourism” but with restricted access to local communities. Destruction of coastal ecosystems also resulted in loss of livelihoods due to significant declines in local fish populations (Huff & Orengo, 2020; Seagle, 2012). In Yogyakarta, Indonesia (Yanuarydy, 2012), the mining project replaced ecologically sustainable agricultural practices which preserved the coastal topsoil and the dune ecosystem, and is resulting in pollution, coastal degradation, increasing salt-water intrusion, and erosion of coastal defense ecosystems (Yanuarydy, 2012, p.19) (EDC7). In the South Taranaki Bight operations in New Zealand, sediment plumes on the seabed environment have had severe effects on phytoplankton and benthic primary productivity due to reduced light availability in the sea. This also leads to possible reduction of fish population and possible impacts on Blue Whales and Maui’s dolphins (EDC13). In Nagonha village, Mozambique, (EDC12), the locals hold the local HMS operations responsible for the severe effects of flash floods in 2015.

In cases where mining operations are proposed, not currently operational or suspended, similar fears are voiced by local communities, activists, and resistance movements. In the case of the Mannar island in Sri Lanka (EDC20), the region is biodiversity rich with coral reefs, mangroves, and seagrasses which will be disrupted if mining is allowed. In the case of Ludlow forests in Australia (EDC1), titanium mining required the clearance of a tall tuart tree forest, a biodiverse ecosystem which was a habitat for endangered species such as Carnaby’s black cockatoo, the brush-tailed phascogale, and the bush wallaby. In the case of the Xolobeni project in South Africa, mining operations will lead to potential destruction of sand dunes in this globally recognized botanical hotspot; along with large-scale potential impacts on local water levels and on the vegetation cover (EDC18).

5.2 | Socioeconomic transformations and livelihood implications

Our analysis shows that HSM extraction can result in severe impacts on the livelihoods of local communities (e.g., EDC6, EDC7, EDC12). Increased salination of local surface water, due to salt-water intrusion when coastal dunes are disturbed, has led to severe reductions in agricultural

productivity (e.g., EDC 14, EDC16, EDC24; Fent, 2020). Destruction of biodiversity rich coastal environments have had drastic effects on livelihood options for local populations who are often dependent on the ecosystem as a source of fisheries and allied activities (e.g., EDC6, EDC9). Destruction of dunes or coastal forests which serve as first lines of defense against coastal surges, storms or other extreme weather events have highly increased the vulnerability of local populations (e.g., EDC12). And finally, if HSM operations require spaces which are already inhabited by people, projects have lead to displacement and dispossession of people (e.g., EDC6, EDC9). Of the 24 EDCs analyzed, the presence of serious socioeconomic transformations and livelihood implications as one main cause of contestations can be identified in at least 21 cases.

In Binh Thuận province in Vietnam where close to 25 extraction projects are located over an area of 19,339 ha of land, operations have resulted in pollution and reduction of local groundwater resources leading to loss of agricultural productivity of rice fields, mango orchards, and cashew orchards (EDC24). In the case of the Grande Côte project in Senegal, mining resulted in the displacement of local vegetable farmers, in decreased agricultural productivity in nearby regions due to reduction of groundwater tables, and led to livelihood precarity among local residents (EDC16). MacArthur in the Philippines was endowed with rich fertile lands and a lake, but due to mining operations close to 70 hectares of irrigated rice fields having been turned into wasteland (EDC14). In Sanyang in the Gambia (EDC22) local women food gardeners face the threat of loss of their entire livelihoods due to ecological degradation and groundwater pollution and reduction.

In Casamance, Senegal, where the Niafarang Project is planned, local communities have engaged in anticipatory resistance to potential dispossession and loss of traditional agricultural practices (EDC15). The local community fears that removal of large volumes of HMS—which stabilize the dune system, would likely result in sanding over of adjacent mangroves, which would in turn result in the encroachment of the sea into their village, or at higher intensities, to the destabilization of the entire dune to a degree which could result in the complete inundation of the rice fields (Fent, 2020). In the Toliara sands project (EDC10), where operations are on hold since 2016 due to local resistance, the proposed extraction of about 407,000 tonnes of ilmenite and 44,000 tons of zircon sands per year is expected to fully clear an area 16 km long and 1–2 km wide of all vegetation and topsoil. This will likely have severe impacts on rural livelihoods which were based on community forestry, hunting and gathering, farming, livestock grazing, and on local well-being (Huff, 2016).

The asymmetric power of national or multinational mining corporations, the State or regionally powerful mining companies, allows HSM extraction to lead to the displacement of local communities. This results in the dispossession from land and ecosystems, and sometimes involves compensation or allocation of different—often less productive lands. In Kerala, India, by 2019, close to 1497 families in Ponmana village had been displaced due to loss of livelihoods due to reduction of fish and crab populations. By 2020, an estimated 6000 families had vacated the region (EDC6). In the case of Kwale Base Resource operations in Kenya, the project initially required the displacement of 5000 indigenous Digo and Kamba people from their ancestral lands. In the planned expansion of the mining operations in 2023, further displacement and dispossession of local residents of the Magaoni community from their ancestral lands is expected to occur (EDC9).

5.3 | Implications on cultural and aesthetic ecosystem values

Large-scale destruction of ecosystems, especially in regions inhabited by indigenous peoples, often have impacts that extend to non-monetarily commensurable cultural, traditional, or spiritual values (Martinez-Alier, 2002). Our analysis shows that such impacts in the case of HSM mining have been related to the loss of unique ecosystems such as coastal forests (EDC1), mangroves, wetlands, biodiversity rich coastal marine ecosystems (EDC6; EDC9), and dune systems (EDC19), especially when these regions are inhabited by and have cultural, religious, or traditional significance to local communities (e.g., EDC5, 15, 18). In the defense of such spaces, anti-mining resistance movements have sometimes utilized non-monetary languages of valuations to highlight and elaborate the extend of loss suffered when local ecosystems are destroyed (Seagle, 2012; Yanuady, 2012). Of the 24 EDCs analyzed, the presence of serious implications on cultural and aesthetic ecosystem values as one main cause of contestations can be identified in at least 11 cases.

Resistance against the Niafarang Project in Senegal (EDC15) utilizes language of sacredness. The local Jola ethnic group consider that “*the land is sacred. God gave us this land. The Jola do not sell land*” (Fent, 2020, p. 892). In the case of the Rio Tinto/QMM in Madagascar (EDC11), land rights are intricately tied to cultural practices and possession of land itself is based upon the location of tombs of ancestors (Seagle, 2012). Here, the sands in dispute are important cultural landscapes, including tombs of several local ethnic groups (Huff, 2016). The local word *tanindrazana*—which means territory, literally translates as “land owned by the ancestors” (Seagle, 2012). People involved in the resistance movement state that “*land cannot be viewed as a solely economic asset; it is also an existential anchor to past, present and future generations. Connecting to the ancestors (dranzana), upholding customary knowledge (fomba) and carrying out labour activities are all tied to everyday land use practices*” (Seagle 2012, p. 455). In the Fairbreeze project in South Africa, mining operations are expected to destroy or degrade over 60 km² of beautiful local dune systems which serve as both an important cultural and aesthetic role for the local communities as well as are the primary means of livelihood sustenance through the tourism industry (EDC18). In Tamil Nadu, India, mining operations resulted in the destruction of beautiful dune systems due to mining operations which eventually left large open sand pits (EDC5).

Finally, dispossessions of people can have deeper implications for local communities. For instance, people involved in resistance in Yogyakarta consider the sandy coastal areas not merely as natural resources or non-arable lands but rather as their “life-space.” Here, the dispossession of

people is not merely about land acquisition, but rather, a “*destruction of their source of life (land, water, air, livelihood and pasture), culture, and dignity*” (Yanuary, 2012, p. 19).

6 | DISCUSSION

The new fields of study called ecological economics, IE, and political ecology, all born in the 1980s, share the socio-metabolic view of the economy. Political ecology and ecological economics are closely connected to IE, that over one hundred years ago used to be called *Warenkunde*—the science of commodities. This article deals only with a few commodities, those in the group of HMS which are sources of titanium, zircon, iron, sillimanite/kyanite, staurolite, monazite, and garnet.

Our analysis of HMS-EDCs shows processes of commodity widening, with frontier expansion occurring across the world. Whereas initial phases of HMS extraction were largely localized to Australia (Morley, 1981), subsequent decades have witnessed an expansion of operations to South Africa, Madagascar, Senegal, and India, among others. A prominent indication of the continual commodity widening is the latest HMS mining operation—the Dundas project in Greenland, in the Arctic commodity extraction frontier (Hanaček et al., 2022). On the other hand, HMS mining is restricted by geological availability to relatively smaller spatial regions within countries (Van Gosen, 2014, 2018), thus resulting in high intensities of extraction. These high extraction intensities result in serious ecological and socioeconomic transformations at frontiers (which have been discussed above). Other social impact of extraction, which requires special attention, has been the subversion of constitutional rights of local communities, and the introduction of violence against local communities and resisting actors.

There have been many cases of threats or arrest of protesters, anti-mining activists and community members, for example, in the case of the Fairbreeze project in South Africa in 2015, the Gambia in 2015 (EDC17, EDC20), and journalists, for example, in the case of Tamil Nadu in India (EDC5). There have been cases of serious physical harm: from the State against protesters, for example, in the case of the Gambia in 2015 (EDC20) and Watu Pecak in Indonesia where a local environmental activist was murdered and several others wounded in 2015 (EDC8); as well as against mining company personnel by anti-mining protesters, for example, in the case of the Richard Bay minerals project of Rio Tinto in 2018 and 2019 and the Xolobeni Titanium Mining Project in 2016 (with activists’ deaths), both in South Africa (EDC17 and EDC19), and protesters allegedly setting fire to a company factory in Thuan Nahm in Vietnam in 2014 (EDC23). There have been cases of displacement and dispossession of local communities as in the case of Kwale Base Operations in Kenya in 2013 and in Kerala, India across several decades (EDC9 and EDC6). Finally, in a more extreme case, mining operations have resulted in threat of war, for example, in the case of the Niarang Project in Senegal in 2018 (EDC14). Overall, given the geographically constrained presence of HMS, the conflicts are highly localized but extremely intense.

The analysis of anti-mining actors involved in such EDCs show differences across time and countries. For instance, in the case of early mining operations in Australia, resisting actors were largely local conservation and environmental groups and civil society actors (EDC1). As commodity widening of frontiers has occurred along the decades, there is a perceptible change in the nature of resisting actors—in Vietnam, Madagascar, India, South Africa Indonesia, etc., participants are a broader mix of local communities, indigenous people, local NGOs, and civil society actors. In the case of Xolobeni, South Africa, the Amadiba Crisis Committee (Healy, 2022, EDC 19) is becoming world famous, and getting also involved in other environmental conflicts. The commodity expansion has also altered the narratives of resistance and the nature of contestations, that is, it has shifted from purely environmental- and conservation-based narratives to the language of livelihoods, dispossessions, displacement, and alteration in access to ecosystem services of local communities. This resistance also extends to purely environmental conservation-oriented programs by multinationals around HMS operations, for example, by Rio Tinto in Madagascar (Huff & Orengo, 2020; Kraemer, 2012), which are largely unsuccessful in addressing EDCs.

The analysis of extractive actors involved in the EDCs indicates that in most cases mining is carried out by multinational corporations (MNCs). Some MNCs are direct owners, for example, BlueJay mining owned Dundas Titanium Project, while others are affiliated with the local State corporations, for example, the Rio Tinto/QMM operations co-owned with the State government in Madagascar. In other cases, mining companies are nationally owned India Rare Earth Minerals and Kerala Minerals and Metals Limited in India, or owned by local/regional politically powerful people, for example, GACH in the Gambia and in Yogyakarta in Indonesia where the local Sultan owns and supports operations. Where large multinational companies are involved, mining operations are often conducted after obtaining official permits, however sometimes involving some degree of subversion of constitutional rights of local communities. In other cases, operations are either fully illegal, for example, Phú Hiệp company and others, in Bình Thuận, Vietnam; and V. V. Minerals in Tamil Nadu, India, or conducted with partial illegalities, for example, Chinese firm Nicua in the Philippines. In other cases, there are regulatory lapses with companies not following legal technical guidelines which can then lead to environmental disasters, for example, in Vietnam, operations by Bình Thuận Minerals Investment and Trade JSC resulted in a large mud spill in 2013 severely affecting local communities. Given the diverse implications of HMS operations, there is a need to ensure that analysis, regulation, and control over such operations account for these diverse ways in which social, cultural, environmental, and constitutional rights are negatively impacted by continuing operations.

The analysis also shows that HMS-EDCs differ from conflicts around aggregate sand mining across several factors. First, extractive actors in the case of sand mining for the construction industry typically tend to be either locally powerful elites, miscellaneous actors extracting and selling

sand through illegal networks, or informal/artisanal miners (Bisht, 2021; Bisht & Gerber, 2017; UNEP, 2022). In the case of HMS operations, we find that extractive actors are typically companies or MNCs, operating either legally, or illegally and/or partially illegally but with tacit consent of the State. The nature of extractive actors can have very significantly different implications. On the one hand, this implies involvement of much larger capital inputs into ensuring that extractive operations proceed despite local resistance, often through collusion with the local State governments; on the other hand, corporations can likely be held accountable more easily given the status of legality, accountability in countries of operations and origin of MNCs, requirements for corporate social responsibility; and the international community. Second, minerals and metals derived from HMS operations are largely exported to large spatial distances, and across international borders, from extraction frontiers. This differs significantly from sand for construction, or development minerals, which are largely transported across shorter geographical distances and traded within national boundaries (Bisht, 2021; UNEP, 2022). Third, the utilization of HMS-derived minerals and metals in high technological applications contrasts with the utilization of construction or development minerals largely in building local infrastructures, public utilities, urbanization, or housing (Franks, 2020).

7 | CONCLUSION

HMS mining is relatively recent, having begun on large scales around the late 1930s. The growth of the industry can be seen be linked to war given its applications in the defense sector, with the first notable increase in extraction occurring in Australia. Since then, the industry has expanded to many other geographical locations across the world, along with diversifications in its applications. Important uses of the products of HSM mining today are in pigments and paint industries, ceramics industry, aerospace and shipbuilding, and in medicine and prosthetics.

Although HMS currently make up a relatively smaller percentage of the overall global sand extraction, they are an important resource, specifically given their use in high tech applications. They represent the low-volume metallic sand-based resource. HMS extraction operations are extremely localized but highly disruptive of local ecosystems. Across different cases explored, HSM extraction has caused intense harm to unique ecosystems (e.g., loss of last Tall Tuart forests in Ludlow forests) (EDC1), drastic ecological disruptions (e.g., destabilization of dune systems in Senegal) (EDC15), created increased vulnerabilities of coastal communities (e.g., in Yogyakarta in Indonesia; Nagonha in Mozambique) (Yanuary, 2012; EDC7; Amnesty International, 2018; EDC14); resulted in reduction of productivity or elimination of traditional livelihoods (EDC11, EDC6) and destruction of culturally significant sites of local communities (EDC11).

HMS operations need to be understood within the framework of extractivism in order to arrive at meaningful solutions to address the myriad problems emerging from them. For instance, HMS extraction results in large-scale and serious local ecological degradation, negative environmental and social impacts of which are cost-shifted onto local communities. Further, significant quantities of resources are exported away from spaces of extraction. Currently the extractive industry is largely controlled by relatively few large multinational mining corporations some examples being Rio Tinto, Mineral Commodities, BlueJay Mining, Astron Mining, and Base Resources (Table 1). They control the exports as either raw materials or with extremely limited processing, across national boundaries to countries with higher capital and techno-infrastructure for using HMS-derived metals. HSM mining operations also result in varying levels of localized conflict generations which have spanned from threats to and arrests of local journalists and activists, to physical violence and murder of anti-HSM mining protesters, and to the threat of war by local anti-State and anti-mining rebel groups.

This article describes the similarities and differences between HSM-EDCs across different geographies, political regimes, socioeconomic, ecological, and cultural contexts, arriving at a general framework to understand these conflicts. The growth and changes in social metabolism and the appearance of environmental conflicts are two sides of the same coin. But concrete analyses are needed depending on the commodities in question (coastal sand for heavy minerals, in this article) and the local circumstances at the commodity extraction frontiers. Existing research on HSM operations and HMS-EDCs is currently very limited. As such, there is scope for further research on these minerals. We have provided a first comparative overview. We have provided a first comparative overview of the multi-dimensional implications related to justice and equity, cultural heritage and values, socioeconomic and ecological cost-shifting, and access to ecosystems that companies engaging in such resource extraction need to be accountable for.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The qualitative data that support the findings of this study are openly available in EJAAtlas - Global Atlas of Environmental Justice at <https://ejatlas.org/>. Underlying data for Figure 1(a) and 1(b) are available in Table S1 and S2 of Supporting Information. The quantitative data that support the findings of this study are openly available in United States Geological Survey, Mineral Commodity Summaries at <https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries>. All other, qualitative, and quantitative, data that supports the findings of this study are available in the supporting information of this article.

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NOTES

¹ EDCs are social conflicts related to the use of the environment and are not coterminous with “economic distribution conflicts” (Martinez-Alier & O'Connor, 1996). In these cases, the socio-environmental damages or “externalities” cannot always be expressed in monetary terms. Other valuation languages such as cultural, spiritual, aesthetic, ecological, and livelihood values related to sense of place and space, belonging, and dignity, are displayed by the social actors of such conflicts.

² This paper does not include all cases of HMS-EDCs across the world—only the ones that have publicly known social resistance movements and were able to be searched through publicly available documents in English.

³ Since aggregates (sand, gravel, pebbles, and cobbles) typically occur and are extracted together (only differing in granular sizes), this process is collectively referred to as sand mining/extraction (Bisht, 2021).

⁴ The 8200 thousand metric tons reported in 2020 (USGS, 2021).

⁵ Estimated to be 40–50 billion metric tons in 2019 (UNEP, 2022).

⁶ The EJAAtlas constitutes the largest existing inventory documenting ecological struggles from around the world (Temper et al., 2018; ejatlas.org).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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