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The Unsustainable Use of Sand: Reporting on a Global Problem

Walter Leal Filho [1,2,*], Julian Hunt [3], Alexandros Lingos [1], Johannes Platje [4], Lara Werncke Vieira [5], Markus Will [6] and Marius Dan Gavriletea [7]

1 European School of Sustainability Science and Research, Hamburg University of Applied Sciences, Ulmenliet 20, D-21033 Hamburg, Germany; iusdrp@ls.haw-hamburg.de
2 Department of Natural Sciences, Manchester Metropolitan University, Chester Street, Manchester M1 5GD, UK
3 Energy Program, International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria; julian.hunt@hotmail.com
4 WSB University in Wroclaw, ul. Fabryczna 29-31, 53-609 Wroclaw, Poland; johannes.platje@wsb.wroclaw.pl
5 Federal University of Rio Grande do Sul—UFRGS, Porto Alegre 90040-060, Brazil; lara.vieira@ufrgs.br
6 Zittau/Görlitz University of Applied Sciences, Theodor-Körner-Allee 16, D-02763 Zittau, Germany; m.will@hszg.de
7 Business Faculty, Babeş-Bolyai University, Horea 7, 400038 Cluj–Napoca, Romania; marius.gavriletea@ubbcluj.ro
* Correspondence: walter.leal2@haw-hamburg.de

Abstract: Sand is considered one of the most consumed natural resource, being essential to many industries, including building construction, electronics, plastics, and water filtration. This paper assesses the environmental impact of sand extraction and the problems associated with its illegal exploitation. The analysis indicates that extracting sand at a greater rate than that at which it is naturally replenished has adverse consequences for fauna and flora. Further, illicit mining activities compound environmental damages and result in conflict, the loss of taxes/royalties, illegal work, and losses in the tourism industry. As sea-level rise associated with climate change threatens coastal areas, sand in coastal areas will play an increasingly greater role in determining the amount of damage from floods and erosion. The present analysis points to the need for swift action to regulate sand mining, monitoring, law enforcement, and international cooperation.

Keywords: sustainability; sand depletion; illegal sand mining; environmental impacts

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Highlights

- The world is facing a global sand crisis
- Negative environmental impacts of excessive sand exploitation are multiple
- Uncontrolled expansion of illegal sand mining: causes and consequences

1. Sand: A Valuable Natural Resource

Sand consumption has increased worldwide, in part due to the growth of the world´s population, increasing standards of living, and rapid urban expansion [1,2]. Sand is used in a wide range of industries and products [3], including water filtration, plastics, and the electronics sector [1]. In fact, almost every house, dam, road, wine glass, and cellphone contains some type of sand-related material [4]. Vast quantities of frack sand are used to extract oil from shale in the fracking industry. As a result of this trend, the United Nations Environment Programme considers that sand has become one of the most consumed natural resources at present [4]. A UNEP report estimates that sand and gravel account for up to 85% of the weight of minerals mined globally each year [5].

Sand refers to loose granular materials that are produced as a result of the disintegration of rocks. It is used as a major component for producing concrete and building materials, asphalt, and glass [1,6]. Whereas sand from beaches and rivers is commonly

used for the construction sector, desert sand is typically too fine or too smooth to bind building materials.

Almost every country is dependent on sand imports (see Figure 1), including those where sand mining activities occur. This is due, in part, to sand supplies being unevenly distributed within and across counties and the differing requirements for the type of sand used in various industries.

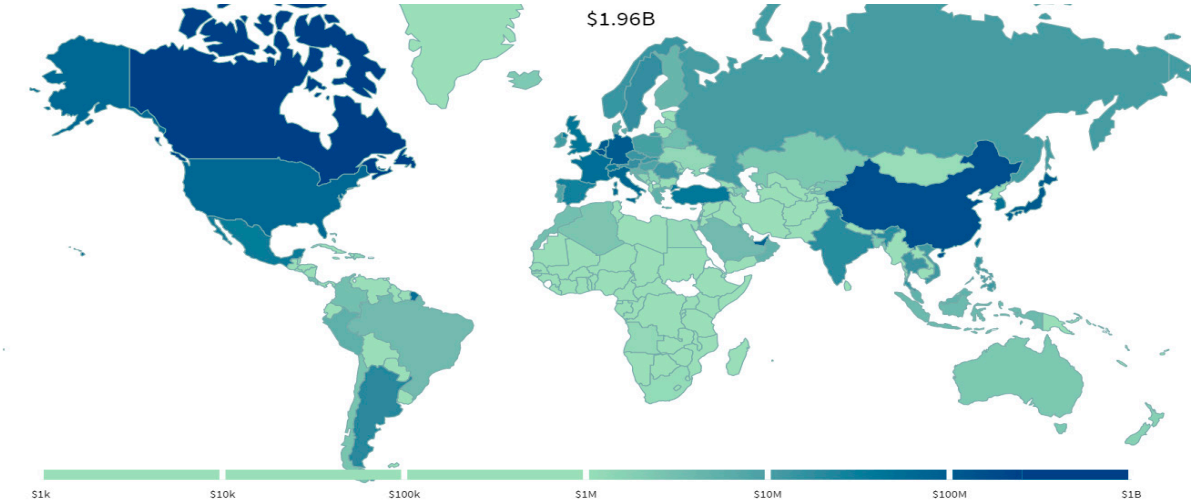

Figure 1. World's sand importers in 2019. *Source:* [7].

Sand is an increasingly valuable commodity and is essential to the economies of countries around the world. Many industries depend on sand as an essential resource in the production of various products. The sand mining industry contributes to job creation and investments in mining areas and sand exportation promotes economic growth. In short, the sand industry provides economic benefits to countries producing and importing sand. Sand and gravel production is dominated by the United States, Netherlands, Spain, Turkey, and India (Table 1). Among the countries that import the greatest amounts mention can be made of Canada, China, Belgium, Luxembourg, Singapore, and Germany [8].

Table 1. Major producers of sand.

Country	Production in 2019 (in 1000 Metric Ton)
China	190.000
United States	110.000
Netherlands	54.000
Spain	36.000
Turkey	14.000
India	12.000
Malaysia	10.000
Germany	7.500
United Kingdom	4.000
Australia	3.000

Source: Modified from Garside (2020) [9].

In 2018, European countries were among the leading exporters, along with North America and Asia (Figure 2).

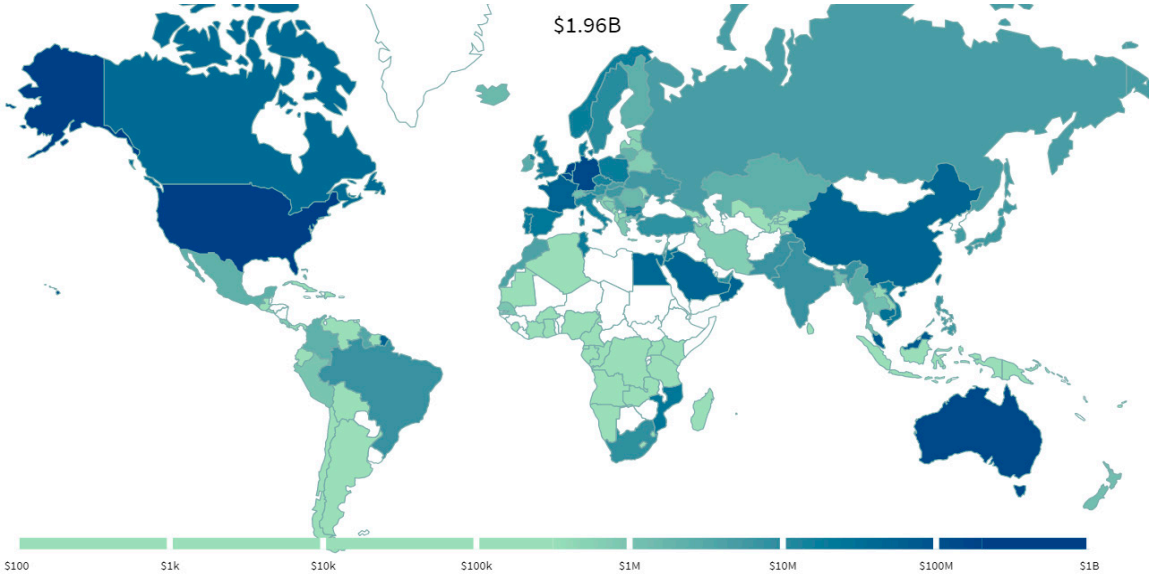

Figure 2. World's sand exporters in 2018. Source: [7].

Unfortunately, the extensive use of sand and the increase in mining activities have negative environmental impacts on both the local and global levels [10], and urgent measures are needed to limit these effects. The environmental consequences vary, in part, depending on where sand is mined and sourced. Three main natural sand sources include pit sand, river sand, and sea sand [11]. To compound the environmental consequences of legal mining and sourcing, illegal activities associated with sand mining and its transportation have been reported in many parts of the world. They most commonly occur in underdeveloped and developing nations [5].

This paper assesses the environmental impacts of sand exploitation and the problems associated with the illegal exploitation of this essential resource.

2. Methodology

To identify the extent to which environmental problems are associated with legal and illicit sand exploitation, we reviewed and analyzed a wide range of literature on the topic, including peer-reviewed literature, UN reports, and statistical documents (see Table 2) while considering the following aspects:

(a) The current degree of sand usage and exploitation across a sample of countries. This analysis was performed in order to obtain an overview of sand consumption across a set of countries, including the amount of sand being explored for future development and use.
(b) The environmental impacts of sand mining and use. The analysis focused on anticipated and potential impacts of sand use, especially on the physical environment.
(c) The degree to which illegal activities are associated with sand exploitation, including the causes, consequences, and measures needed to combat this phenomenon.

Table 2. Some recent studies on sand mine and their sustainability impacts.

Paper/Title	Focus	Authors
Impact of sand mining on alluvial channel flow characteristics	Physical impacts of sand mining	[12]
Time is running out for sand	General impacts of sand exploitation	[13]
Sand mining on North Stradbroke Island: an Islander view of the rehabilitation of the lands	Views on sand mining from indigenous people from Queensland/Australia	[14]
Detection of illicit sand mining and the associated environmental effects in China's fourth largest freshwater lake using daytime and nighttime satellite images	Aquatic environmental effects of illegal sand dredging Lake Hongze/China	[15]
Regulatory and policy implications of sand mining along shallow waters of Njelele River in South Africa	Exploration of regulatory and policy implications of sand mining operations in Njelele River (South Africa)	[16]
River bank instability from unsustainable sand mining in the lower Mekong River	Analysis of current sand extraction rates versus annual sediment load in Mekong River	[17]
Public perspective on the environmental impacts of sea sand mining: Evidence from a choice experiment in South Korea	Interviews and quantitative analysis regarding environmental impacts of the sea sand mining project in South Korean EEZ	[18]
Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research	Literature review on ecological impacts	[19]
Inventory of Estuarine and Lagoonal Ecosystems Subjected to Sand-Mining Activities in Southern Benin (West Africa)	Inventory of ecosystems and of potentially affected sites	[20]
Impact of Sand Mining on Zooplankton of River Ganga in and Around Patna, Bihar, India	Effects of sand mining on the reduction of species diversity and abundance of zooplankton In Ganga River (India)	[21]

The innovation of this approach is that it focuses not only on sand exploitation in quantitative terms but also classifies countries according to the amounts of sand they use. The analysis also considers illicit mining activities. The assessment of environmental impacts includes determining the physical impacts as well as the consequences on fauna and flora.

3. Results and Discussion

Demand for sand is increasing non-linearly, particularly in Asia and especially for concrete production. China used more sand for concrete production in 2011 and 2013 than the United States used during the entire 20th century [5]. The scale of the problem can be better assessed if one considers the fact that that one ton of cement can require up to 10 ton of sand to make concrete.

In 2018, China and India accounted for more than 60% of global cement production, with China producing more than all other countries combined [22].

Interestingly, small countries like Singapore (which largely uses sand for land reclamation) account for a significant share of sand imports. Singapore's proportion of sand imports ranged between 2.3% and 14% from 1995 to 2017 [23]. To accommodate increased global demand, there are new pressures to mine greater quantities of sand and to find alternative substitutes. Finding substitutes may take on greater importance if the rate of sand use exceeds its renewability rate [24,25].

3.1. Overview of Sand Mining Activities

Asia now has the highest level of sand mining [4,15,26,27]. Figure 3 shows some examples of sand mining levels around the world.

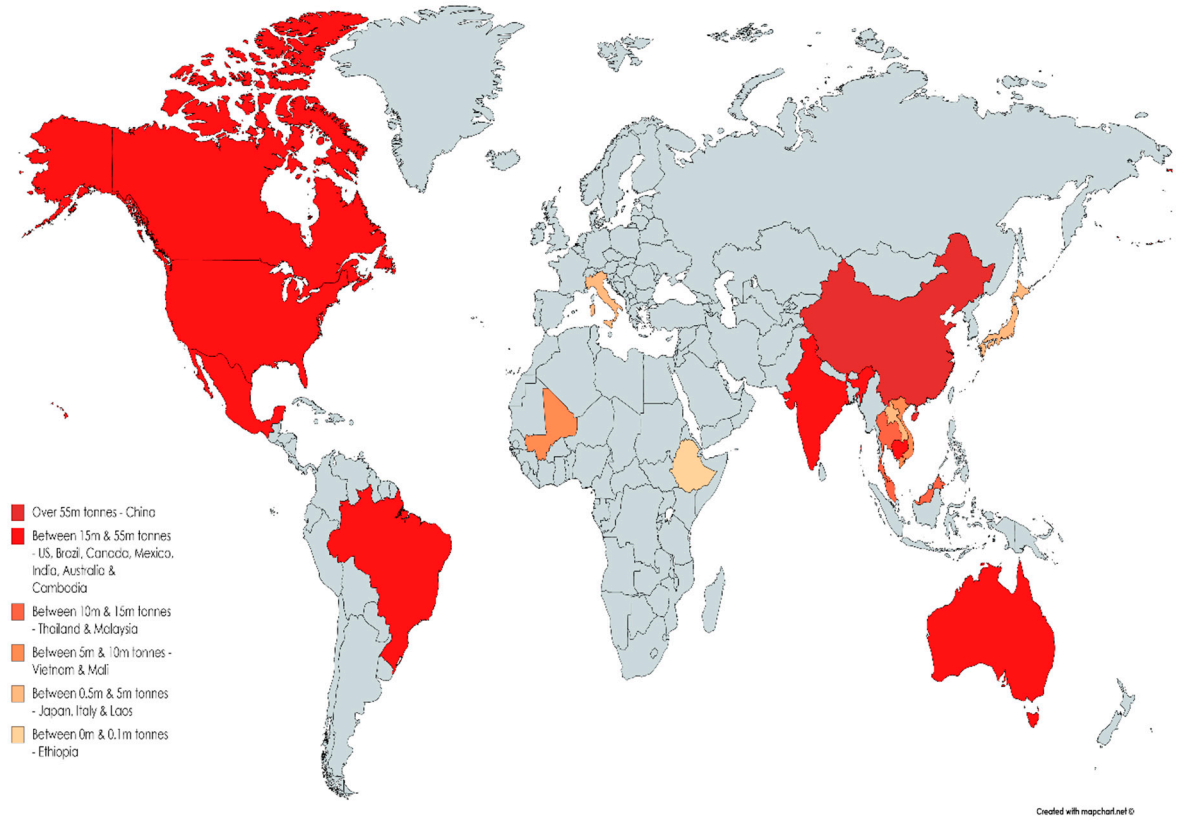

Figure 3. Overview of sand mining in selected countries (grey: not considered in the analysis). Source: [4,15,26,27].

Figure 3 shows that the degree of sand mining can be classified into six main categories:
Category 1: 0 to 0.1 m ton (e.g., Ethiopia)
Category 2: 0.1 m and 5 m ton (e.g., Japan, Italy, Laos)
Category 3: 5 m and 10 m ton (e.g., Vietnam, Mali)
Category 4: 10 m and 15 m ton (e.g., Thailand, Malaysia)
Category 5: 15 m and 55 m ton (e.g., United States, India, Cambodia, Brazil)
Category 6: Over 55 m ton (e.g., China)

Table 3 presents some of the main legal and illegal sand mining activities worldwide, according to the available information and our analysis (sources presented in Table 3). The table presents the mine or region name, country, whether the activity is legal or illegal and in operation, and a description of the mine. The relevant literature quoted under "description of mine" is cited in the column "References". In some cases, no specific data is available (marked as n/a). Most of the sand mining activities started in the 20th century and have remained operating until the present day. Out of the 20 sand mines reported, six involve illegal activities. However, this situation is more complex to track and control.

Table 3. Some of the main legal and illegal sand mining activities worldwide.

Mine or Region Name	Location Country	Situation	Main Exporting Country	Operation Status	Operation Start Date	Operation End Date	Description of the Mine with Quotes from the Literature (See Column "References)" to Facilitate a Greater Understanding	References
KwaZulu-Natal	South Africa	Illegal	Sold privately to local sand companies and individuals	Operational	n/a.	Open	Extract sand directly from main river channels and adjacent sandbanks.	[28]
Guarapari	Brazil	Legal	Use in Brazil only	Closed	1890	1994	Large sand-mined area covering about 1.2 ha (maximum 3.25 m depth). Previously exploited sand-mined areas differed from the undisturbed site in terms of plant species composition patterns.	[29]
Paraíba do Sul River	Brazil	Legal	Use in Brazil only	Operational	1940	Open	Sand extraction exceeds 15 million tons per year causing relevant environmental problems. In Brazil, the Vale do Paraíba is the most important sand production area.	[30]
Serra do Índio—Santarém	Brazil	Legal and Illegal	Exports are inexpressive and consumption is local	Operational	1970	Open	Between 2002 and 2014, around 14,059 m^3 of sand were extracted.	[31]
Kuznica Warezynska	Poland	Legal	Use in Poland only	Closed (Recreational area)	1967	2002	The operation occurred in four layers within the 12.713 km^2 area of the mine. After periodic activity of sand mine, a water reservoir was created in 2003–2005.	[32]
Poyang Lake	China	Legal	Supply sand for the construction industry in China	Operational	2001	Open	Dredging began in 2001 after sand mining in the Yangtze River had been banned. The lake's discharge ability dramatically increased after the initiation of extensive sand mining, which accelerated lake drainage and lowered water levels.	[33,34]
Lijiang River	China	Illegal	Use in China only	Operational	2012	Open	Sand mining activities have been extending toward the riparian forestlands. The effect of sand mining is more serious than that of converting forestland into farmland, playing a vital role in the degeneration of ecosystems.	[35]
Kathmandu Valley	Nepal	Legal and Illegal	Use in Nepal only	Operational	1991	Open	About 1865 m^3 sand from the river and 1238 m^3 from terraces are excavated per day in which 45% of the excavations were found to be illegal. Unsystematic mining has caused erosion and instability of the riverbanks and pollution of rivers.	[36]
Tamil Nadu	India	Illegal	North America and Europe	Operational	n/a	Open	Large-scale extraction of beach sand has been reported. Along a 50-km stretch of the Tamil Nadu coastline, industrial-scale extraction of beach sand has led to the destruction of fisheries, and flooding is a growing risk.	[37]
Orissa Sands Complex (OSCOM)	India	Legal	USA, UK, France, Germany, Norway, Japan	Operational	1980s	Open	Beach sand mining and mineral separation activity are carried out over the mining lease area of 2464 hectares.	[38,39]
Chavara	India	Legal	USA, UK, France, Germany, Norway, Japan	Operational	1922	Open	The adjacent area has one of the best mineral sand deposits in the country. The mines contain as high as 40% heavy minerals, extending over a stretch of 23 km in the coastal belt of Neendakara and Kayamkulam.	[40,41]
Manavalakurichi unit (MK)	India	Legal	USA, UK, France, Germany, Norway, Japan	Operational	1910	Open	The annual production capacity of the mineral separation plant is 91,200 t per annum (tpa) of Ilmenite and other associated minerals such as Rutile, Zircon, and Garnet.	[42,43]
Nilwala River	Sri Lanka	Illegal	Use mostly in Sri Lanka	Operational	n/a	Open	Over-extraction of sand has led to salinization of the drinking water supply, collapse of river banks, and loss of valuable riparian land. It is estimated that the mining of sand has increased three-fold when compared to 1997.	[44]

Table 3. *Cont.*

Mine or Region Name	Location Country	Situation	Main Exporting Country	Operation Status	Operation Start Date	Operation End Date	Description of the Mine with Quotes from the Literature (See Column "References)" to Facilitate a Greater Understanding	References
Monterey Bay–California	United States	Legal	Use in the US	Closed	1906	1990	Substantial amounts of sand were mined directly from the shoreline until it was hypothesized that sand mining was a significant contributor to shoreline erosion. An estimated 6.3 million cubic meters of sand were mined before it ceased in 1990.	[45]
Amite River–Louisiana	United States	Legal	Use in the US	Operational	1930	Open	At the disturbed floodplain and channel, the combined gravel and sand extraction has exceeded 10 million tons per year. Large disturbances on the Amite River have become much more common due to a steady increase in mining activity in this area. Production reached a peak in the early to mid-1980s.	[46,47]
Azores—Santa Bárbara, São Miguel	Portugal	Legal	Use in Portugal	Closed	1960	1995	The main source of sand for industrial purposes in the early 1960s resulted in volumetric depletion of the dune cover and lowering of the surface of the berm, triggering cliff erosion. In total, some 950,000 m^3 of sand have been removed, the dunes making up half of this figure.	[48]
New Amanful, Funkoe and Adjuah—Ahanta West District	Ghana	Legal	Use in Ghana	Open	1950	Open	The process of sand mining has accelerated coastal environmental degradation to an alarming rate in many areas. The main effects of uncontrolled sand mining include loss of land (19.2%), destruction of the beach (18.2%), destruction of the road (16.5%), land conflict (13.7%), loss of vegetation (12.2%), destruction of property (11.8%), and use of child labor (8.4%).	[49]
Kazan Plain	Turkey	Legal	Use in Turkey	Closed	1980	2006	Because of the large and deep excavations by the sand–gravel pits, the aquifer has thinned and has been removed entirely in some places. There are serious unfavorable impacts on the groundwater system caused by the sand–gravel pits that operate generally below the water table with excessive extraction	[50]
Lake Tana	Ethiopia	Legal	Use in Ethiopia	Operational	1992	Open	The ecology of the mined rivers was seriously affected by sand mining, which interfered with migratory routes of fishes and resulted in the loss of their spawning grounds.	[51]
Pantai Labu	Indonesia	Legal	Mostly used in Indonesia	Operational	2008	Open	The impact of marine sand mining results in environmental damage (degradation) of the coast, such as abrasion and decreased productivity of marine fisheries due to declining water quality. The declines in seawater quality are especially in TSS (Total Suspended Solid) parameters.	[52]

3.2. Causes and Consequences of Illegal Sand Mining

Illegal sand mining activities are increasing worldwide and negatively impacting terrestrial, riverine, and marine environments [53] and are associated with adverse social and socioeconomic consequences. There are numerous causes of illegal mining activities, including:

- motivation for financial profit,
- increasing global sand demand,
- lack of monitoring and control systems,
- relaxed policies and procedures that allow individuals and businesses to acquire mining titles for sand mining exploration, to self-monitor production, and to displace community members from mining areas,
- lack of monitoring of sand extraction volume,
- mining taxes and royalties are paid by the mine owner/operator based on the extracted sand volume, and acts of evasion of payment may occur in tandem with illegal activities,
- poverty, low level of education, and lack of information about negative consequences of illegal mining,
- deficiencies in fulfilment of technical specifications for sand extraction.

Furthermore, areas that are forbidden and restricted for mining activities are sometimes not defined properly, which may make illegal exploitation easier.

The present review of the literature indicates that there is limited research related to the consequences of illegal mining activities for some specific countries. However, Table 4 presents some of the negative consequences that are associated with illegal mining, based on the available literature.

Table 4. Some of the negative consequences of illegal sand mining.

Negative Consequences	References	Country/Region
Environmental damages	[54–59]	India
	[60]	Zimbabwe
	[61]	Indonesia
	[62]	Botswana
	[63]	South Africa
	[64]	Lower Mekong River
	[65]	Greece
Taxes/royalties losses	[27,37]	India
	[65]	Greece
Illegal work	[60]	Zimbabwe
	[37]	India
	[62]	Botswana
Conflict driver	[27,37,58]	India
	[66,67]	Kenya
	[62]	Botswana
Losses in tourism industry	[61]	Indonesia
	[68]	Morocco

This analysis underscores the need for developing, adopting, and enforcing measures and laws to limit and prevent illegal actions related to sand exploration at the local, regional, and national levels in each country involved in this activity.

A legal framework to regulate mining activities requires cooperation amongst all the sectors and stakeholders involved, appropriate regulation, monitoring, and enforcement, and efficient control systems. Reasons for illegal activities in developing and developed countries may differ. In order to reduce or prevent illegal sand mining in developing countries, it is important to consider the need for related programs, including the following:

- governments must develop, adopt, and promote effective strategies for poverty and unemployment reduction;
- develop, adopt, and implement unified strategies to address various aspects of sustainable development and environment protection, including creating mechanisms to evaluate the possibility of ecological disasters resulting from excessive illegal sand exploitation, as well as educating the public;
- impose efficient and fair taxes/royalties for sand mining license holders in order to stimulate legal activities and to discourage illegal mining;
- enact and enforce laws at the local, regional, and national levels to regulate the mining sector, including consequences for non-compliance (e.g., meaningful sanctions and penalties).

3.3. Environmental Impacts of Sand Mining

The very high volume of sand being currently extracted is having a serious negative impact on rivers, deltas, and coastal and marine ecosystems, such as loss of land through river or coastal erosion, the lowering of water levels, and decreases in the amount of sediment supply [69,70], and is affecting the economic and social development as well [2]. The scope of these adverse effects extends from the local area to larger regions that are far away from the sites where sand is taken [1]. For example, mining in China's Poyang Lake—which the United Nations Environment Programme believes to be the world's largest sand-extraction site—is thought to have lowered the water levels in that region [5].

Because sand is being extracted at a far greater rate than that at which it is naturally replenished, the depletion of existing sand reserves is damaging fauna and flora at significant levels. Table 5 presents some of the main environmental impacts associated with sand exploitation.

Table 5. Some of the adverse environmental impacts of sand exploitation.

	Adverse Environmental Impact	Reference
Fauna	Habitat destruction for different species	[56,71]
	Depletion of fish populations	[72,73]
	Hindrance of fish migration	[74,75]
	Replacement of lotic species by lentic species	[76–78]
	Extinction of certain local species, Invasive species	[72,73,76]
	Reduced fish reproduction	[51,79,80]
	Impacts in food web structure	[76,81]
	Oxygen depletion	[82]
Flora	Loss of benthic organisms	[73]
	Vegetation removal	[83]
	Destruction of riparian habitat	[79,84]
		[82]
Land/Soil	Bed degradation	[73,85,86]
	Flattening of the longitudinal riverbed gradient	[86]
	Bank erosion	[87]
	Lowering the average of riverbed elevation	[86]
	Beach erosion	[83]
	Reduced integrity of coastlines with lower capacity to handle stormy weather	[88]
Water	Changes to landscape	[56,83]
	Channel incision	[19,87,89,90]
	Channel widening	[19,91–93]
	Channel erosion and instability	[5,93,94]
	Waterway siltation	[73]
	Increased water turbidity	[73]
	Change of river flow pattern	[95]
	Deterioration of water quality (including groundwater)	[56,73,93]
	Deepening of the water depths	[86]
	Saltwater movement upstream	[64,86]
	Changes in tidal level, range, and duration	[86]
Air	Dust pollution	[56,83,96,97]
	Noise and vibration	[83,96,97]

Table 5 highlights the serious and irreversible damages on the terrestrial, aquatic, and atmospheric environments generated by sand mining activities. These damages also harm the social and economic sphere of sustainable development. The degree of impact depends, in part, on the type and intensity of sand mining, the fragility of the different elements of the ecosystem and biodiversity, and country-specific issues [98]. While sand mining provides direct socio-economic benefits for the region or countries (e.g., job creation, tax revenues), the direct and indirect negative environmental impacts can negatively impact other sectors of the economy, such as agriculture, tourism, fishing, public health [2,99–101], and society (e.g., flood protection, access to drinking water, erosion prevention).

The current analysis is especially concerning given that sand resources in many locations around the world are needed to help buffer the adverse impacts of climate change. Specifically, the International Panel on Climate Change projects that the sea level will rise nearly one meter by 2100 [102], and sand in coastal areas is one of the only tools that can help curb the direct impact of rising sea levels on land areas [78]. Governments that allow sand removal from coastal areas, inlets, and rivers may be creating a situation that will compound the environmental damage their countries will experience as a result of sea-level rise associated with climate change. Indeed, in the coming years, they may need to invest significant resources to reinforce coastal areas that have been made more vulnerable as a result of sand mining.

Figure 4 presents a cluster map of the social, environmental, and economic impacts of sand mining, based on our analysis of the literature [1,4,19,78,83,91]. One assumption is that as the world population increases, the demand for sand is likely to continue to grow, which corresponds to the increasing need for infrastructure, housing, etc. (viz., socio-economic development). The keywords presented in Figure 4 should be interpreted as part of an initial model for assessing the impact of sand mining on socio-economic development. The model identifies the associations between sand demand, sand mining activities, direct and indirect environmental effects, social impacts, and economic impacts.

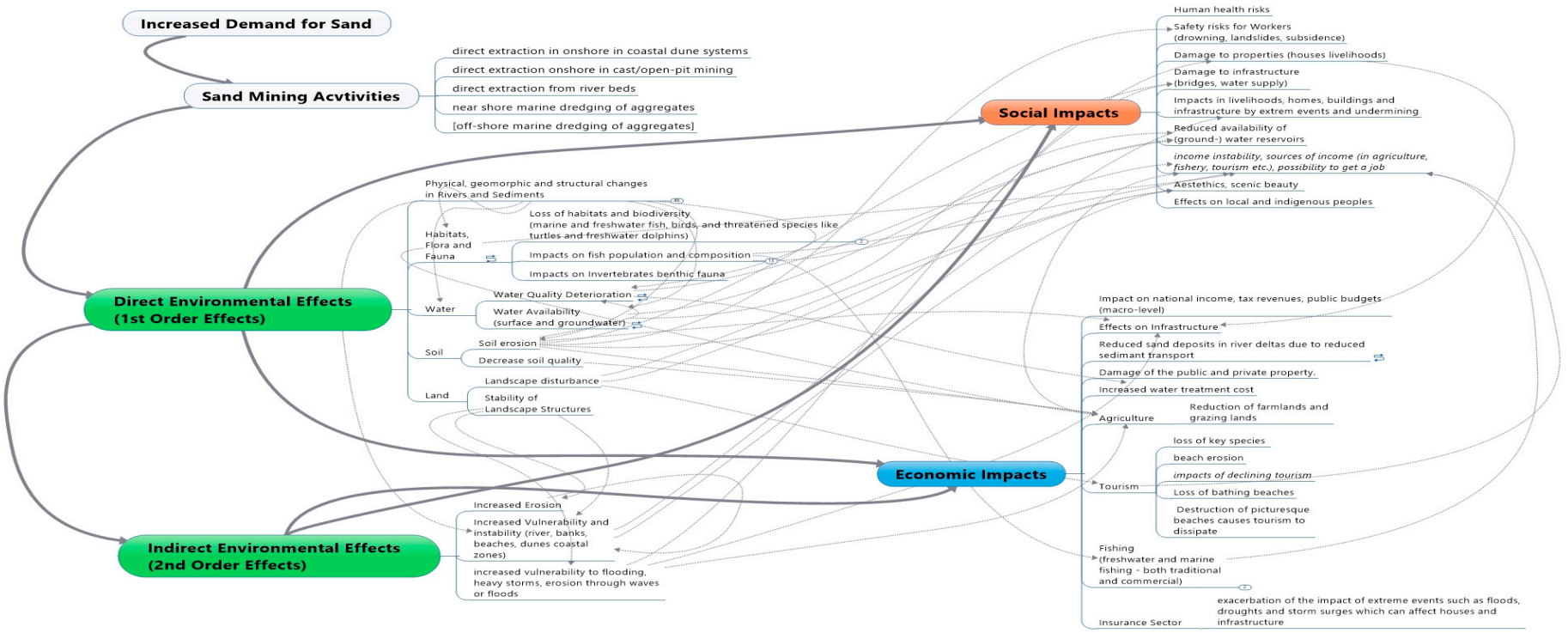

Figure 4. Cluster Map on Environmental Impacts of Sand Mining (based on [1,4,19,78,83,91]. Understanding the connections and correlations between direct and indirect environmental impacts and social and economic impacts is central to developing and promoting policies and programs that will stimulate and guide the sand industry and governments toward sustainable development practices.

4. Conclusions and Future Prospects

Despite the increasing worldwide dependence on sand, the large quantity of sand and gravel excavated, the significant environmental impacts, and the socio-economic issues associated with sand mining and use, policymakers have largely ignored these pressing issues, and the public often has little knowledge of them. Importantly, as the COVID-19 pandemic and other issues take the attention of government officials and the public, this pressing problem may become even less visible.

With the expectation that coastal areas are at increased risk due to rising sea levels associated with climate change, there is little question that sand in coastal areas will play an increasingly greater role in determining the amount of damage from floods and erosion. The findings point to the need for swift action by governments and agencies around the world to create global regulations that prevent the sourcing of more sand than the Earth can naturally create. These actions should consider how regulating sand use could promote economic and environmental stability regionally and within countries and reduce the detrimental effects of sand production and export [4].

The current analysis highlights the need for a global mechanism to monitor sand extraction and its impacts. Scientific and environmental impact assessments should be systematically implemented prior to any authorization for sand extraction. Further, increased efforts are needed to encourage countries to strengthen the enforcement of existing laws and to develop new regulations as needed. These measures should consider ways to resist promoting short-term over long-term benefits and to incorporate environmental consequences in decision-making [78].

The current analysis suggests that governments and the private sector should increase investment in research and development and identify sustainable alternatives for common sand as a building material (such as alternatives to conventional concrete). Finding a suitable alternative may have the potential to reduce carbon dioxide emissions from concrete production, which accounts for nearly 4% of global carbon dioxide emissions [103]. Potential substitutes that are currently available include quarry stone dust, industrial waste [104], plastic waste [105], and wood production residuals [4]. Careful analysis of the environmental and social-economic consequences of alternative materials is needed to determine the pros and cons compared to sand.

The current analysis also gives direction towards promptly developing an international framework for sustainable sand mining. A global framework could include international laws and enforcement mechanisms, such as a licensing system designed to reduce sand use, monitoring systems, and clean technologies that reduce environmental damage. It is likely that such an approach would need considerable support from those countries and businesses most engaged in sand development in order to realize the expected benefits.

Finally, to reduce the negative environmental impacts of sand mining activities, active measures should focus on four areas:

a. informing the general public about the negative effects of sand mining in order to raise awareness of associated environmental issues,
b. engaging governments, agencies, and community members in monitoring and surveillance actions in order to identify potential threats to the environment due to sand mining activities,
c. providing an efficient legal framework for regulating sand mining activities and reducing or preventing illicit mining activities,
d. reducing sand usage by replacing natural sand with substitution material in different industries,

As the COVID-19 pandemic creates economic hardship worldwide, there may be new pressures to source sand illegally. In fact, there is evidence that monitoring activities of industries around the world have reduced as a result of COVID-19, as governments take measures to minimize citizen exposure to the virus [106]. Indeed, less developed countries, where the majority of illicit sand sourcing is taking place, have the highest unemployment

and poverty rates. Immediate local, national, and international action is needed to address the serious issue of sand exploitation.

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References

1. Gavriletea, M.D. Environmental Impacts of Sand Exploitation. Analysis of Sand Market. *Sustain. J. Rec.* **2017**, *9*, 1118. [CrossRef]
2. Torres, A.; Brandt, J.; Lear, K.; Liu, J. A looming tragedy of the sand commons. *Science* **2017**, *357*, 970–971. [CrossRef]
3. USGS, U.S. Geological Survey. Sand and Gravel (Industrial), Silica Statistics and Information. 2011. Available online: http://minerals.usgs.gov/minerals/pubs/commodity/silica/mcs-2010-sandi.pdf (accessed on 3 May 2020).
4. UN Environment. The Search for Sustainable Sand Extraction Is Beginning. 2019. Available online: https://www.unenvironment.org/news-and-stories/story/search-sustainable-sand-extraction-beginning (accessed on 3 May 2020).
5. UNEP-GEAS. Sand, Rarer than One Thinks. 2014. Available online: https://na.unep.net/geas/archive/pdfs/GEAS_Mar2014_Sand_Mining.pdf (accessed on 17 April 2020).
6. Dinh, C. Asia's Hunger for Sand Is Harmful to Farming and the Environment. 2020. Available online: https://www.economist.com/asia/2020/01/18/asias-hunger-for-sand-is-harmful-to-farming-and-the-environment (accessed on 3 May 2020).
7. Atlas of Economic Complexity. Who Imported Natural Sands in 2018? Available online: https://atlas.cid.harvard.edu/explore/geo?year=2018&country=undefined&tradeDirection=import&productClass=HS&product=855&target=Product&partner=undefined&startYear=1995 (accessed on 3 May 2020).
8. The Observatory of Economic Complexity (OEC). 2018. Available online: https://oec.world/en/profile/hs92/52505/ (accessed on 3 May 2020).
9. Garside, M. Major Countries in Industrial Sand and Gravel Production Worldwide i2018 and 2019. 2020. Available online: https://www.statista.com/statistics/376665/industrial-sand-and-gravel-production-bytopcountries/ (accessed on 27 June 2020).
10. Huang, B.; Zhao, F.; Fishman, T.; Chen, W.-Q.; Heeren, N.; Hertwich, E.G. Building Material Use and Associated Environmental Impacts in China 2000–2015. *Environ. Sci. Technol.* **2018**, *52*, 14006–14014. [CrossRef]
11. Lakshmi, K.; Ashwini Manjunath, B.T.; Karthick, T.R.; Manjunath, M.S. Partial replacement of sea sand and desert sand in place of river sand for mortar in construction. *Glob. Res. Dev. J. Eng.* **2017**, *2*, 81–85.
12. Barman, B.; Kumar, B.; Sarma, A.K. Impact of sand mining on alluvial channel flow characteristics. *Ecol. Eng.* **2019**, *135*, 36–44. [CrossRef]
13. Bendixen, M.; Best, J.; Hackney, C.; Iversen, L.L. Time is running out for sand. *Nat. Cell Biol.* **2019**, *571*, 29–31. [CrossRef]
14. Burgin, S. Sand mining on North Stradbroke Island: An Islander view of the rehabilitation of the lands. *Int. J. Environ. Stud.* **2020**, *77*, 954–968. [CrossRef]
15. Duan, H.; Cao, Z.; Shen, M.; Liu, D.; Xiao, Q. Detection of illicit sand mining and the associated environmental effects in China's fourth largest freshwater lake using daytime and nighttime satellite images. *Sci. Total Environ.* **2019**, *647*, 606–618. [CrossRef]
16. Gondo, T.; Mathada, H.; Amponsah-Dacosta, F. Regulatory and policy implications of sand mining along shallow waters of Njelele River in South Africa. *Jàmbá J. Disaster Risk Stud.* **2019**, *11*, 727. [CrossRef] [PubMed]
17. Hackney, C.R.; Darby, S.E.; Parsons, D.R.; Leyland, J.; Best, J.L.; Aalto, R.; Nicholas, A.P.; Houseago, R.C. River bank instability from unsustainable sand mining in the lower Mekong River. *Nat. Sustain.* **2020**, *3*, 217–225. [CrossRef]
18. Kim, J.-H.; Yoo, S.-H. Public perspective on the environmental impacts of sea sand mining: Evidence from a choice experiment in South Korea. *Resour. Policy* **2020**, *69*, 101811. [CrossRef]
19. Koehnken, L.; Rintoul, M.S.; Goichot, M.; Tickner, D.; Loftus, A.-C.; Acreman, M.C. Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research. *River Res. Appl.* **2020**, *36*, 362–370. [CrossRef]
20. Lalèyè, R.K.; Agadjihouèdé, H.; Chikou, A.; Adjagbo, H.; Assogba, C.; Lédéroun, D.; Lalèyè, P.A. Inventory of Estuarine and Lagoonal Ecosystems Subjected to Sand-Mining Activities in Southern Benin (West Africa). *J. Environ. Prot.* **2019**, *10*, 473–487. [CrossRef]
21. Prabhakar, R.; Kumari, A.; Neetu, R.K.S. Impact of Sand Mining on Zooplankton of River Ganga in and Around Patna, Bihar, India. *Environ. Ecol.* **2019**, *37*, 1301–1308.
22. Globaltrade, Wave of Global Sand Trade May Be Depleting Beaches. 2019. Available online: https://www.globaltrademag.com/wave-of-global-sand-trade-may-be-depleting-beaches/ (accessed on 3 May 2020).

23. OEC. Which Countries Import Sand? 2017. Available online: https://oec.world/en/visualize/tree_map/hs92/import/show/all/2505/2017/ (accessed on 3 May 2020).
24. Mining Technology. Can Sand Mining ever Be Green? 2017. Available online: https://www.mining-technology.com/features/featurecan-sand-mining-ever-be-green-5842185/ (accessed on 3 May 2020).
25. Padmalal, D.; Maya, K. Impacts of river sand mining. In *Sand Mining—Environmental Impacts and Selected Case Studies*; Padmalal, D., Maya, K., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 31–56.
26. Brown, O.; Peduzzi, P. Driven to Extraction: Can Sand Mining Be Sustainable? Hoffmann Centre for Sustainable Resource Economy. 2019. Available online: https://hoffmanncentre.chathamhouse.org/article/driven-to-extraction-can-sand-mining-be-sustainable/#footnote-6 (accessed on 4 May 2020).
27. Salopek, P. Inside the Deadly World of India's Sand Mining Mafia, National Geographic. 2019. Available online: https://www.nationalgeographic.com/environment/2019/06/inside-india-sand-mining-mafia/ (accessed on 3 May 2020).
28. Chevallier, R. Illegal Sand Mining in South Africa. Governance of Africa's Resources Programme Policy Briefing. Available online: https://www.africaportal.org/publications/illegal-sand-mining-in-south-africa/ (accessed on 3 May 2020).
29. Garbin, M.L.; Misaki, F.; Ferreira, P.F.; Guidoni-Martins, K.G.; Soares, R.B.; Mariotte, P.; Sansevero, J.B.B.; Rocha, P.G.; Silva, A.G. Long-term regeneration of a tropical plant community after sand mining. *Ecol. Evol.* **2018**, *8*, 5712–5723. [CrossRef]
30. Santo, E.; Sánchez, L. GIS applied to determine environmental impact indicators made by sand mining in a floodplain in southeastern Brazil. *Environ. Geol.* **2002**, *41*, 628–637. [CrossRef]
31. Da Silva, E.F.; Bento, D.F.; Mendes, A.C.; Da Mota, F.G.; Mota, L.C.S.; Fonseca, A.I.T.; Almeida, R.M.; Santos, L.D.O. Environmental impacts of sand mining in the city of Santarém, Amazon region, Northern Brazil. *Environ. Dev. Sustain.* **2018**, *22*, 47–60. [CrossRef]
32. Różkowski, J.; Rahmonov, O.; Szymczyk, A. Environmental Transformations in the Area of the Kuźnica Warężyńska Sand Mine, Southern Poland. *Land* **2020**, *9*, 116. [CrossRef]
33. de Leeuw, J.; Shankman, D.; Wu, G.; de Boer, W.F.; Burnham, J.; He, Q.; Yesou, H.; Xiao, J. Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China. *Reg. Environ. Chang.* **2010**, *10*, 95–102. [CrossRef]
34. Lai, X.; Shankman, D.; Huber, C.; Yesou, H.; Huang, Q.; Jiang, J. Sand mining and increasing Poyang Lake's discharge ability: A reassessment of causes for lake decline in China. *J. Hydrol.* **2014**, *519*, 1698–1706. [CrossRef]
35. Qin, Y.; Chen, Z.; Ding, B.; Li, Z. Impact of sand minig on the carbon sequestration and nitrogen removal ability of soil in the riparian area of Lijiang River, China. *Environ. Pollut.* **2020**, *261*, 114220. [CrossRef] [PubMed]
36. Sayami, M.; Tamrakar, N.K. Status of sand mining and quality in northern Kathmandu, Central Nepal. *Bull. Dep. Geol.* **2007**, *10*, 89–98. [CrossRef]
37. Mahadevan, P. Sand Mafias in India. Disorganized Crime in a Growing Economy. 2019. Available online: https://globalinitiative.net/wp-content/uploads/2019/07/Sand-Mining-in-India-Report-17Jul1045-Web.pdf (accessed on 3 May 2020).
38. IREL. Indian Rare Earths Ltd.a. OSCOM, 2020a. Available online: http://www.irel.co.in/oscom. (accessed on 24 July 2020).
39. The New Indian Express. Residents Stall Dredging, Orissa Sands Complex Files Complaint. Available online: https://www.newindianexpress.com/states/odisha/2018/sep/23/residents-stalldredging-orissa-sands-complex-files-complaint-1876021.html (accessed on 28 June 2020).
40. IREL. Indian Rare Earths Ltd.a. Chavara Mineral Division, 2020b. Available online: http://www.irel.co.in/chavara-mineral-division. (accessed on 24 July 2020).
41. Department of Atomic Energy (DEA). Indian Rare Earths—Its Genesis and Growth. 2001. Available online: http://www.dae.gov.in/node/266. (accessed on 7 September 2020).
42. IREL. Indian Rare Earths Ltd.a. Manavalakurichi Mineral Division, 2020c. Available online: http://www.irel.co.in/manavalakurichi-mineral-division. (accessed on 24 July 2020).
43. Nuclear Threat Initiative. Mineral Separation Plant. Available online: https://www.nti.org/learn/facilities/877/ (accessed on 28 June 2020).
44. Piyadasa, R. River sand mining and associated environmental problems in Sri Lanka. In *Sediment Problems and Sediment Management in Asian River Basins*; IAHS: Hyderabad, India, 2011.
45. Thornton, E.B.; Sallenger, A.; Sesto, J.C.; Egley, L.; McGee, T.; Parsons, R. Sand mining impacts on long-term dune erosion in southern Monterey Bay. *Mar. Geol.* **2006**, *229*, 45–58. [CrossRef]
46. Mossa, J.; McLean, M. Channel planform and land cover changes on a mined river floodplain. *Appl. Geogr.* **1997**, *17*, 43–54. [CrossRef]
47. Harmon, B.; Hammons, H.; Jacobson, T.; Nguyen, N.; Peterson, E.; Shah, T.; Stich, X.; Wright, A. The Hungry River: Designing a Future for the Amite River's Former Sand and Gravel Mines. 2020. Available online: https://baharmon.github.io/blog/amite-sand-mine (accessed on 3 May 2020). [CrossRef]
48. Borges, P.; Andrade, C.; Freitas, M.C. Dune, Bluff and Beach Erosion due to Exhaustive Sand Mining—The Case of Santa Barbara Beach, São Miguel (Azores, Portugal). *J. Coast. Res.* **2002**, *36*, 89–95. [CrossRef]
49. Mensah, J.V. Causes and Effects of Coastal Sand Mining in Ghana. *Singap. J. Trop. Geogr.* **1997**, *18*, 69–88. [CrossRef]
50. Apaydın, A. Dual impact on the groundwater aquifer in the Kazan Plain (Ankara, Turkey): Sand-gravel mining and over-abstraction. *Environ. Earth Sci.* **2012**, *65*, 241–255. [CrossRef]
51. Mingist, M.; Gebremedhin, S. Could sand mining be a major threat for the declining endemicLabeobarbusspecies of Lake Tana, Ethiopia? *Singap. J. Trop. Geogr.* **2016**, *37*, 195–208. [CrossRef]

52. Doloksaribu, D.C.N.; Barus, T.A.; Sebayang, K. The impact of marine sand mining on sea water quality in Pantai Labu, Deli Serdang Regency, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *454*, 012086. [CrossRef]
53. UN Environment (UNEP). Rising Demand for Sand Calls for Resource Governance, 2019a. Available online: https://www.unenvironment.org/news-and-stories/press-release/rising-demand-sand-calls-resource-governance (accessed on 3 May 2020).
54. Kuttipuran, M. *RIVERS: Physical Modifications*; Donnelley: Singapore, 2006.
55. Bagchi, P. Unregulated Sand Mining Threatens Indian Rivers. *J. India Together* **2010**, *21*, 7–9.
56. Saviour, N.M. Environmental impacts of Soil and Sand Mining: A Review. *Int. J. Sci. Environ. Technol.* **2012**, *1*, 125–134.
57. Pereira, K. Sand Mining—The Unexamined Threat to Water Security. 2013. Available online: http://ismenvis.nic.in/Database/Illegal_sand-mining_India_3457.aspx (accessed on 3 May 2020).
58. Rege, A. Not biting the dust: Using a tripartite model of organized crime to examine India's Sand Mafia. *Int. J. Comp. Appl. Crim. Justice* **2016**, *40*, 101–121. [CrossRef]
59. Elavenil, S.; Jenila Livingston, L.M.; Parameswari, K. Case study on illegal sand mining in Tamil Nadu: Alternate solution by replacing natural sand by M-sand. *Int. J. Mech. Prod. Eng. Res. Dev.* **2017**, *7*, 279–284. [CrossRef]
60. Lange, V. Illegal Sand Mining Leaves Zimbabwe Potholed. 2011. Available online: https://www.dw.com/en/illegal-sand-mining-leaves-zimbabwe-potholed/a-14879433 (accessed on 3 May 2020).
61. Rochayati, N.; Herianto, A.; Johari, H.I. Community understanding and attitude levels on the implementation of illegal sand mining on the Induk Beach, West Lombok. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *413*, 012035. [CrossRef]
62. Madyise, T. Case Studies of Environmental Impacts of Sand Mining and Gravel Extraction for Urban Development in Gaborone. Master's Thesis, University of South Africa, Pretoria, South Africa, 2013.
63. Adu-Gyamfi, F. The Environmental Degradation Resulting from Illegal Sand Mining in Port St. Johns East. Cape. The Portfolio -Research Proposal (HMENV80 –773080). 2016. Available online: https://www.researchgate.net/publication/291335557_ENVIRONMENTAL_DEGRADATION_RESULTING_FROM_ILLEGAL_SAND_MINING (accessed on 3 May 2020).
64. Bravard, J.P.; Goichot, M.; Gaillot, S. Geography of sand and gravel mining in the Lower Mekong River: First survey and assessment. *EchoGéo* **2013**, *26*, 2–18. [CrossRef]
65. Podimata, M.V.; Yannopoulos, P.C. A conceptual approach to model sand–gravel extraction from rivers based on a game theory perspective. *J. Environ. Plan. Manag.* **2015**, *59*, 120–141. [CrossRef]
66. Muthomi, S.; Okoth, P.; Were, E.; Vundi, S. An Examination of the Nature of Sand Harvesting Conflicts and Their In-fluence on Poverty Alleviation Initiatives in Makueni County, Kenya. *J. Educ. Pract.* **2015**, *6*, 28–36.
67. EJAtlas. Sand Mining and Related Violence in Makueni County, Kenya. 2018. Available online: https://ejatlas.org/conflict/sand-mining-and-the-sand-related-violence-in-makueni-county-kenya (accessed on 3 May 2020).
68. UN Environment (UNEP). Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources, GRID-Geneva, United Nations Environment Programme, Geneva, Switzerland, 2019b. Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/28163/SandSust.pdf?sequence=1&isAllowed= (accessed on 4 May 2020).
69. Pearce, F. The Hidden Environmental Toll of Mining the World's Sand, Yale Environment 360. 2019. Available online: https://e360.yale.edu/features/the-hidden-environmental-toll-of-mining-the-worlds-sand (accessed on 3 May 2020).
70. WWF. Uncovering Sand Mining's Impacts on the World's Rivers. 2018. Available online: https://wwf.panda.org/our_work/water/freshwater_news/?333451/Uncovering-sand-minings-impacts-on-the-worlds-rivers (accessed on 3 May 2020).
71. Young, R.; Griffith, A. Documenting the Global Impacts of Beach Sand Mining. Geophysical Research Abstracts, v. 11, GU 2009-11593, EGU General Assembly. 2009. Available online: https://ui.adsabs.harvard.edu/abs/2009EGUGA..1111593Y/abstract (accessed on 3 May 2020).
72. Ambak, M.A.; Isa, M.M.; Zakaria, M.Z.; Ghaffar, M.A. *Fishes of Malaysia*; Universiti Malaysia Terengganu: Kuala Terengganu, Malaysia, 2010.
73. Yen, T.P.; Rohasliney, H. Status of Water Quality Subject to Sand Mining in the Kelantan River, Kelantan. *Trop. Life Sci. Res.* **2013**, *24*, 19–34.
74. Dugan, P.J.; Barlow, C.; Agostinho, A.A.; Baran, E.; Cada, G.F.; Chen, D.; Cowx, I.G.; Ferguson, J.W.; Jutagate, T.; Mallen-Cooper, M.; et al. Fish Migration, Dams, and Loss of Ecosystem Services in the Mekong Basin. *Ambio* **2010**, *39*, 344–348. [CrossRef] [PubMed]
75. Haghnazar, H.; Saneie, M. Impacts of pit distance and location on river sand mining management. *Model. Earth Syst. Environ.* **2019**, *5*, 1463–1472. [CrossRef]
76. Freedman, J.A.; Carline, R.F.; Stauffer, J.R., Jr. Gravel dredging alters diversity and structure of riverine fish assemblages. *Freshwater Biol.* **2013**, *58*, 261–274. [CrossRef]
77. Paukert, C.; Schloesser, J.; Fischer, J.; Eitzmann, J.; Pitts, K.; Thornbrugh, D.; Bouska, K. Effect of Instream Sand Dredging on Fish Communities in the Kansas River USA: Current and Historical Perspectives. *J. Freshw. Ecol.* **2008**, *23*, 623–633. [CrossRef]
78. Koehnken, L.; Rintoul, M. Impacts of Sand Mining on Ecosystem Structure, Process and Biodiversity in Rivers, WWF Review. 2018. Available online: https://d2ouvy59p0dg6k.cloudfront.net/downloads/sand_mining_impacts_on_world_rivers__final_.pdf (accessed on 20 June 2020).
79. Kondolf, G.M. Geomorphic and environmental effects of instream gravel mining. *Landsc. Urban Plan.* **1994**, *28*, 225–243. [CrossRef]
80. Harvey, B.C.; Lisle, T.E. Effects of Suction Dredging on Streams: A Review and an Evaluation Strategy. *Fish. Habitat* **1998**, *23*, 8–17. [CrossRef]

81. Kanehl, P.; Lyons, J. *Research Report 155: Impacts of In-Stream Sand and Gravel Mining on Stream Habitat and Fish Communities, Including a Survey on the Big Rib River*; Wisconsin Department of Natural Resources: Madison, WI, USA, 1992.
82. Boers, M. Effects of a Deep Sand Extraction Pit. Final Report of the PUTMOR Measurements at the Lowered Dump Site, Rijkswaterstaat. 2005. Available online: https://repository.tudelft.nl/islandora/object/uuid%3A3e60f497-ced3-4dab-8d90-8f8c549e11e1 (accessed on 3 May 2020).
83. Pitchaiah, P.S. Impacts of Sand Mining on Environment—A Review. *SSRG Int. J. Geoinform. Geol. Sci.* **2017**, *4*, 1–5.
84. Kondolf, G.M.; Piégay, H.; Landon, N. Changes in the riparian zone of the lower Eygues River, France, since 1830. *Landsc. Ecol.* **2007**, *22*, 367–384. [CrossRef]
85. Galay, V.J. Causes of river bed degradation. *Water Resour. Res.* **1983**, *19*, 1057–1090. [CrossRef]
86. Jia, L.; Luo, Z.; Yang, Q.; Ou, S.; Lei, Y. Impacts of the large amount of sand mining on riverbed morphology and tidal dynamics in lower reaches and delta of the Dongjiang River. *J. Geogr. Sci.* **2007**, *17*, 197–211. [CrossRef]
87. Jordan, C.; Tiede, J.; Lojek, O.; Visscher, J.; Apel, H.; Nguyen, H.Q.; Quang, C.N.X.; Schlurmann, T. Sand mining in the Mekong Delta revisited—Current scales of local sediment deficits. *Sci. Rep.* **2019**, *9*, 1–14. [CrossRef]
88. Hossein, F.; Shadi, B. Modeling the assessment of socio-economical and environmental impacts of sand mining on local communities: A case study of Villages Tatao River Bank in North-western part of Iran. *Resour. Policy* **2018**, *55*, 87–95.
89. Brown, A.V.; Lyttle, M.M.; Brown, K.B. Impacts of Gravel Mining on Gravel Bed Streams. *Trans. Am. Fish. Soc.* **1998**, *127*, 979–994. [CrossRef]
90. Khaleghi, S.; Surian, N. Channel Adjustments in Iranian Rivers: A Review. *Water* **2019**, *11*, 672. [CrossRef]
91. Kondolf, G. PROFILE: Hungry Water: Effects of Dams and Gravel Mining on River Channels. *Environ. Manag.* **1997**, *21*, 533–551. [CrossRef]
92. Isik, S.; Dogan, E.; Kalin, L.; Sasal, M.; Agiralioglu, N. Effects of antrhopogenic activities on the Lower Sakarya River. *Catena* **2008**, *75*, 172–181. [CrossRef]
93. Lusiagustin, V.; Kusratmoko, E. Impact of Sand Mining Activities on the Environmental Condition of the Komering River, South Sumatera. *Int. Symp. Curr. Prog. Math. Sci.* **2016**, *1862*, 30–198.
94. Ashraf, M.A.; Maah, M.J.; Yusoff, I.; Wajid, A.; Mahmood, K. Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia. *Sci. Res. Essays* **2011**, *6*, 1216–1231.
95. Padmalal, D.; Maya, K.; Sreebha, S.; Sreeja, R. Environmental effects of river sand mining: A case from the river catchments of Vembanad lake, Southwest coast of India. *Environ. Earth Sci.* **2008**, *54*, 879–889. [CrossRef]
96. Ghose, M.; Majee, S. Sources of air pollution due to coal mining and their impacts in Jharia coalfield. *Environ. Int.* **2000**, *26*, 81–85. [CrossRef]
97. Mkpuma, R.O.; Okeke, O.C.; Abraham, W.M. Environmental Problems of Surface and Underground Mining: A review. *Int. J. Eng. Sci.* **2015**, *4*, 12–20.
98. Montoya, J.M.; Pimm, S.L.; Solé, R.V. Ecological networks and their fragility. *Nat. Cell Biol.* **2006**, *442*, 259–264. [CrossRef] [PubMed]
99. Levrel, H.; Pioch, S.; Spieler, R. Compensatory mitigation in marine ecosystems: Which indicators for assessing the "no net loss" goal of ecosystem services and ecological functions? *Mar. Policy* **2012**, *36*, 1202–1210. [CrossRef]
100. Polasky, S. What's Nature Done for You Lately: Measuring the Value of Ecosystem Services. *Choices* **2008**, *23*, 42–46.
101. Silvertown, J. Have Ecosystem Services Been Oversold? *Trends Ecol. Evol.* **2015**, *30*, 641–648. [CrossRef]
102. IPCC. *The 5th Assessment Report*; IPC: Geneva, Switzerland, 2014.
103. Robbie, A. Global CO2 Emissions from Cement Production. *Earth Syst. Sci. Data Discuss.* **2017**, 1–52. Available online: https://www.earth-syst-sci-data.net/10/195/2018/ (accessed on 3 May 2020).
104. Sankh, A.; Biradar, P.; Naghathan, S.; Ishwargol, M. Recent Trends in Replacement of Natural Sand with Different Alter-Natives. 2014. Available online: https://pdfs.semanticscholar.org/8d30/26acf58f84fbcaa69794ee3ba87f097616c0.pdf?_ga=2.266035143.995349164.1588623249-1177513750.1574152845 (accessed on 4 May 2020).
105. LaFarge Sand Alternatives for Sustainable Construction. 2019. Available online: https://lafargeholcim.co.tz/sand-alternatives-for-sustainable-construction/ (accessed on 21 June 2019).
106. UNESCO. COVID-19 Disruptions in Ocean Observations Could Threaten Weather Forecast and Climate Change Predictions. 2020. Available online: https://en.unesco.org/news/covid-19-disruptions-ocean-observations-could-threaten-weather-forecast-and-climate-change (accessed on 9 June 2020).