WWF

REVIEW

2018

IMPACTS OF SAND MINING ON ECOSYSTEM STRUCTURE, PROCESS & BIODIVERSITY IN RIVERS

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WWF is one of the world's largest and most experienced independent conservation organizations, with over 5 million supporters and a global Network active in more than 100 countries.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by: conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

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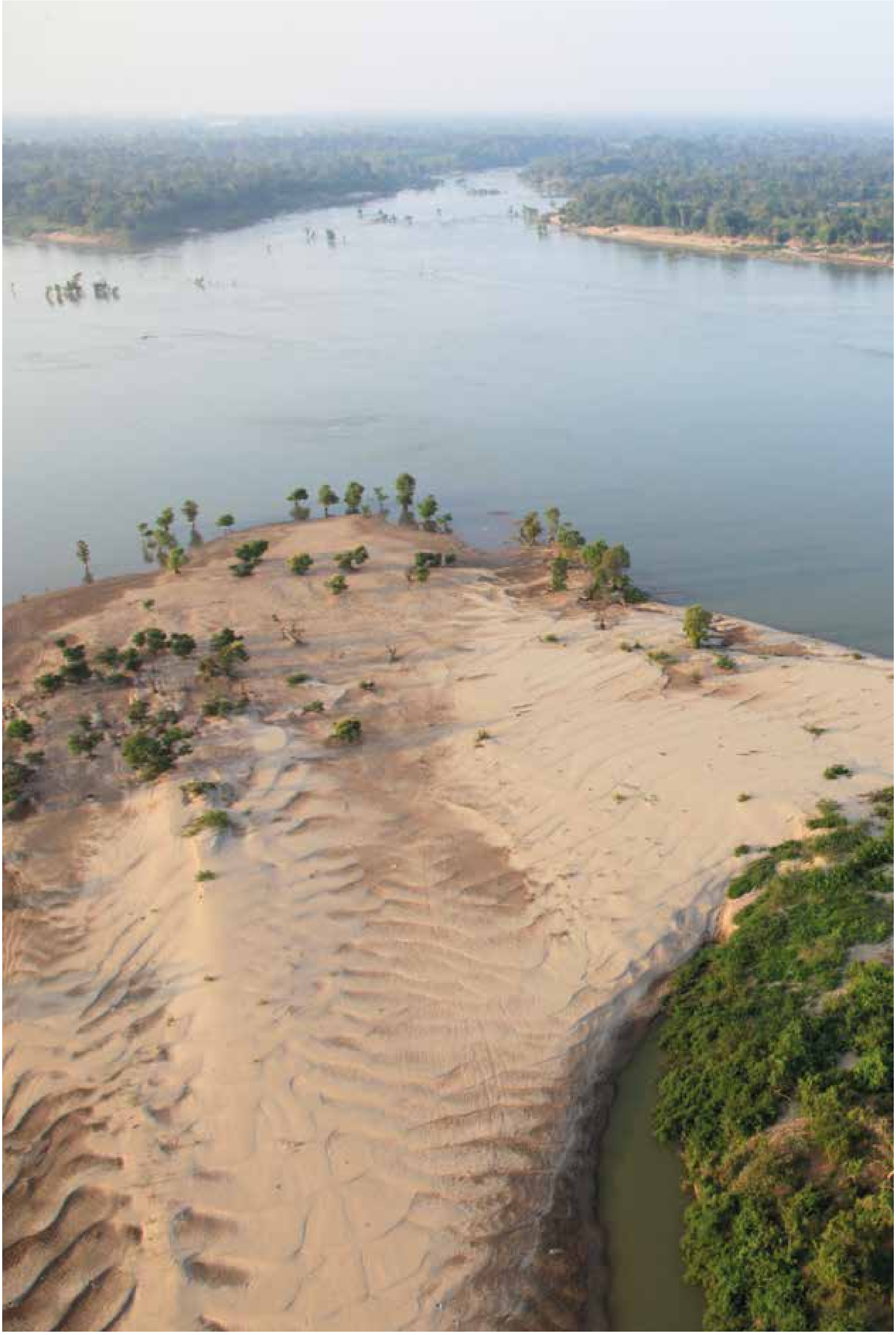

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EXECUTIVE SUMMARY

WWF is a solution-oriented advocate of clean flowing rivers that believes that by better understanding and communicating the impacts of sand mining – aggregate extraction encompasses sand, gravel, pebbles or cobbles, but is collectively referred to as sand mining – on rivers, the organisation can influence key decision-makers to ensure that extraction is done sustainably. To do this, a strong evidence base for past, current and potential impacts of sand mining on rivers and their ecosystems is required.

This report aims to provide an authoritative review and summary of the available scientific literature associated with sand mining impacts, a context for this information with respect to global sources, demands and trends, and an understanding of what the estimated present status and perceived associated impacts of sand mining are on a global scale.

Two evidence-based research approaches have been used in this review. A Quick Scoping Review (QSR) was used to survey the scientific literature describing the impact of sand mining on ecosystems. This highly structured objective approach involved reviewing papers obtained by searching scientific databases using terms relevant to the question 'What evidence is there of impacts of aggregate mining on ecosystem structure, process and biodiversity in rivers, floodplains and estuaries'. All papers that were relevant to the central question were categorised by geographic location, system type, inference method, type of mining, scale of mining, end use of mined product, geomorphic impacts, social impacts and presence and interaction with other stressors.

The other parts of this review consisted of a web-based literature review that included media articles, government reports and websites. Investigated topics included the trends in sand use and availability, expected future trends, regulation and governance, and the prevalence of sand mining activities not captured in the scientific literature, including illegal activities. Many of the views and conclusions of these pieces are opinions and inferences, as hard facts are in short supply. Potential avenues for future research, community engagement and communication are provided.

Sand and gravel are used in a wide range of applications, but of reported uses, the vast majority is consumed in construction materials such as cement. Global demand has increased rapidly over the past two decades and has largely been driven by growth in the Asia Pacific region, particularly in China. China is the largest cement producer in the world, accounting for 58% of global production. It is predicted that the per capita consumption of concrete in China may decrease, but demand in other developing countries is also rapidly increasing. India is projected to surpass China in population within the next five to ten years and the combination of this population growth and increased urbanisation could quadruple its demand for concrete and aggregate if it follows a similar trajectory to China. The demand for aggregates in other developing nations in Asia and Africa is also expected to increase dramatically in the coming years.

INTEGRATING THE QUICK SCOPING REVIEW RESULTS WITH THE HIGH AND INCREASING DEMAND FOR AGGREGATE IN DEVELOPING COUNTRIES STRONGLY SUGGESTS THAT THIS DEMAND CANNOT BE MET ON A SUSTAINABLE BASIS FROM RIVERS.

In addition to construction, land reclamation is a major use of sand and aggregate, with Singapore being the world's largest importer. Neighbouring nations have officially banned the export of sand, but a thriving illegal trade is reported in the mainstream media

The QSR analysis showed that most investigations into the impact of sand mining on ecosystems has been completed in temperate rivers in western countries where sand mining occurred historically, but has since ceased. These countries now have strict regulations governing the extraction of aggregate, and there is little active in-stream mining occurring. The scientific studies overwhelmingly identified channel incision as the most common physical impact, but beyond that, the physical responses of rivers differed depending on the characteristics of the river (underlying material, slope, catchment land use, etc.). Collectively the QSR papers highlight the decadal time-frames over which rivers respond and recover from sand mining disturbances, and the importance of land use in determining river response.

The QSR papers report ecological impacts associated with sand mining including the direct disturbance and removal of habitats in rivers, deltas and coastal areas, loss or changes to the vegetation structure of riparian zones, and increased or decreased downstream sedimentation affecting habitat quality. Sand mining was found to interfere with a number of ecological processes, such as macroinvertebrate drift, fish movements, abundance and community structures, and food web dynamics. The studies often inferred impacts on populations, such as loss of native species and increases in invasive alien species, but few had long-term data sets to confirm this. There is limited evidence that rivers can sustain sand extraction if the extracted volumes are within the natural variability of the sediment load of the system, based on one year of extractions, but no studies have demonstrated the sustainability of sustained extractions over prolonged time frames.

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A significant finding of the QSR is that the countries and rivers for which there is science-based evidence related to the impacts of sand mining are not the countries that are rapidly developing and where extensive illegal sand mining is reported by the media. The lack of scientific and systematic studies of sand mining in these rapidly developing countries prevents accurate quantification of the volumes of material being mined, or the type, extent and magnitude of impacts. An estimate of potential impacts can only be made by inferring that results from studies elsewhere can be applied to locations without direct evidence.

Integrating the QSR results with the high and increasing demand for aggregate in developing countries strongly suggests that this demand cannot be met on a sustainable basis from rivers.

In most countries, sand mining is officially regulated through national mining and environmental protection legislation, with authority for regulation devolved to the State or District level. Legislation is frequently accompanied by non-binding guidelines to improve the sustainability of the activity. This governance structure results in many small administrative entities having responsibility for implementing and enforcing these regulations, hampering management at the catchment level. The lack of enforcement of regulations is a common issue identified by the mainstream media.

Options for reducing the construction industry's dependence on sand mining identified through a literature review, included recycling concrete, fixing rather than replacing concrete, researching the suitability of waste materials as aggregate substitutes, and developing new construction materials and design approaches.

In contrast to the relatively low number of scientific studies dedicated to impacts associated with sand mining, there is an abundance of media articles highlighting the growing demand yet dwindling availability of sand in developing countries. The illegal extraction of river and coastal sand is reported to occur in as many as 70 countries, often with the support of complicit governments. The social impacts of the illegal trade are also widely reported, with violence commonly reported against protestors or those who attempt to report illegal activities. Media reports highlight that impoverished communities engage in the illegal trade as it provides a higher income than other activities, even though they perceive that sand extraction is destroying the rivers on which they depend for their livelihoods.

The conclusions of the review include:

- Developed countries with good governance do not in general use rivers as a source of aggregate. In these countries demand is met with terrestrial pits and a growing reliance on marine resources. There is growing social awareness of the impacts marine sand mining has on beaches and coastal ecosystems, and opposition to the activity is increasing;
- The extraction of sand from rivers in developing countries is reported by the press to be having severe and widespread impacts on rivers and coasts, but a lack of reliable information prevents scientific confirmation or quantification; and
- The demand for sand is increasing, and preventing or reducing likely damage to rivers will require the construction industry to be weaned-off river sourced aggregate, either through the substitution of materials or alterations to building designs and methods so that extraction is reduced to levels that are proven to be sustainable/have little negative ecological impact. This type of societal shift is similar to that required to address climate change, and will necessitate changes in the way that sand and rivers are perceived, and cities are designed and constructed.

RECOMMENDATIONS ARISING FROM THIS REVIEW INCLUDE:

- Increasing public awareness of the growing demand and finite supply of sand is critical to effecting change and is recommended. In the short term, public awareness can increase pressure on governments for stricter regulations and governance, including the identification of off stream sources of aggregate. In the longer-term, public awareness and acceptance will be required for any shift away from the present market system whereby sand underpins all development, yet is the cheapest of commodities;
- Research into economic incentives or certification schemes that could drive a reduction in the extraction of sand from rivers is recommended;
- Scientific research in rivers where in-stream sand mining is active is required to enhance understanding and quantification of impacts, identify management and remediation methods (if and where required) for rivers and underpin communication strategies. Recommendations for future research include quantifying the present situation in rivers where sand mining is occurring through the implementation of short-term ‘rapid’ assessments, in combination with longer term investigations to understand changes over the time-scales at which rivers and ecosystems respond to change. Rivers where sensitive or endangered species reside, and their habitat needs are known would provide good initial targets for research, and provide robust information for communication. Evidence of where economically valuable species are being lost would provide information on economic trade-offs. The severe lack of information regarding rivers in developing countries must rapidly be addressed.

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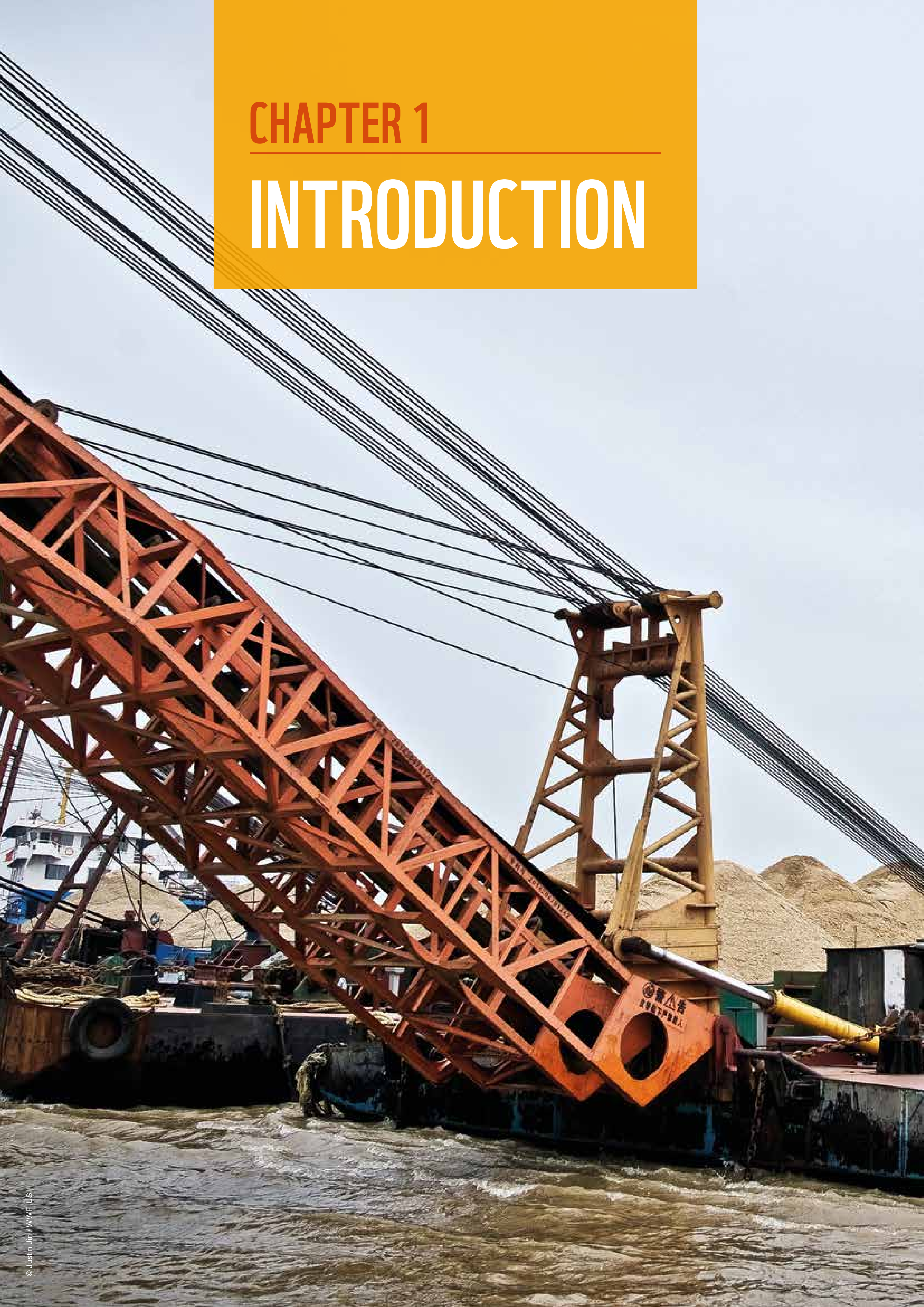
Acronyms

ACAI	Area of Collective Action and Innovation within WWF
BRI	Belt Road Initiative, China
CNY	Chinese Yuan Renminbi (currency unit)
DID	Department of Irrigation and Drainage, Malaysia
DMR	Department of Mineral Resources, South Africa
EECCA	Europe, Eastern Europe, Caucasus and Central Asia
EIA	Environmental Impact Assessment
EU	European Union
FSC	Forest Stewardship Council
GIS	Geographical Information System
GDP	Gross Domestic Product
HEC-RAS	Hydrologic Engineering Center River Analysis System
IUCN	International Union for Conservation of Nature
MA	Marine Aggregate
MoEFCC	Ministry of Environment, Forests and Climate Change (MoEFCC), India
MME	Ministry of Mines and Energy, Cambodia
MRC	Mekong River Commission
MRLSD	Mountain River Lake Regional Sustainable Development, Global Nature Fund
PET	Polyethylene terephthalate plastic
PICO	QSR elements Population, Intervention, Comparator, Outcome
QSR	Quick Scoping Review
SCOPUS	Abstract and citation database of peer-reviewed scientific literature
SMARA	Surface Mining and Reclamatio Act of 1975 (USA)
WoS	Citation database of peer-reviewed scientific literature
UNEP	United Nations Environment Programme
USD	United States dollar
USGS	United States Geological Surve

CHAPTER 1

INTRODUCTION



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1 Introduction

Mineral aggregates are the most mined material in the world, with extraction sites located near virtually every city and town. In a summary compiled by UNEP (2014) it is estimated that between 32 and 50 billion tonnes of aggregate (sand and gravel) are extracted globally each year (Steinberger et al., 2010). Sand and gravel have underpinned the construction industry since Roman times, and are the materials upon which the buildings, roads, and infrastructure in all cities are based. It is also the material of choice for land reclamation. Due to the presently widespread availability of aggregate deposits, and the inexpensive methods required for extraction, transport is typically the limiting 'cost' for use, thus requiring a large number of sources located close to markets.

Rivers are a preferred source of sand and gravel for a number of reasons: cities tend to be located near rivers so transport costs are low, the energy in a river grinds rocks into gravels and sands, thus eliminating the costly step of mining, grinding, and sorting rock, and the material produced by rivers tends to consist of resilient minerals of angular shape that are preferred for construction. Deposits of river sand also offer the advantages of being naturally sorted by grain-size, easily accessible, and able to be transported inexpensively using barges. Despite plentiful supplies of desert sand, these are generated by aeolian processes, which produce materials unsuitable for making concrete.

The benefits of this inexpensive river derived resource are evident, but the present market cost of aggregate is unlikely to reflect the environmental and social price of the commodity. The term 'unlikely' is used because there is a lack of definitive scientific investigations that quantify the link between aggregate extraction from river systems and ecological impacts.

This report aims to provide an authoritative review and summary of the available scientific literature associated with sand mining impacts, and to provide a context for this information with respect to global sources, demands and trends.

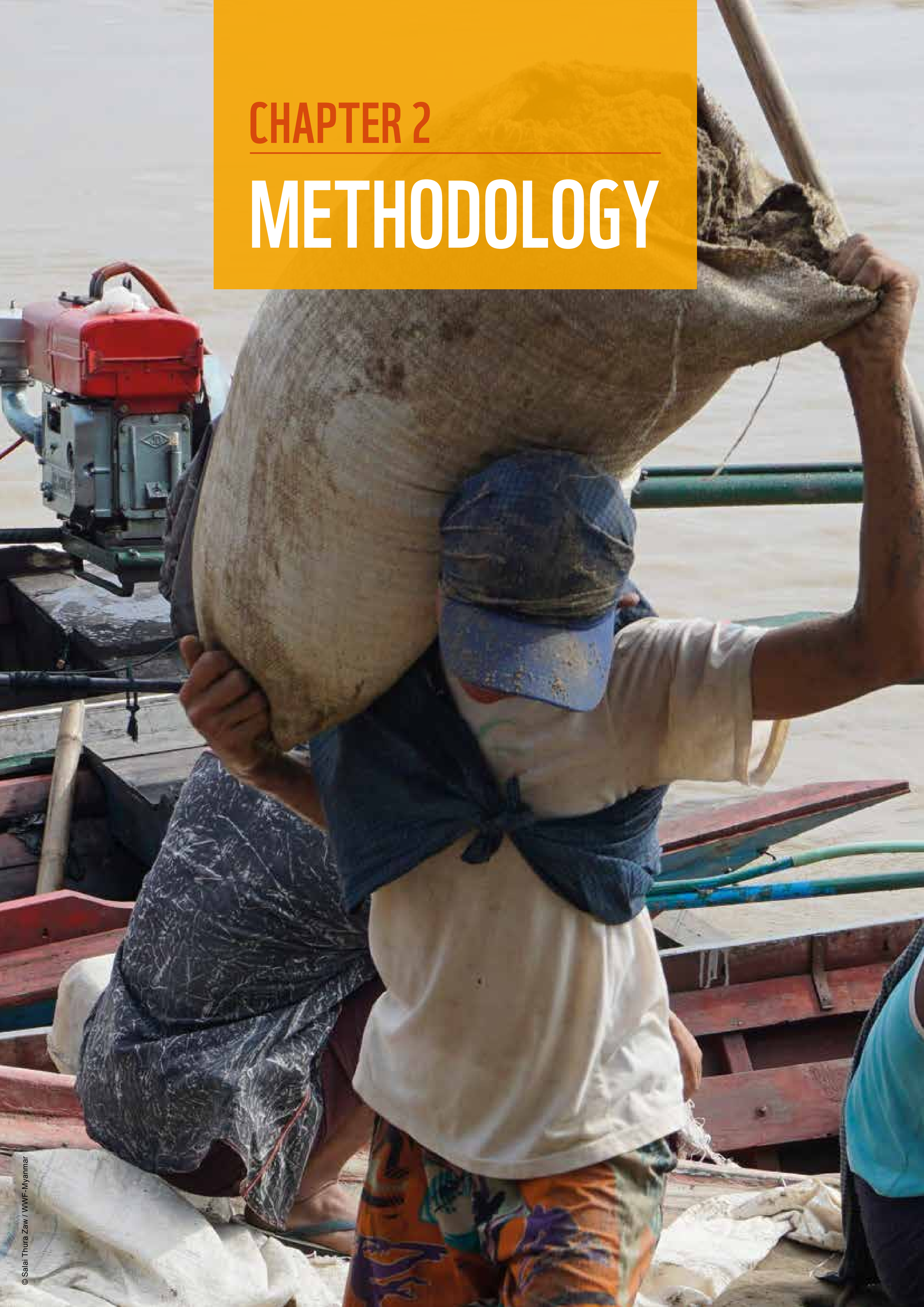
The main emphasis of this report is on aggregate extraction from rivers, which encompasses sand, gravel, pebbles or cobbles, but is collectively referred to as sand mining. Rivers includes all riverine components: channels, banks and floodplains. The review of ecological impacts has focussed on river systems, however, other information garnered from the investigation has been included where relevant even though it may be associated with sand extraction from coastal areas. Similarly, information that does not distinguish river derived sand from terrestrial sources is included where relevant to provide the large -scale context of the aggregate industry, such as in regional trends or international trade.

The report is structured to provide a description of the methods used in the investigations (Chapter 2) followed by an overview of aggregate and sand use on a global scale, patterns of trade and future trends (Chapter 3). Chapter 4 provides a brief overview of rivers, describing sediment transport processes and how these are altered by sand mining and other activities. The main body of the report, Chapter 5, summarises the findings of the QSR. The results are presented and interpreted by a range of criteria (e.g. geographic location, types of mining, sand use, etc.), impacts (geomorphological, ecological, social) and other stressors (land use, damming, flood control). Chapter 6 presents an overview of regulation and governance in different countries, and Chapter 7 discusses potential management and mitigation options. Based on the information reviewed, challenges are identified and recommendations for future research are presented (Chapter 7).

The final section of this report includes four case studies that highlight different components of the findings and issues identified by this investigation. They are provided as examples that could be used to communicate the present status and challenges associated with sand mining in the world today.

CHAPTER 2

METHODOLOGY



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2 Methodology

2.1 QSR approach for central question

It is imperative that WWF, other organisations and decision makers formulate policy based on the best and most rigorous scientific information available. It is equally important that the available scientific information is surveyed, analysed and presented in as quantitative and transparent a manner as possible, that is, without bias regarding the types, severity, or extent of ecosystem impacts associated with aggregate mining. To ensure a methodical, thorough and defensible approach to the investigation a structured Quick Scoping Review (QSR, Collins, et al., 2015) methodology was adopted. A QSR "aims to provide an informed conclusion on the volume and characteristics of an evidence base and a synthesis of what that evidence indicates in relation to a question" (Collins, et al., 2015). The time and effort required to complete a QSR exceeds that of a generic literature review but is not as extensive or as detailed as a Rapid Evidence Assessment or a Full Systematic Review, although a QSR can serve as the basis for these more in-depth investigations (Collins, et al., 2015). The QSR level of review is considered suitable for this first step of assisting stakeholders to better understand the issues associated with sand mining.

The QSR process focuses on a question that is refined through the identification of the relevant Population, Intervention, Control, and Outcome elements relevant to the topic. These components are collectively referred to as the PICO elements. In the case of the sand mining QSR, these elements have been identified through the development and use of a conceptual model, based on the linkages between sand mining activities and potential direct and indirect impacts on ecosystems. These relationships are shown schematically in Figure 2.1.

Conceptually, sand mining has the potential to alter river ecosystems through direct and indirect impacts. Direct impacts are those in which the extraction of material is directly responsible for the impact to the ecosystem, such as due to the loss of floodplain areas or removal of gravel, cobble or other habitat that is recognised as underpinning a specific ecosystem processes (e.g. the removal of gravel beds that are recognised as important fish spawning areas). Indirect impacts are related to ecosystem changes that are promoted due to physical changes in the river system resulting from sand extraction. The removal of material from a river channel can alter river hydraulics due to changes in the depth, width or slope of a river, which in turn can alter ecosystem processes. These types of impacts can be more difficult to directly link to sand mining, as other interventions can result in similar changes. An example is where the implementation of dams has reduced sediment delivery and increased dry season flows to a river segment that is also experiencing sand mining. The river channel will physically respond similarly to all of these pressures (increased flow, reduced sediment input, sediment extraction) so isolating the impact of sand mining from the combined impact of all activities may not be possible.

The situation is further complicated by the existence of thresholds in many river systems. Changes associated with a range of activities may result in limited change for an extended period, but once a threshold is reached change may become rapid and irreversible i.e. a tipping-point will have been crossed. A relevant example of this is the reduction in sediment within a river reach leading to channel incision. At first this change may not affect water velocities or connectivity with floodplains as the channel responds to the new condition, but as the incision progresses and the river channel becomes steeper, water velocities will increase resulting in increased rates of incision. At some point, a threshold will be passed and a significantly higher flow rate will be required for water to reach channel full levels and enter the floodplain, even though there has been no step-change in the level or type of catchment activities.

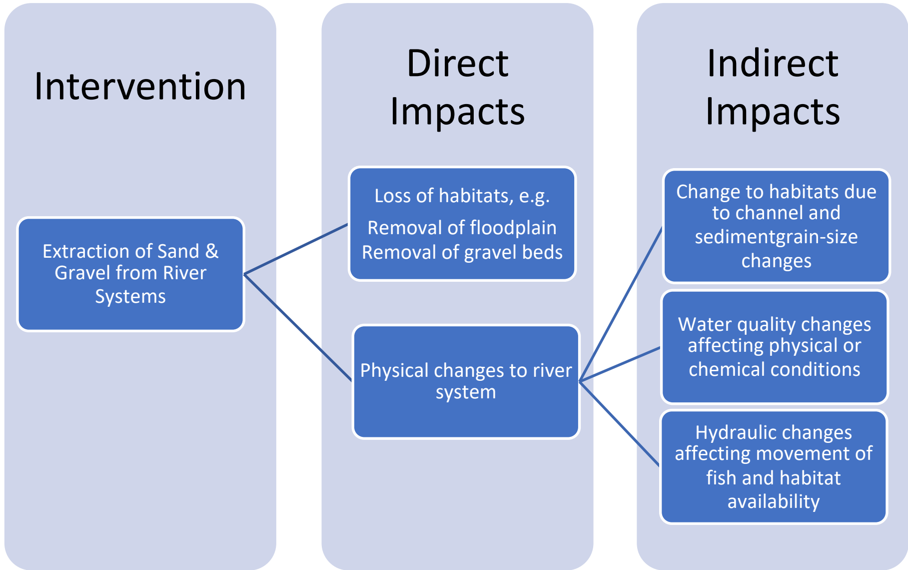

Figure 2.1. Schematic of the simple conceptual model used to define the QSR question and PICO elements. Direct and indirect impacts listed are provided as examples and are not an exhaustive list. See Section 4 for a more exhaustive discussion of potential changes.

The central question and PICO elements for the QSR were identified using the conceptual model as a guide, with a summary presented in Table 2.1.

Table 2.1. Summary of QSR question and PICO elements. After Collins, et al., (2015).

Question	**Evidence of the impacts of aggregate mining on ecosystem structure, process and biodiversity in rivers, floodplains and estuaries**
Population	All rivers and estuaries of the world documented in papers and reports available on the Web of Knowledge and SCOPUS written in English
Intervention	Removal of large quantities of sand or gravel
Comparator	Pre- and post-extraction conditions at a site or reference condition and post-extraction condition
Outcome	Change in river, estuarine or floodplain ecosystem, either geomorphic or other aspects of the ecosystem

The term geomorphic is specifically included in the Outcome of the QSR to include cases where physical channel changes have been documented but direct or indirect impact on biotic aspects of the ecosystem have not.

Papers for the QSR were obtained using a variety of search terms from the Scopus and Web of Science (WoS) databases (Table 2-2). Search results were included or excluded depending on whether they fulfilled the requirements outlined in Table 3. The search was also restricted to papers since 1992, reflecting a time period of 25-years. Results that fulfilled the inclusion criteria were subsequently categorized in a spreadsheet by their publication date, geographical location, type of system considered, the study method, the inference method, type of extraction, scale of extraction, use of extracted aggregate, presence of other stressors, the comparator employed, and the physical, biological, and political impacts on the system. The spreadsheet is attached in Annex 1 and could serve as the starting point for development of a database, or a more rigorous evidenced based review.

Some papers fulfilled the inclusion criteria but could not be accessed and so were not reviewed. The level of access to the literature during the review was equivalent to that available in a typical university setting, with access to established journals relevant to the topic (e.g. *Geomorphology*). The scientific databases were queried several times in December 2017 and January 2018, with the final dates for searching shown in Table 2-2.2. The final column in the Table indicates the number of additional papers included in the QSR for review. The decreasing numbers of identified papers with progressive search term groups reflects the identification and inclusion of relevant papers during previous searches. In total, 505 papers were reviewed with 62 papers ultimately included in the central QSR.

Table 2-2. QSR search terms and number of results

Final Search Date	Database	Search terms	Total no. of results	No. reviewed	No. of additional papers included for review
4/1/17	SCOPUS	aggregate mining river	142	142	34
	WoS	aggregate mining river	83	83	4
8/1/17	SCOPUS	gravel mining river	522	200	11
	SCOPUS	Ecology sand mining river	48	48	8
	SCOPUS	Ecology gravel mining river	27	27	5
	SCOPUS	Ecology aggregate mining river	5	5	0
Total			**827**	**505**	**62**

Table 2-3. Inclusion and exclusion criteria for the QSR.

Papers were included if they…	Papers were excluded if they…
Interpreted scientific findings regarding the impact of aggregate extraction on riverine systems, including floodplains and estuaries	Did not consider riverine, estuarine or lacustrine systems
Were in English	Did not discuss aggregate extraction
Published in the last 25 years	Were in a language other than English
	Were inaccessible, due to incorrect link, or paywall

Table 2-4. Summary of categories used to evaluate the QSR papers.

Category	Descriptor
Publication date	Date of publication of scientific paper
Geographical location	Location of river(s) investigated
Type of system	Riverine, estuarine, coastal
Study method	Type of investigation adopted for the scientific investigation, including: direct observation, comparison of present conditions with historical condition, comparison of historical data over a period of time, comparison of historical data or observations with modelling results, review of scientific literature
Inference method	How the study method was implemented. Generally a comparison of parameters or indicators, such as flow, sediment transport, morphology of river channel, changes to fish abundance or other indices, vegetation species and / or abundance, etc
Type of aggregate extraction	Describes the physical process used to extract the aggregate, including various types of dredging, bar scalping, re-routing the river, etc
Scale of aggregate extraction	Volume of material extracted, either annually or as a total volume, if specified.
Use of extracted aggregate	Final use of the extracted aggregate if specified, such as construction. Also indicated if extraction was for channel maintenance.
Presence of other stressors	List of other activities that could also affect geomorphology or ecosystem of river system being investigated. Included land use changes, reforestation, deforestation, urbanisation, in-channel works, etc
Comparator used in the study	The parameter or indicator used to identify change in the river system
Physical, biological or political impacts on the system	A description of the type of impact detected by the investigations

2.2 Non-QSR components

The QSR approach was adopted to systematically quantify the documented impacts of sand mining on river systems. A conventional literature review was completed to provide information related to the context and trends within the global sand mining industry. This includes information about regional sources, international trade and predicted future demand. A literature review approach was also adopted for the Case Studies, which reflect current environmental, social and political issues and draw upon the popular media as well as the scientific literature.

CHAPTER 3

THE AGGREGATE (SAND & GRAVEL) INDUSTRY (NON-QSR)

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3 The aggregate (sand and gravel) industry (non-QSR)

3.1 Uses of aggregate

Mineral aggregates have been used for a wide range of applications for millennia. UNEP (2014) estimates that up to 50 billion tonnes of aggragate is extracted annual, although the absence of global data on extraction makes quantification difficult. Up to 30 billion tonnes of this total is consumed in the construction industry in the production of concrete and asphalt, which is made up of 80% and 90% of sand, respectively (UNEP, 2014). Road bases are another major sand use, with 1km of highway requiring 30,000 tonnes of sand (Villioth, 2014). Land reclamation is another large-scale use of sand, with floodplains frequently targeted for reclamation using sand extracted from the neighbouring river (Figure 3.1). Land reclamation drives Singapore to be the world's largest importer of sand, with the country increasing its national area by over 20% between 1960 and 2017, with additional expansion planned for the future (Figure 3.2).

Figure 3.1.Progressive infilling of the floodplain of the Mekong River near Phnom Pehn. Google Earth images from (left) 2012 (centre) Feb 2013 (right) Nov 2013.

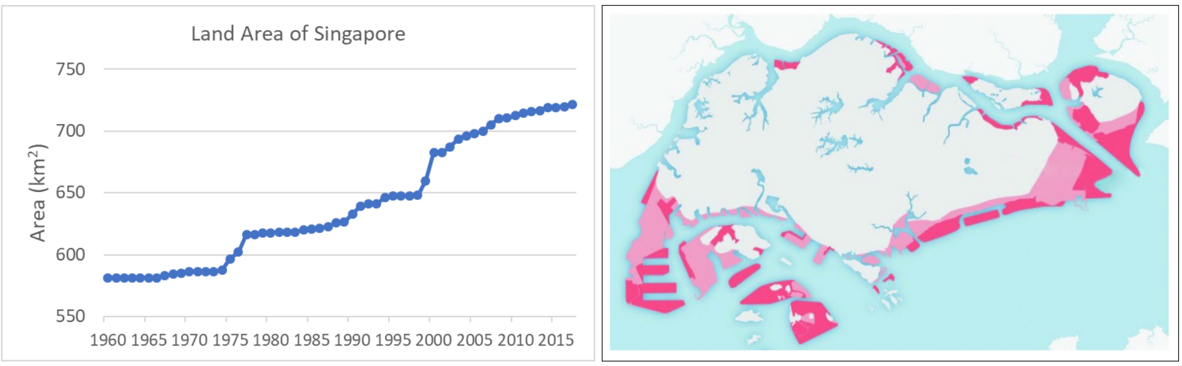


Figure 3.2. (left) Land area of Sinapore 1960 – 2018 (right) Pink areas show reclaimed land, red areas indicate potential future reclamation (Area data from Data.gov.sg; map from (Seng, 2017)

Many other applications require sand with specific characteristics or composition. A fast-growing component of the sand industry is frac sand used in the extraction of oil from shales. This sand is presently derived from land-based sand deposits of high silica content and specific size grains, but the increasing demand is driving the search for new sources. Sands with extremely high silica content (>99%) are used for the production of micro-chips and optical lenses. Although the quantities of sand used for these specialist applications are small, the environmental impacts associated with extraction can be substantial owing to the limited availability necessitating exploitation in potentially sensitive environments (see Section on WWF surveys). Water filtration is another industry dependent on sand with specific characteristics with respect to size, composition and sphericity. Other markets for small and specialised aggregate include golf courses, horse arenas and beach volleyball (Owen, 2017).

3.2 Sources of aggregate

Naturally sourced aggregates are found in both terrestrial and marine deposits (Gelabert, 1997). The 'source' and associated processes determine the characteristics of the aggregate, and the uses for which they are appropriate.

Terrestrial aggregates may occur within residual soil deposits; however, most suitable sources of aggregate are riverine deposits found within mountain and river valleys. Frequently these deposits are located within or adjacent to environmentally important areas making extraction undesirable (Kowalska & Sobczyk, 2014). Glacial materials are also a locally important source of aggregates in some high latitude regions. Materials rivers draining glaciers (fluvioglacial) can form locally large and well sorted deposits suitable for direct use or requiring minimal washing (Langer, 1993).

Offshore marine deposits are common, but there are many barriers to exploiting this resource. Extracting marine aggregates requires costly specialised equipment, and the resulting material must often be graded before use (Pereira, 2012). Furthermore, marine aggregates often contain chloride and shell fragments. Incorporating aggregates with chlorides into construction cement can increase the rate at which support structures corrode within reinforced concrete (Angst, et al., 2009), while shells are generally flat and sharp, decreasing the workability of the concrete (Yang, et al., 2009). Beach sands suffer from similar chemical and compositional constraints. In contrast, aggregates from terrestrial sand dunes suffer from the opposite problem, as they are primarily composed of well-rounded grains whose shape hampers their ability to bind together (Al-Harthy, et al., 2007).

The presence of organic material may also render aggregates unsuitable for use in concrete as substances such as fertilizers, seeds and organic matter can retard the concrete's set, cause discolouration and affect the concrete's hardness (PPC Ltd, 2016).

River aggregates are generally unaffected by these problems, and so are highly desirable for use in construction (Sing, et al., 2012). River deposits are generally easily accessible and may be extracted without the use of expensive equipment (Mingist & Gebremedhin, 2016). Furthermore, riverine aggregates are often well graded (Lusty, 2011), contain little organic matter, are of a suitable shape for use in concrete and do not contain chlorides or shells (Green Facts, 2017). As a result, aggregates obtained from rivers do not need not to be processed to the same degree as those obtained from other sources.

Aggregates can also be obtained by crushing quarried rock. The manufacture of crushed rock requires greater and more expensive processing as compared to sand extracted from rivers, and the mechanically produced aggregate is recognised as having poor shape for construction applications. The blending of crushed rock with other aggregate sources also increases the water demand and possibility of cracking when used to create cement (Lusty, 2011). Despite this, it is often used in areas where riverine deposits are not available.

Increasingly construction aggregates are being made artificially using a number of different methods and source materials. Methods vary as a function of material, but the process chain generally consists of mixing the source material with a binding agent, creating pellets of the required size and finalising the pellets, usually through sintering (Priyadharshini, et al., 2012). A range of waste materials can be used in this process; hence the creation of artificial aggregates may provide a sustainable alternative to natural aggregates (Daggubati & Nazneen, 2014). This topic is discussed in more detail in Section 7.3.

Limited information is available about the relative amount of aggregate derived from different sources or final uses. One example from the European Aggregates Association (Figure 3.3) shows that crushed and terrestrially derived pit-mined aggregate is the largest source of material in the EU, with manufactured, recycled or marine aggregates collectively contributing <10% of the total. Ninety percent of the aggregate is used in the production of concrete, asphalt or as structural material.

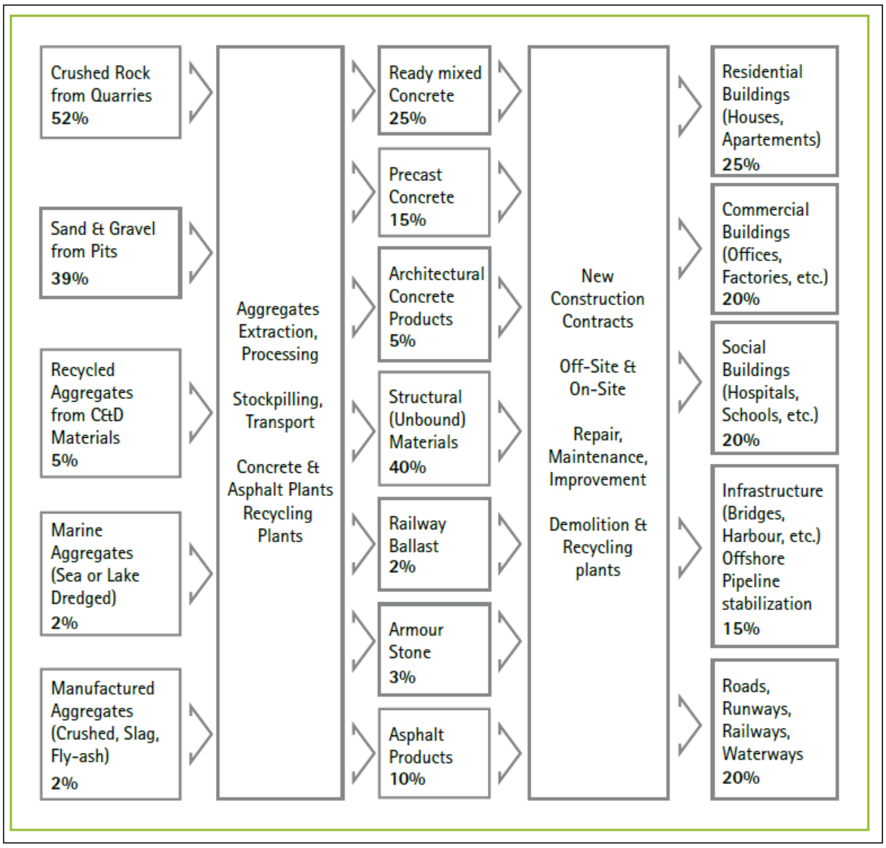


Figure 3.3. Distribution of sources and uses of aggregate in the European Union (EUPG, 2012)

3.3 Global usage of aggregates

Several recent studies have investigated global trends in material extraction and consumption in an effort to understand the resource requirements of modern societies. In these studies, materials have generally been classified as either biomass, fossil fuels, metallic ores, or non-metallic minerals (a category that includes aggregates). While the absolute amount and global share of each category varies between studies, all consistently list non-metallic m

inerals as the most extracted resource (e.g. Figure 3.4) and indicate that construction materials make up the vast majority of non-metallic minerals extracted (e.g. Figure 3.5).

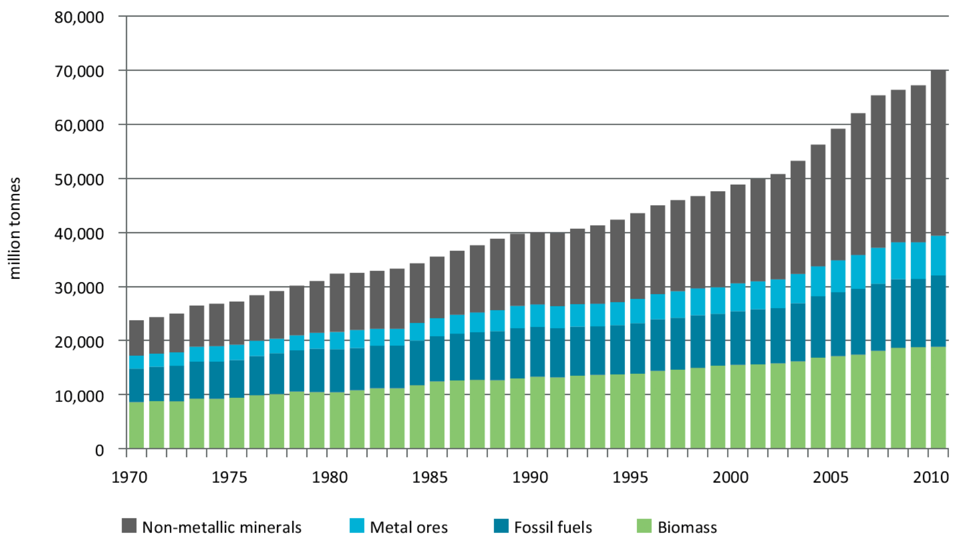


Figure 3.4: Global material extraction based on domestic extractions by four material categories, 1970-2010, million tonnes. Figure from UNEP (2016).

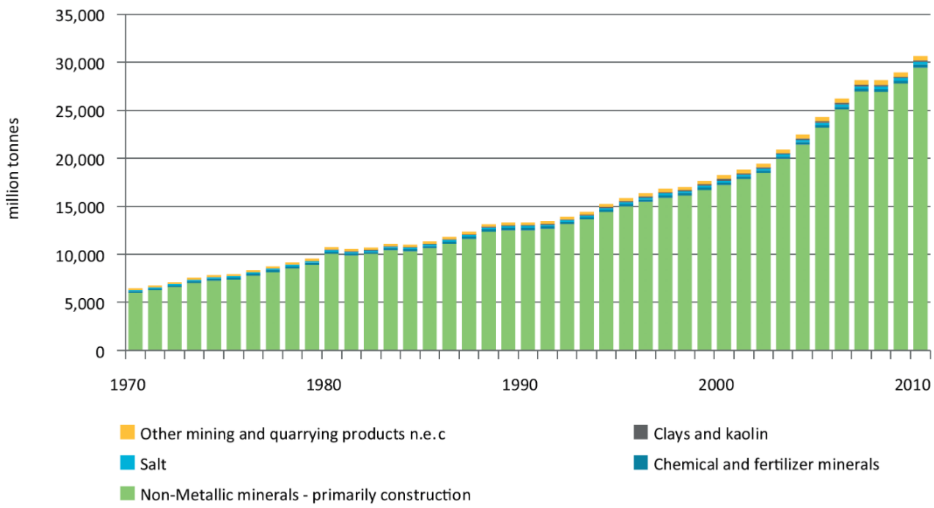


Figure 3.5. Global extraction based on domestic extractions of non-metallic minerals by material subcategories, 1970-2010 , million tonnes. Figure from UNEP (2016).

Miatto et al. (2016) were more specific and reported that sand and gravel (e.g. aggregates) made up 31.1% and 40.8% of all non-metallic minerals extracted in 2010 respectively (Figure 3.6). Within the construction industry, non-metallic minerals were primarily used for the construction of buildings and infrastructure (Figure 3.7).

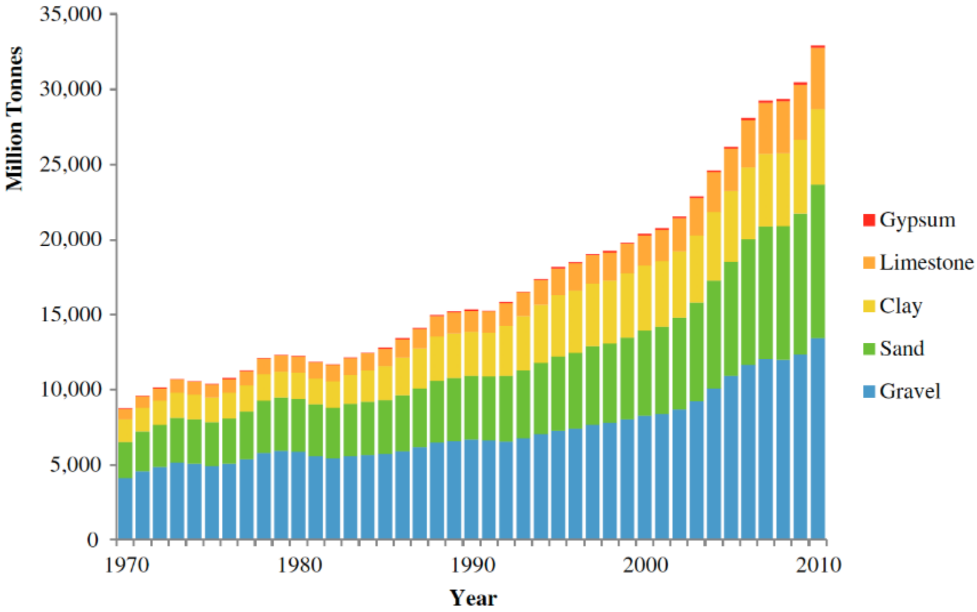


Figure 3.6. Global extraction of non-metallic minerals by type, 1970-2010, million tonnes. Figure from Miatto, et al. (2016).

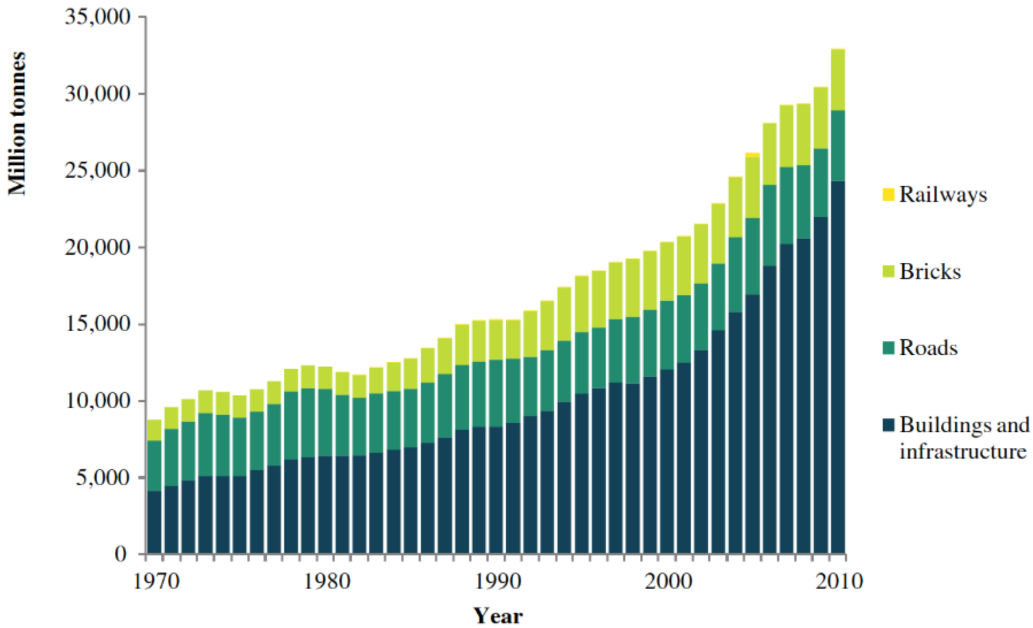


Figure 3.7. Global extraction non-metallic minerals by sector of use, 1970-2010, million tonnes . Figure from Miatto et al. (2016).

The quantity and relative proportions of different material categories changed dramatically in the period from 1970 to 2010. UNEP (2016) estimated that 23.7 billion tonnes of material were extracted globally in 1970, with this figure growing to approximately 70.1 billion tonnes by 2010 at a mean annual growth rate of around 2.7%. During this period, non-metal mineral extraction grew at a greater rate than any other category, with its share of global material extraction increasing from 27% to 47% over this period, far exceeding biomass (37% to 27%), fossil fuels (26% to 17%) and metal ores that remained fairly constant at approximately 10% (Figure 3.4).

Krausmann et al. (2009) reported a similar increase in globally consumed materials from approximately 27 billion tonnes to 60 billion tonnes between 1970 and 2005, with the share of non-metallic minerals increasing from 26% to 39% of the total over the same time span (Figure 3.8).This is in close agreement with the increases in both material amount extracted globally (23.7 to approximately 59 billion tonnes) and share of non-metallic minerals (27% to 41%) reported by UNEP (2016) over the same period. Krausmann et al. (2009) also reported rapid growth in the consumption of construction minerals over the time frame (Figure 3.9). A similar investigation by Schaffartzik et al. (2014) arrived at lower estimates of extration, although the authors acknowledged that their calculations likely underestimated the total volumes extracted by 15-20%.

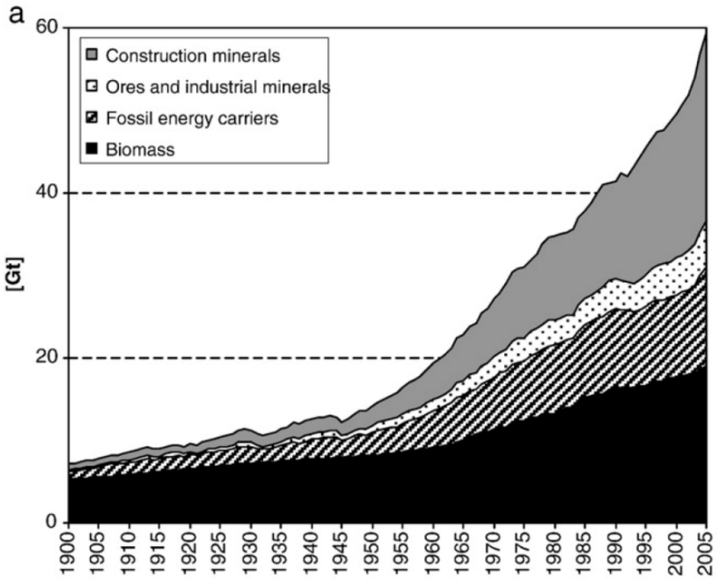


Figure 3.8. Total material use by material type from 1900 to 2005. Figure adapted from Krausmann et al, (2009).

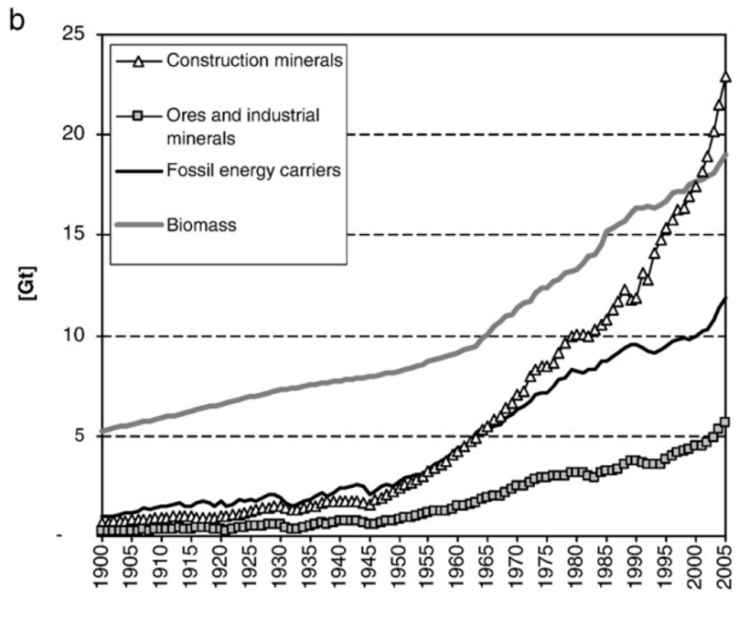


Figure 3.9. Total material usage by material type from 1900 to 2005. Figure adapted from Krausmann et al, (2009).

Miatto, et al. (2016) used a more sophisticated approach that incorporated specialised engineering knowledge as compared to the previously cited studies and arrived at substantially higher estimates of non-metallic mineral extraction as compared to the other studies (Figure 3.10). However, they also note that their calculations do not take into account that some construction activities use recycled concrete products, and so do not increase the demand for aggregates. While the use of recycled concrete in construction is widespread in some countries such as Japan (OECD, 2002) and the Netherlands (Fraaij, et al., 2002), these countries are the exception, and on a global scale this oversight is unlikely to have a significant effect.

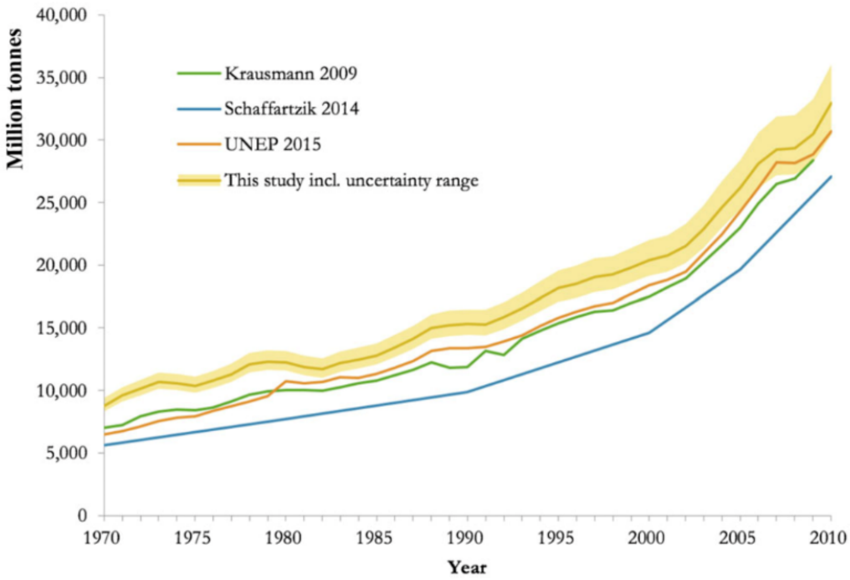


Figure 3.10. Comparison of global non-metallic mineral extraction reported in past studies. Figure adapted from Miatt, et al. (2016).

Despite the variations in findings due to differences in methodologies and source data, there are consistent findings across all of studies:

- Non-metallic ores constitute the largest volume of extracted material.
- The vast majority of non-metallic minerals are used in the construction industry.
- The pattern of extraction and use of non-metallic ores shows several stepped increases over the time-frames of the investigations. The first of these coincided with the end of the Second World War in the mid-1940s, with subsequent increases in the rate of extraction and use occurring around 1990 and 2000, respectively.
- The rate of non-metallic ore extraction is increasing at higher rates as compared to the other material groups.

3.4 Regional usage

The studies mentioned above divided the globe into regions for more detailed analysis – Africa; Asia and the Pacific; Eastern Europe Caucasus and Central Asia (EECCA); Europe; Latin America and the Caribbean; North America; and the Middle East (Figure 3.11). When the results are viewed in this manner, it becomes immediately obvious that the extreme growth in globally extracted materials is predominantly driven by growth in Asia and the Pacific (Figure 3.12).

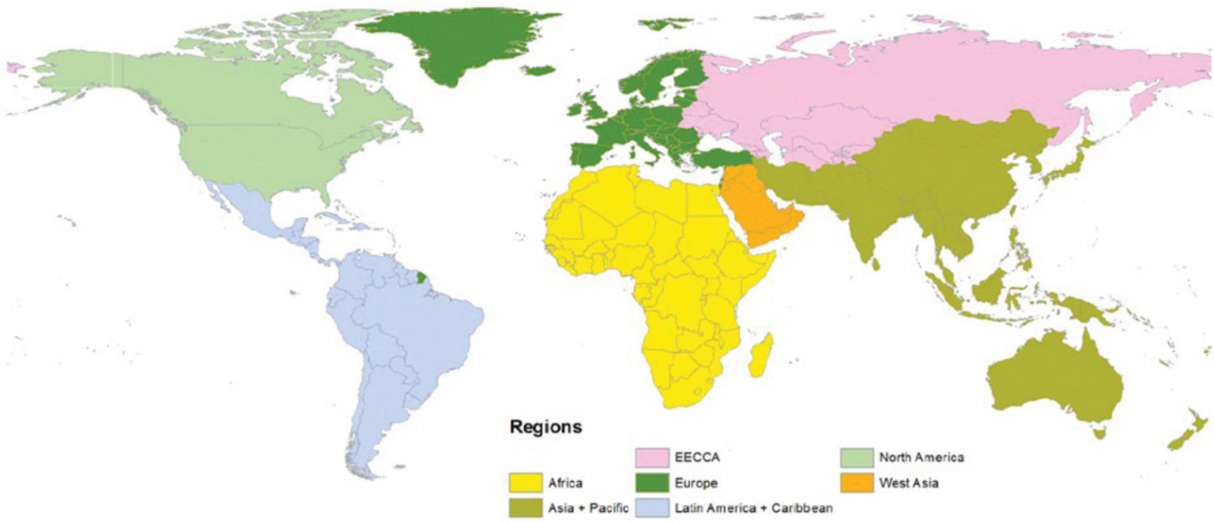


Figure 3.11. Regional classifications employed by UNEP (2016) , Miatto et al. (2016), Krausmann et al. (2009) and Schaffartzik et al. (2014). Figure from UNEP (2016).

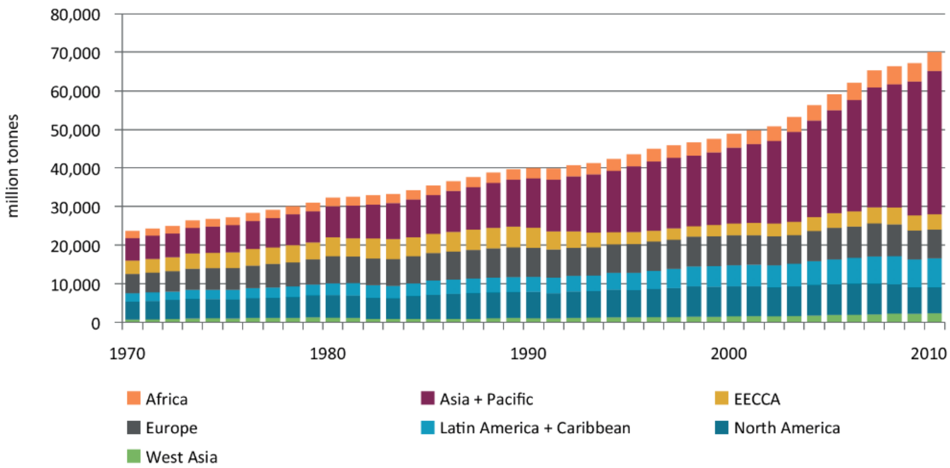


Figure 3.12. Domestic material extraction by seven subregions, 1970-2010, million tonnes. Figure from UNEP (2016).

The per capita domestic extraction within Asia and the Pacific by category (Figure 3.13) shows that an increase in the quantity of non-metallic minerals has been responsible for most of the growth within the region. This demonstrates that the increase cannot be attributed solely to population growth, but also to an increase in usage on a per capita basis. Note that Figure 3.12 and Figure 3.13 represent gross amounts extracted and per capita extraction respectively, and so are not directly comparable. Nevertheless, Figure 3.13 is sufficient to demonstrate that the growth recorded in the Asia and Pacific region was driven by an increase in use of non-metallic minerals.

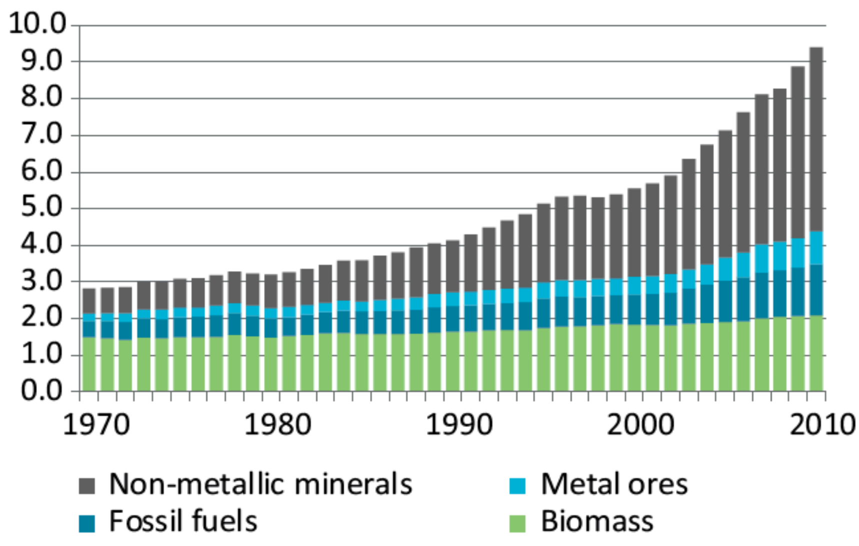


Figure 3.13. Regional domestic extraction per capita in Asia and the Pacific by material category. Units are tonnes per capita. Figure from UNEP (2016).

Africa, West Asia, and Latin America and the Caribbean also experienced rapid growth in non-metallic mineral extraction over this timeframe, albeit at lower growth rates and from much lower starting points (Figure 3.12).

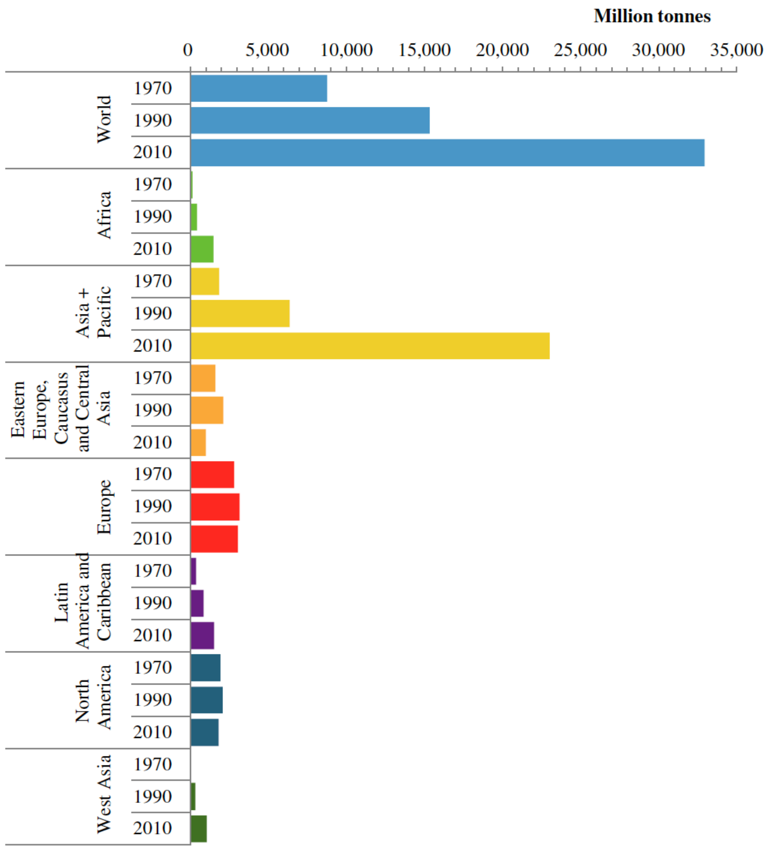


Figure 3.14. Non-metallic mineral extraction in seven world regions for 1970, 1990, and 2010. Results shown as million tonnes. Figure from Miatt, et al. (2016).

Unlike the developing nations discussed above, the amount of non-metallic minerals extracted by the developed, affluent regions of North America and Europe remained constant between 1970 and 2010 (Figure 3.14). The per capita extraction of non-metallic minerals remained relatively constant in Europe and decreased to near the global average in North America (Figure 3.15). This lack of growth may indicate generally low rates of population growth combined with the majority of vital infrastructure required for these societies already being in place prior to the 1970s.

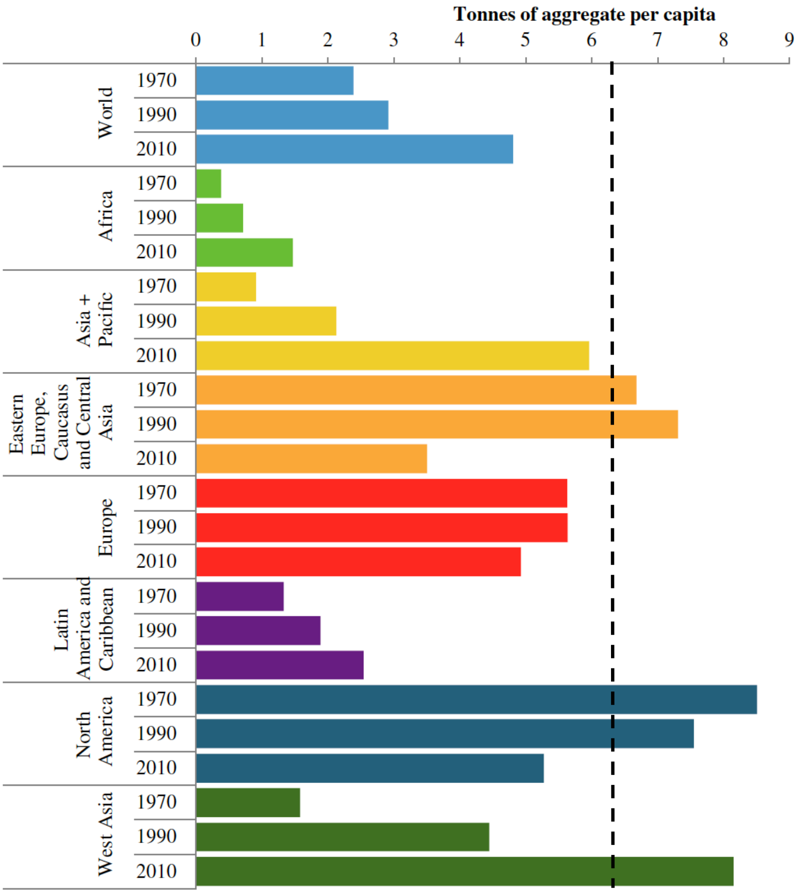


Figure 3.15. Per capita extraction of non-metallic minerals in seven world regions 1970, 1990, and 2010, tonnes. Figure from Miatto et al. (2016). Black lines shows approximate value of 6.3 tonnes per capita which is suggested as the rate at which societies stabilise (UNEP, 2016).

Until 1990 the amount of non-metallic minerals extracted by the EECCA region grew relatively quickly (Figure 3.14) and approached similar absolute and per capita levels of extraction to North America and Europe (Figure 3.15). This was followed by a notable contraction resulting from the significant economic and political changes that occurred in the early 1990s. Total material extraction levels remained low throughout most of the 1990s, before showing signs of growth in the 2000s.

3.5 Future trends

Based on the trajectories of the material extraction data, demand for aggregates is likely to continue to increase into the future. Globally, population growth and urbanisation are predicted to occur in the coming decades and will necessitate the construction of more housing and infrastructure; construction that will likely require large quantities of aggregates. The growth in demand for non-metallic minerals between 1990 and 2010 was also driven by increasing affluence (UNEP, 2016), likely contributing to the increased use per capita. As the quality of life improves for the populations in developing countries, this factor is likely to continue to drive growth in the coming decades.

Recent increases in aggregate extraction have largely been a result of increased extraction within the Asia and Pacific region, with this increase in demand largely being driven by China. China is responsible for approximately 79% and 58% of the region's and world's cement production respectively (USGS, 2017). While there have been some questions about the sustainability of China's current growth in cement and construction, there are no signs of deceleration yet, and it is likely that such growth will continue into the immediate future. UNEP (2016) and Krausmann et al. (2009) suggest that the per capita extraction of non-metallic minerals in North America and Europe of approximately 6.3 tonnes may represent the level at which society's demands for aggregates stabilise. Neither the Asia and Pacific region as a whole nor China have reached this level. Prior to stabilising at these levels, extraction rates in both Europe and North America reached levels as high as 9.6 tonnes per capita before declining. This suggests that rapid growth in most regions of the world is likely to continue.

While somewhat overshadowed by China, India has also recently experienced dramatic growth in the quantities of non-metallic minerals extracted (Figure 3.16). Given that India's population is projected to exceed China's as soon as 2022 (United Nations, Department of Economic and Social Affairs, Population Division, 2015), and its economy is one of the world's fastest growing (World Bank Group., 2017), it is likely that India will become a major factor in increasing the demand for non-metallic minerals in the coming century. Comparing present per capita extraction in India with that of China (Figure 3.16) shows that if India follows a similar development trajectory, the demand for aggregate could quadruple in the coming years. While China and India are the most notable, the Asia and Pacific region is home to numerous other emerging countries with large populations that are also expected to experience rapid development in the coming decades.

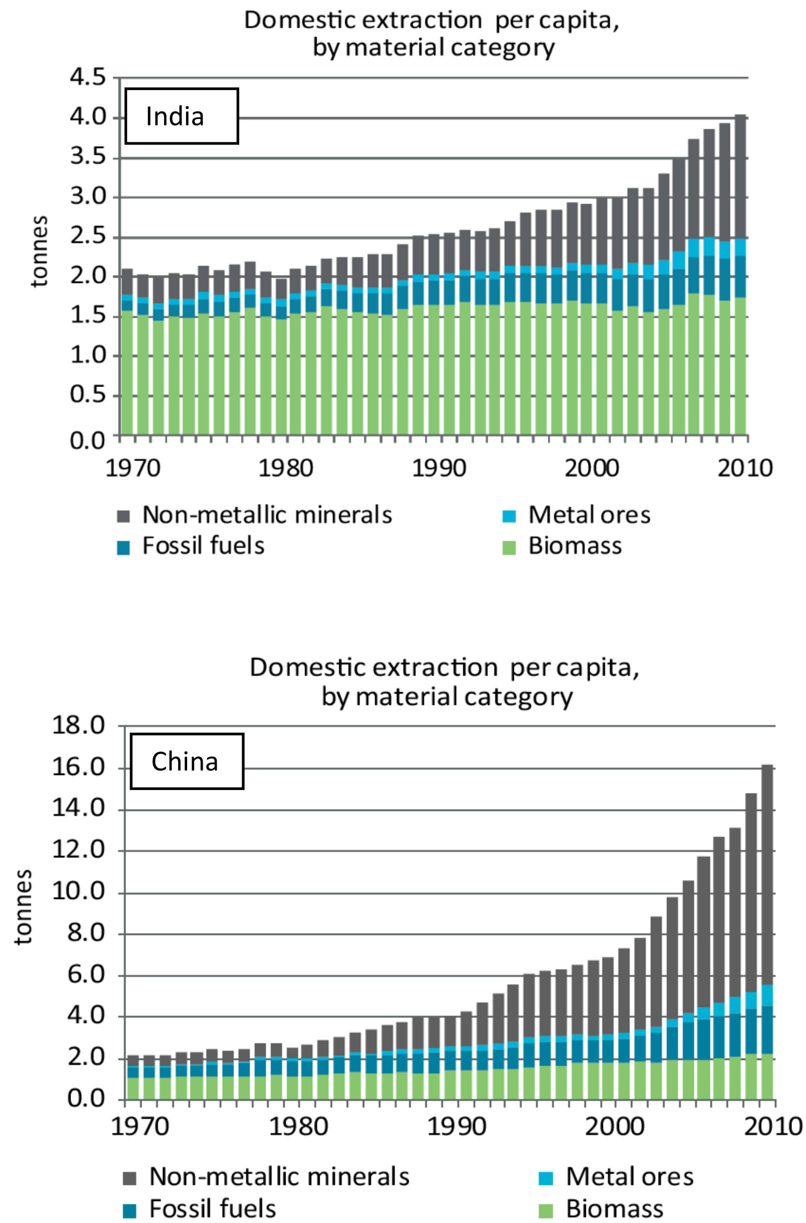


Figure 3.16. Per capita domestic extraction by material category in (top) India and (bottom) China. Note difference in scale. Figure from Miatto et al. (2016).

The Latin America and Caribbean region also contains a number of developing countries, including the eight largest economy in the world, Brazil. While growth in Brazil has recently been stymied by an economic recession, the amount of non-metallic materials extracted increased rapidly in the twenty years preceding this period. The economy appears to be recovering, so non-metallic mineral extraction may again begin to increase. Also relevant is the recent (January 2018) announcement by the Brazilian government that the policy of developing mega-hydropower projects needs to be rethought (The Guardian, 2018). These projects are major consumers of aggregate (hydropower infrastructure, access roads, camps) and declining construction within this sector could affect national aggregate usage trends.

The African region's combination of rapid population growth and lack of development suggest that the rapid growth observed in non-metallic mineral extraction over the past decades may continue in the years to come. Africa's per capita decrease in total material extraction also suggests that while the construction industry is growing, the overall material welfare of the population has declined (UNEP, 2016). If this trend were to reverse, it is likely that the current growth in non-metallic mineral extraction would accelerate. The African region currently combines one of the least-urbanised populations in the world (Africa Growth Initiative, 2016) with the world's highest population growth rate (UN, 2015), hence an increase in these categories will further increase the demand for infrastructure and aggregate.

The extraction of non-metallic minerals by Europe and North America is likely to remain fairly constant, continuing the trend of the last 50 years. While North America's per capita extraction of non-metallic minerals decreased over these five decades, this may reflect a period in which infrastructure in the US has been poorly maintained (Economic Development Research Group, 2016). This trend could reverse when the required maintenance does occur, however it is unlikely to result in significant growth as the vast majority of the regions infrastructure is already in place. Furthermore, the populations of these regions are highly urbanised (United Nations, Department of Economic and Social Affairs, Population Division, 2014) and are experiencing little growth (UN, 2015), hence a significant increase in infrastructure requirements is unlikely.

The accelerating growth in non-metallic mineral extraction observed within the EECCA since the mid-1990s is likely to slow in the near future. The region's population is predicted to decrease markedly by 2050 and the region is relatively well developed compared to other regions with accelerating demand.

3.6 Trade

In 1970, non-metallic minerals, which are predominantly aggregates, were rarely traded internationally, with only 145 million tonnes of trade recorded in that year. This accounted for approximately 5% of all global exports of materials and was the least of any material category (e.g., non-metallic minerals, metal ores, fossil fuels and biomass, UNEP, 2016). Over the following four decades the amount of non-metallic materials traded grew by an average of 5% per year and now equates to one billion tonnes, however this large quantity still accounts for less than 10% of global material exports in the categories listed above. This relatively small amount of trade is likely a result of aggregates being abundant in most countries in the world, cheap to extract and process, while also being heavy and expensive to transport (UNEP, 2016).

While only a small proportion of aggregates are traded, they nevertheless play a key role in global exports due to their use in the construction of the infrastructure (factories, transport links etc.) used to create and move goods that are subsequently traded. When these materials are considered, the key role aggregates play in global trade becomes apparent as they account for approximately 40% of all resources consumed in the creation and export of goods (UNEP, 2016).

Table 3.1 and Table 3.2 show the 10 largest importers and exporters of sand and aggregates in the world in 2016 according to the Observatory of Economic Complexity (Massachusetts Institute of Technology, 2018)[1].

[1] The figures on the OEC are constantly updated and changing. The values shown here were current as of 22 May 2018.

Table 3-1: Top 10 global sand importers and exporters (Massachusetts Institute of Technology, 2018).

Exporters	Gross value (USD x 10^6)	Share of world total (%)	Importers	Gross value (USD x 10^6)	Share of world total (%)
USA	363	19	Singapore	176	9.2
Germany	166	8.7	Canada	141	7.4
Netherlands	159	8.3	Belgium	138	7.2
Belgium	155	8.1	Netherlands	132	6.9
Australia	134	7	Germany	122	6.4
Malaysia	120	6.3	China	99	5.2
China	61	3.2	Japan	88	4.6
Vietnam	61	3.2	Italy	63	3.3
France	59	3.1	Mexico	63	3.3
Saudi Arabia	55	2.9	UAE	55	2.9
Total Top 10	1,333	70	Total Top 10	1,077	56
World total	1,910	-	World total	1,910	-

Table 3-2: Top 10 global importers and exporters of aggregates. (Massachusetts Institute of Technology, 2018)

Exporters	Gross amount (USD x 10^6)	Share of world total (%)	Importers	Gross amount (USD x 10^6)	Share of world total (%)
UAE	619	26	Qatar	405	17
Norway	214	9.0	USA	198	8.3
China	190	8.0	Netherlands	186	7.8
Germany	171	7.2	Singapore	169	7.1
Belgium	114	4.8	Germany	124	5.2
France	100	4.2	Kuwait	124	5.2
Mexico	74	3.1	Hong Kong	112	4.7
Canada	71	3	France	102	4.3
Indonesia	76	3.2	Switzerland	95	4
UK	67	2.8	Denmark	64	2.7
Top 10 total	1,697	71	Top 10 total	1,578	67
World total	2,380	-	World total	2,380	-

The countries that export the largest volumes of sand include the USA, Germany, the Netherlands, and Belgium, with the USA exporting almost twice as much as the next highest importer, Germany. Singapore is by far the largest importer of sand, while import levels in the next three countries (Canada, Belgium, and the Netherlands) are similar. Several countries appear on both lists, with this likely reflecting the different types of sand required for different industrial uses. Many of the largest importers of sand are located near the largest exporters, suggesting that the distance over which sand is traded is limited.

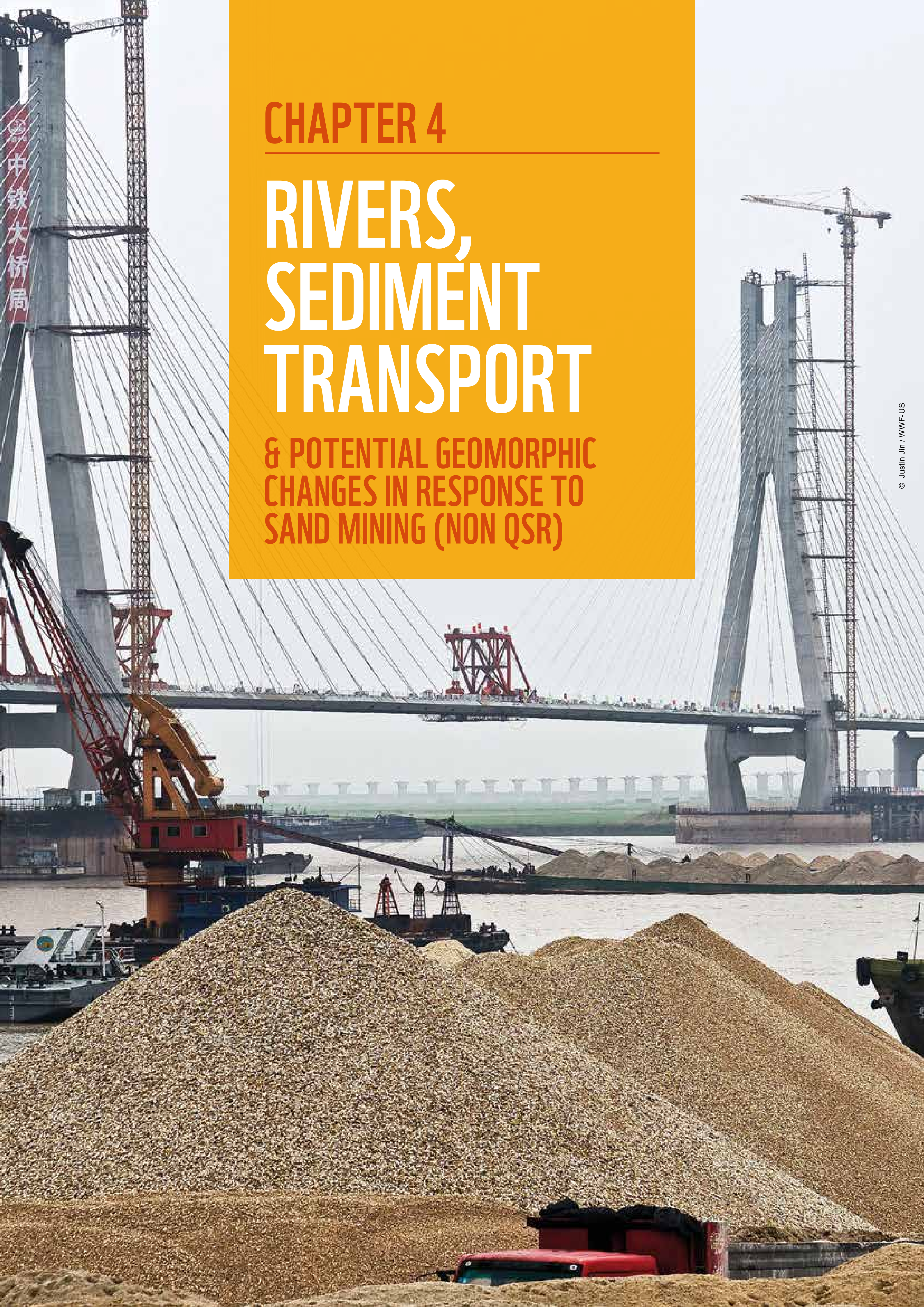
The UAE exports more aggregates than the next three highest exporters combined, with the amount of exports decreasing gradually for the other nine countries. While the difference in importers of aggregates was less pronounced as compared to sand, Qatar imported far more aggregates than any other country. Only France and Belgium were amongst the world's highest importers and exporters, perhaps indicating that aggregates are used for less specialised applications than sand, or that it is easier for certain regions within these countries to engage with international rather than domestic trade.

These values are based on the trade figures reported by the respective countries. Discrepancies in reported sand exports and imports between countries have been documented (Chakrya & Amaro, 2016), suggesting that some of the data are incomplete, or erroneous. Illegal imports have also been linked with such discrepancies (UNEP Global Environmental Alert Service, 2014).

CHAPTER 4

RIVERS, SEDIMENT TRANSPORT

& POTENTIAL GEOMORPHIC CHANGES IN RESPONSE TO SAND MINING (NON QSR)



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4 Rivers, sediment transport and potential geomorphic changes in response to sand mining (non QSR)

This section provides a snapshot of types of sediment, how sediment moves through river systems and why and how river channels respond to sediment extraction. The geomorphic response of rivers to flow and sediment changes is well established, and this material is presented to facilitate the understanding of how sand mining can lead to physical changes to the river channel. The QSR results are used to identify how these physical changes affect ecosystems.

4.1 Rivers as linkage between mountains and the sea

River systems are the corridors that connect the continents with the oceans, with the movement of water and sediment through waterways controlling the characteristics and distribution of fluvial, riparian and floodplain habitats (Stanley, et al., 2016). The supply and delivery of sediment and water to river systems is dynamic and governed by the hydrologic and geologic characteristics of a catchment, combined with modifications and alterations arising from human activities (Williams, 2012). The overarching temperature regime and rainfall pattern of a catchment exerts a strong control on the weathering of the landscape, how sediment enters river systems and when material is transported. Historical climates are also important as sediment reserves may have deposited under different conditions, such as glacial periods (Williams, 2012). Large scale, long-term changes to the landscape (development, clearing, land use change) and / or climate will induce changes to the sediment regimes of rivers.

Sediment dynamics within river channels and floodplains are highly complex, and related to the magnitude, duration, frequency, seasonality and rates of water level change of the river flow (Graf, 1998). Different sediment components have different pathways as they are transported through rivers to the sea. Fine-grained sediment, which is generally derived from the physical erosion of 'soft' rocks, chemical weathering of silicate minerals and the breakdown of organic matter, tends to be rapidly transported through rivers once in suspension due to their small size (Biedenharn, et al., 2006). These materials are only deposited and stored in very low energy environments, such as deep quiescent channels, backwater environments, flood plains or the sea. Fine-sediment tends to be transported year-round and is responsible for the movement and delivery of nutrients owing to their high surface area to volume ratio that provides large areas for nutrients to adsorb, and the high organic content of the material (Owens, et al., 2005). Fine-sediments also affect water quality and biological activity by controlling light penetration into a waterway (Owens, et al., 2005). The dispersal of fine-grained sediments in estuarine and coastal environments fuels the productivity of these areas brackish and marine environments (Figure 4.1)

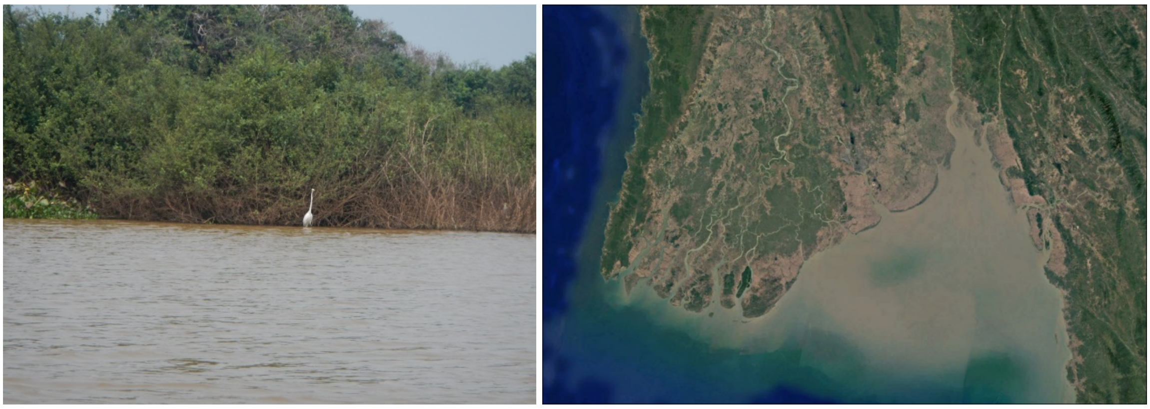

Figure 4.1. Fine-grained sediments control light penetration and water quality and deliver nutrients to ecosystems (left) Egret in the Mekong River in Lao PDR; (right) Google Earth image of sediment plume associated with the Ayeyarwady and neighbouring rivers.

Very coarse material, consisting of coarse sand and larger material (pebbles, cobbles and boulders), is generally transported on an episodic basis during conditions of very high flow. This material typically moves as bedload – rolling or bouncing along the bed of the river, requiring many events to move through the system, with interludes of storage. The length of time between flow events sufficient to move this material depends on the flow regime and may range from months to years to decades (Biedenharn, et al., 2006).

Sediment of intermediate size, consisting of fine to coarse sand can be transported in suspension, or as bedload depending on the hydraulic conditions of the river. These grain-sizes can be transported in suspension in large volumes during high flows, and as bedload under lower energy flows. Sand can also require many years to move through a river system, being stored in the bed, banks and bars of a river system. The continuous delivery of sand to deltaic systems is an important component in the maintenance of delta and shoreline stability and provide the first line of protection against storm surges and other extreme weather events (Anthony, et al., 2015). Collectively, the transport and depositional patterns of clay, silt, sand and larger size material create a physical mosaic of in channel habitats that underpins the ecological functioning of rivers (Figure 4.2).

Figure 4.2. The storage of sand and coarser grained sediment in river systems provides structural stability of river channels and creates the habitats that underpin the ecological functioning of rivers.

4.2 How rivers respond to changes associated with sand mining

This section presents a brief overview of the fundamental geomorphic responses that are recognised as occurring within rivers in response to sediment extraction. It is included to provide background information regarding the physical changes that are associated with ecosystem changes in the QSR.

Removing sediment stores and altering sediment transport, such as can occur with sand mining, will promote physical changes in a river channel. Alluvial river systems or reaches, in which the river channel is developed within sediment deposits, are most susceptible to change, as the channel, banks, bars and floodplain are all potentially mobile. However, changes in sediment transport will also affect bedrock controlled reaches where localised sediment deposits or insets provide substrate for vegetation and habitats exploited by riverine, riparian and terrestrial species for spawning, feeding and nesting (Owens, et al., 2005).

Rivers have a dynamic equilibrium between river flow, river slope, sediment supply and sediment size, and changing any of these factors will promote either deposition or erosion such that the channel establishes a new equilibrium with the flow and sediment conditions (Langbein & Leopold, 1964). If sediment is available, the channel may regain its former geometry, but excess or insufficient supply will alter the morphology. Seasonal changes within rivers, where sediments are deposited and stored during low flow conditions and then remobilised during periods of high flow reflects this dynamic equilibrium, with the channel continually adjusting to the changing flow and sediment conditions (Langbein & Leopold, 1964). The range of these conditions comprises the natural variability of the river.

A useful way to consider rivers was identified by (Lane, 1954) who proposed that sediment transport and river morphology was maintained by the balance between four factors: sediment load, sediment grain-size, water flow, and the slope of the river. These components can be depicted as a balance to demonstrate how a river channel will respond to changes to any of these factors (Figure 4.3). Increasing sediment loads and / or increasing sediment size without changing flows or river slopes will promote deposition in the river channel. Similarly, increasing stream slope and/or increasing discharge without altering the sediment load will induce bed erosion due to the excess energy of the river.

This 'balance' can be used to understand the multi-faceted potential changes that can occur with sand. Changes associated with sand mining include:

- A reduction in the sediment load of the river: Extracting material will reduce the total volume of sediment available for transport, thus causing bed erosion;
- A reduction in the sediment size available for transport: Sand mining generally targets medium to coarse sand and gravels, reducing the availability of this grain-size and reducing median grain-sizes. This change will promote bed erosion;
- A local increase in the slope of the river through the removal of material: Sand mining deepens channels and the resulting depression can locally increase river slope. This will promote localised bed erosion due to increased river velocities caused by the increased slope.

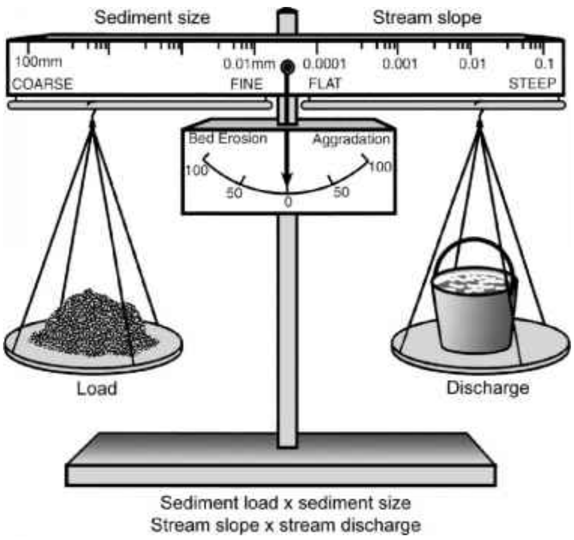

Figure 4.3. Lane's Balance showing relationship between sediment load, sediment size, stream slope and discharge. Changes to any of these factors will cause a river channel to either erode or aggrade (experience deposition) to establish an equilibrium with the new conditions.

Each of these changes promotes local erosion that can propagate both upstream and downstream, with the process described by. The upstream propagation of erosion from sand mining sites occurs due to the creation of a nick point in the river bed river. Turbulence created as water flows over this point causes erosion of the river bed, with the nick point retreating in an upstream direction (Padmalal & Maya, 2014, Figure 4.4). The upstream movement of the nick point increases the slope of the river, resulting in an increase in water velocity during high flow events, leading to increased erosion downstream. This process of lowering the bed of the river causes channel incision. Once initiated, the deeper and steeper river bed will cause an increase in water velocity, which in turn will increase river energy and erosion, creating a positive feedback for incision to continue. Channel incision is frequently accompanied by channel narrowing, due to the deeper, higher slope river channel being able to convey water at a faster rate.

Rivers narrowed through incision may also become disconnected from their floodplains. Floodplains are important habitats and provide range of ecosystem services that and floodplain maintenance is dependent on episodic inundation. The exchange of water, sediment and organisms during inundation contribute to both in-stream and floodplain productivity, while simultaneously allowing groundwater flows to recharge. Floodplains allow the river to spread out during periods of high water, and slow and absorb high flows. This reduces both flood intensity and magnitude and hence limits their impact on downstream riparian habitats and infrastructure. Sediment deposition provides an influx of nutrients which are exploited by ecosystems and agriculture. In rivers with deeply incised channels, greater water volumes are required before rivers overtop their banks and hence floodplain inundation occurs less frequently. As a result, floodplains are no longer able to fulfil their important ecological and social roles.

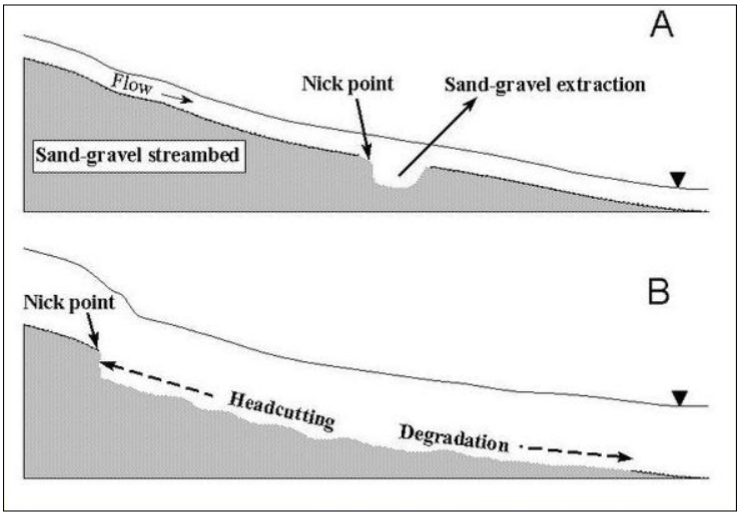

Figure 4.4. Propagation of bed changes upstream and downstream associated with river bed disturbance. A shows initial disturbance; B shows propagation of nick point upstream and increased erosion downstream during high flows due to increased bed slope. Figure from (http://ponce.sdsu.edu/three_issues_sandminingfacts01.html

Erosion of a nick point can also occur in a lateral direction in a river channel. As the erosion reaches the river banks, the bank toes can become undercut and destabilised, leading to bank collapse and ultimately channel widening. Whether a channel will narrow or widen when subjected to bed incision depends on factors including the composition of the river bed, sediment supply and the flow regime.

In the case of braided river systems (e.g., a river with multiple channels separated by mobile islands), incision can lead to a fundamental change in the nature of the river system, with flow confined to only one channel as the channel deepens (Padmalal & Maya, 2014). This change allows afforestation to occur in past river channels and gravel bars, decreasing erosion, accelerating the formation of stable islands, and contributing to the stability of the new single channel system.

The impacts of incision may spread beyond a river's banks. By deepening the base of the river the banks and surrounding permeable areas drain to this lowered level, hence the ground-water level can also decrease, affecting groundwater availability and recharge (Nandakumaran, et al., 2014).

The removal of sand from sand bars, known as bar skimming or scalping can lead to bar erosion, local channel widening, and downstream erosion. The removal of gravel or course sand from bars exposes the under lying finer-grained sediment to erosion by high flows, thus causing a loss of the bar and increasing the flow capacity of the channel (Padmalal & Maya, 2014). Additional channel widening can occur if the extraction causes river bank instability and collapse. Over time, the increased capacity of the channel can reduce local water velocities and locally increase sedimentation, which can exacerbate downstream erosion due to an additional reduction in transported sediment.

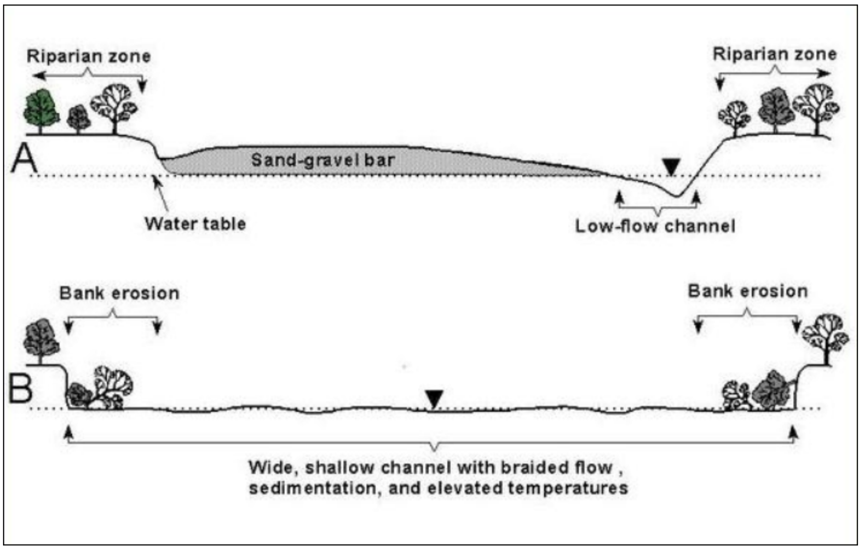

Figure 4.5. River response to the extraction of sand and gravels from bars. Figure from (http://ponce.sdsu.edu/three_issues_sandminingfacts01.html

Dry mining on floodplains may also alter the course of rivers. Such mining often creates a series of deep pits near river courses. During flood events these pits may be inundated, erode and become linked, forming an alternative channel that the river continues to flow through following the recession of flood waters (Bureau of Reclamation, 2005). These sudden changes prevent further mining in these locations, create stagnant lakes, and can increase bank erosion. Floodplain mining that intercepts the water table also has the potential to alter ground water levels, if pits are pumped dry to allow access to the sand resource and contaminate aquifers (Padmalal & Maya, 2014).

Other physical impacts of sand mining that impact the physical condition of rivers include the creation of sediment laden plumes during mining that move downstream and deposit in undesirable locations, potentially coating substrates and making them unusable as habitat (Owens, et al., 2005). Sediment plumes will also reduce the depth of light penetration in rivers. This is accentuated by sand mining generally coinciding with periods of low river flow when water clarity is naturally high. A reduction in light will affect algal and aquatic vegetation growth.

At a large scale, sand mining reduces the volume of sediment moving through the river and delivered to the river delta and coastal zone. In the absence of continued sediment deposition, deltas can erode and subside, reducing their capacity as highly productive agricultural areas. Delta fronts and coastal zones provide the first line of defence against storm surges and extreme weather events, and degradation of a delta can translate into increased flooding and associated damage to communities and nations (Anthony, 2016).

4.3 Catchment activities and sand mining

Sand mining rarely occurs in isolation of other river and catchment developments. Dams, weirs, flood mitigation infrastructure, groynes, other water uses and land use changes all have the potential to impact river flows, sediment transport and channel characteristics. Some of the more commonly recognised linkages between development and river impacts include:

- Dams and weirs: These structures have a direct impact on river systems because they have the potential to alter both the flow regime and sediment budget of a river. Large dams can modulate high flows and increase low flows, thus changing the sediment transport characteristics of a river system. Dams trap sediment, with larger sediment sizes preferentially captured by impoundments. This reduces the overall volume of sediment available for transport, starves the downstream river from specific sediment sizes and alters the range of sediment sizes available for transport. Downstream channel incision, river bank collapse and change to the nature of the river bed are common changes below dams. These processes are very similar to those associated with aggregate mining;

- Channel modification can be implemented for a number of reasons, including flood control measures, the straightening of rivers to allow for the development of floodplains, dredging to enable navigation and the diversion of river water for use in irrigation. Modifying river channels can have many of the same effects as aggregate mining. Straightening and narrowing rivers results in greater flow speeds, exacerbating incision. Levees designed for flood protection may cut rivers off from their floodplains, while also straightening and shortening rivers;

- Land use: The types and distribution of vegetation within a river catchment will affect the amount of sediment generated in the catchment, and the pattern and rate of water and sediment runoff. Deforestation can increase sediment input, whereas afforestation can decrease inputs. Different agricultural processes will also affect river inputs, such as slash and burn agriculture increasing sediment loads, or ploughing patterns that promote rapid runoff and soil erosion. Land use change is linked with development, driving the market for construction materials; hence, areas undergoing rapid rates of development and land clearing can also have a high demand for sand, thus increasing pressures on local rivers.

CHAPTER 5

QSR RESULTS

EVIDENCE OF THE IMPACTS OF AGGREGATE MINING ON ECOSYSTEM STRUCTURE, PROCESS AND BIODIVERSITY IN RIVERS, FLOODPLAINS AND ESTUARIES

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5 QSR Results - Evidence of the impacts of aggregate mining on ecosystem structure, process and biodiversity in rivers, floodplains and estuaries

This section presents the findings of the QSR, with the characteristics and findings of the 65 papers included in the analysis presented here. The results of the QSR were classified by the following attributes: publication date, geographical location, type of system considered, the study method, the inference method, type of extraction, scale of extraction, presence of other stressors, use of extracted aggregate, the comparator employed, and the physical, biological, and political impacts on the system (spreadsheet in Annex 1). In this section, each of these attributes is analysed and discussed. Where relevant, the findings of the QSR have been supplemented with additional information derived from literature searches into more specific sub-topics.

The distribution of publication dates of the scientific papers included in the QSR (Figure 5.1) shows an increase in the number of relevant papers over time, with about 75% of the papers published within the last 5 years. This trend of increasing papers likely reflects an increase in awareness of sand mining as an environmental issue. No analysis of media coverage of sand mining has been completed, but there have been numerous articles published in mainstream newspapers, magazines and websites over the past few years, with the features focusing as much on the social impact as the environmental impact of sand extraction. Many of these popular articles refer to a small number of technical publications, such as the UNEP Global Environmental Alert (2014) *Sand, rarer than one thinks*. Whether the increase in technical publications has driven an increase in media attention, vice versa, or whether the demand for sand, and the impacts associated have reached a threshold that cannot be ignored, is unknown.

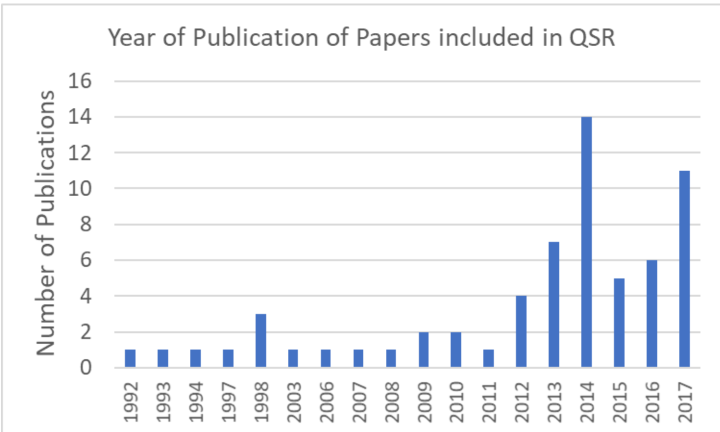


Figure 5.1. Distribution of publication dates of scientific papers included in the QSR.

5.1 Geographical distribution of investigations

Most papers identified through this review focussed on the river systems in Europe (23) and North America (16) (Figure 5.1). The 17 studies that considered Western Europe were limited to and evenly spread between France (7), Spain (5), and Italy (5), with the majority (10) of these studies considering rivers in mountainous areas. In each of these countries significant riverine aggregate mining occurred during the early- to mid-20th century, before becoming heavily regulated or banned in the 1980s and 1990s. Unlike many developing countries, little illegal mining is thought to be occurring in Western Europe, hence these studies provide valuable insights into the long-term effects of aggregate mining, the ability of rivers to rehabilitate themselves following the cessation of mining, and the efficacy of various management strategies. Of course the historic under-reporting of extracted volumes of sand may remain an issue.

Six studies were completed in Eastern Europe, with four of these investigating rivers within the Polish Carpathians. The reason for this narrow focus is not immediately obvious, as aggregate mining has occurred throughout Eastern Europe, however it may be that the inclusion of several mined rivers in the Natura 2000 sites raised the profile of the Polish Carpathians. This may also be a result of only considering studies written in English or indicate that Poland considers aggregate mining to be a more pressing issue than its neighbours in the region and is more likely to fund research in the area.

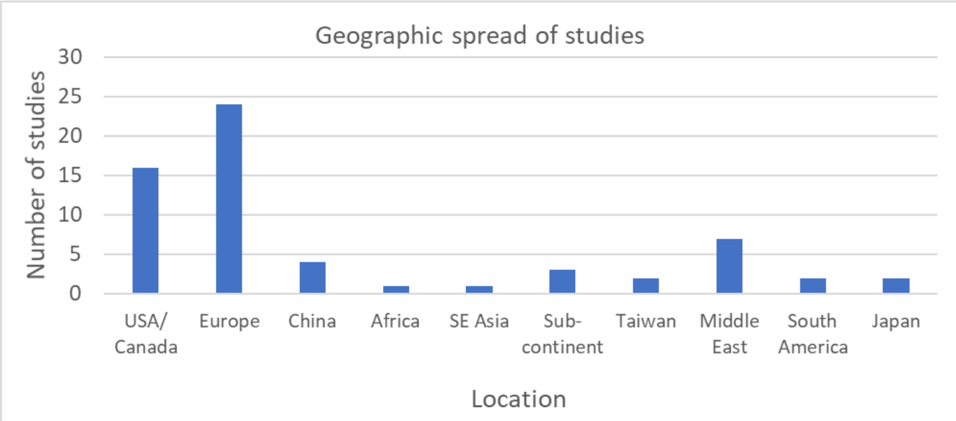


Figure 5.2. Geographic spread of studies considered within the QSR.

In North America, Californian rivers received the most attention, with multiple studies also considering the Allegheny River in Pennsylvania. In 2014, California and Pennsylvania were the second and third highest producers of sand and gravel for construction in the US behind Texas, hence this focus may reflect the quantities removed. Information about the sources of aggregates within these states is scarce, hence the lack of studies from other states may be a result of sand being obtained from non-riverine sources.

The next highest number of studies as from the Middle-East where investigations covered a number of rivers in Iran, and on the Harşit stream and Lower Sakarya River in Turkey. Four studies investigated the impacts of sand mining within China, with three of these focusing on the largest sand mining area in the world, Poyang Lake. Three more studies reported on the impacts of sand mining within the Indian subcontinent, while Africa, South East Asia, Taiwan, South America, and Japan were the focus of one or two papers each.

The small number of studies obtained from many regions of the world makes it difficult to determine why a few rivers have received a disproportionately large amount of attention, while others appear to have been ignored. This apparent bias may be attributable to limiting the QSR search to papers in English. Many studies offer little justification for why their study site was chosen beyond that it has been affected by sand mining, however it seems unlikely that this could be the main consideration as sand mining is ubiquitous throughout the world. In certain areas, the same authors appear numerous times, perhaps suggesting that study sites are determined by the interests of individual researchers, or the availability of funding.

The small number of papers from non-English speaking regions is surprising and represents a critical gap in the current literature. As previously discussed, the majority of the world's aggregates are being extracted within Asia and the Pacific, while the extraction of aggregates is increasing rapidly in Africa and Latin America. There is also rapid growth in the EECCA, however this region was not the focus of a single study.

There are several possible explanations for the paucity of studies from these regions. Perhaps the most obvious is that this review only considered articles written in English. Several papers from these regions were rejected for the QSR as they were in the local language rather than English, or when an English abstract was available, it did not contain the range of criteria being considered under the QSR. In developing regions, investigations into riverine aggregate mining may also be limited by a lack of funding, or by a lack of political motivation. There have been numerous reports, particularly from India, of elected and public officials being involved with and protecting illegal sand mining operations. In such situations it is unlikely that researchers would receive the funding or access necessary to investigate the impacts of these operations. Reports in the media of physical harm, including execution of people speaking out against sand mining may also affect the viability of investigations. The relatively small number of studies from these regions makes it impossible to determine the exact factors responsible.

5.2 System type considered

The majority of studies focussed on rivers which partially reflects the term 'river' being included in the QSR search. Most investigations focussed on reaches within one river or from multiple rivers (Figure 5.3). Five studies considered complete river catchments, and considered other factors in addition to sand mining, such as land use changes in the catchment. Four studies examined lakes (three focused on Lake Poyang), while deltas, estuaries, streams, ephemeral rivers, and coastal environments received less attention.

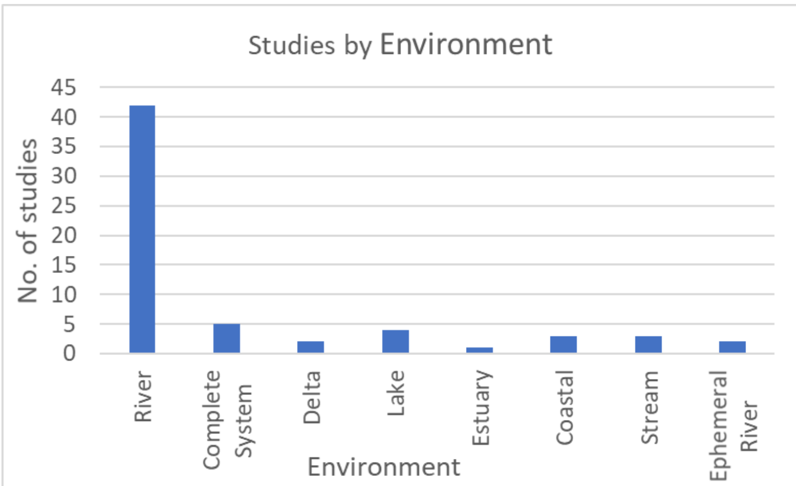


Figure 5.3. Systems considered by studies included in the QSR.

The studies that considered single or multiple rivers generally did so by investigating a limited number of river reaches. This approach reflects the availability of historical information and is likely also driven by logistical and funding limitations. Whilst reach specific investigations document local impacts of sand mining, they do not provide information about more distal impacts, such as delta or coastal shoreline starvation, or upstream or downstream morphological changes to river channels.

Studies that considered complete river systems provided greater insights into the impact of sand mining on rivers. However, they also had to contend with confounding factors such as dams, torrent control works and land use changes within catchments that can impact rivers and obscure or exacerbate the impact from sand mining, making attributing impacts to individual stressors difficult.

5.3 Inference methods

Nine different investigative methods for determining changes associated with sand mining were captured in the QSR, with the most common inference method based on the comparison of current conditions to historical images and maps. An approach that was only slightly less common was the monitoring of biological and ecological factors (Figure 5.4). Other common methods included measuring water quality indicators and changes in geomorphological and hydrodynamic features.

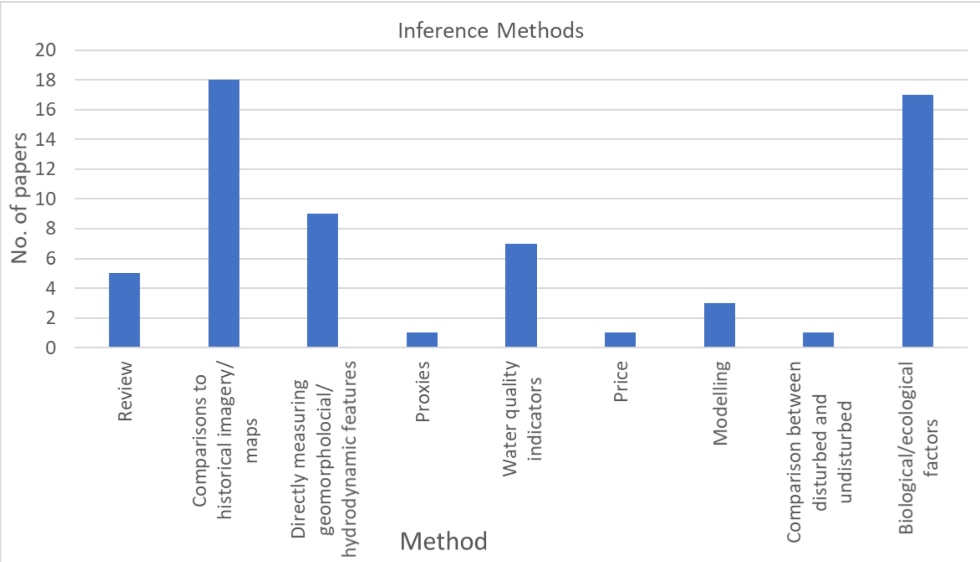


Figure 5.4. Inference methods used by studies included in the QSR

Several review papers were included in the QSR analysis even though the QSR approach is typically limited to primary sources. There are several reasons for these inclusions:

- They were the only source of information about a region of the world, such as eastern Europe, and expanding the geographic cover of papers in this manner was considered acceptable as some of the primary sources were not in English;
- The papers included pre-1992 references to sand mining impacts in rivers. These review papers were considered important for providing the historic perspective;
- The papers summarised a series of conference presentations outlining ecological responses to sand mining, but primary sources for these findings were not returned in the QSR search.

The relevance of the information contained within these non-primary sources was considered to be of sufficient value for inclusion in this review.

The availability of historical maps and images is a major factor in determining where investigations are focussed. This approach is also hindered by the lack of 'pre' mining air photos in rivers where extraction pre-dates aerial photography. Uncertainties associated with this approach include the long time-period between some photos that limited the potential to directly link cause and response in rivers. This is particularly relevant in rivers where extreme flow (and sediment) events are major determinants in river morphology, so distinguishing between sand mining (or other changes) and large events is difficult. A positive aspect of this approach is the potential to capture changes over long time periods, which reflect the time-scales at which sand mining can alter rivers.

Other investigative approaches, such as monitoring water quality indicators or documenting changes in river geomorphology over fairly short time periods, provided information about immediate impacts, but do not provide representative information about how sand mining will affect the system in the long-term on a catchment basis. The inability to monitor sand mining sites prior to operations limited the collection of baseline information. Many studies addressed this issue by using a neighbouring and comparable system or a river reach from the same river that was not undergoing sand mining as a control.

The difference between investigative techniques limited the comparisons of results obtained by different studies. Comparing systems is also limited by the inherent differences between rivers.

5.4 Type of mining

One key factor in the potential impact of sand mining on rivers is the type of mining being performed. Riverine aggregate mining activities can be broadly broken down into three categories; in-stream or wet mining, dry mining, and bar skimming or scalping. In-stream mining involves aggregate being extracted directly from the bed of flowing rivers and can occur within the main channel or margins of a river. Dry mining takes place on floodplains, seasonally exposed river margins, or in ephemeral rivers that are dry throughout portions of the year. Bar scalping or skimming involves removing the upper layer of exposed sand bars (to varying depths).

Sixty percent (38) of the studies reported the type of mining occurring within the river, with the vast majority (35) discussing the impacts of in-stream mining. Eight focussed on the impacts of dry mining, with only two addressing bar skimming. A lone study reported on an instance where a river was rerouted to allow access to aggregate deposits. Many studies reported on the effects of multiple types of mining.

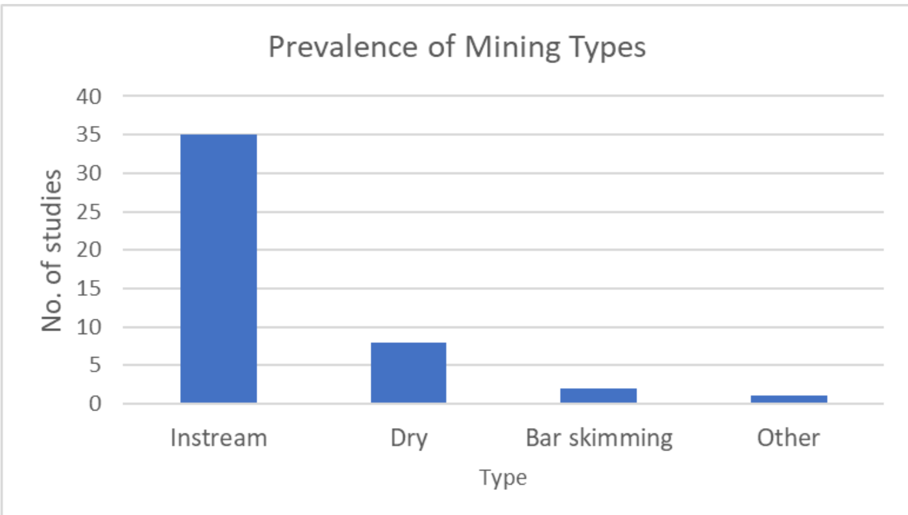


Figure 5.5. Mining types reported in the studies included in the QSR.

The studies that did report the type of mining frequently did not include specific information about how it was conducted. This can be an important factor as manual in-stream mining is likely to have different impacts as compared to in-stream filtering or dredging; similarly, in-stream mining within active channels will have different effects to mining conducted in pools or on watercourse margins.

5.5 Scale of mining

The quantities of extracted material from rivers under investigation were reported by only 20 of the 63 studies. Quantities were reported as either volume or mass and were reported over time frames ranging from individual years to decades. Several studies stated that recent extraction volumes were not available and instead reported historical data. Many also cautioned that the reported values did not include quantities of illegally mined aggregates; quantities thought to be significant in certain regions. Table 5-1 summarises the published volumes of extracted material with all values converted to volume (based on density of 1.6 t/m^3). The quantities ranged from <10,000 m^3/year to >230 million m^3/year. Some of the smaller volumes such as the 5,000 – 8,000 m^3/year (Kondolf G., 1993) are associated with channel maintenance for flood control in aggrading rivers. The largest reported volumes, by two orders of magnitude, are those extracted from Poyang Lake in China, where over 1,800 million m^3 of material are estimated to have been extracted at a rate of about 235 millionm^3/year in under a decade. This volume is equivalent to a 10 m wide path, of 1 m depth for 188 km. The next most notable quantity is associated with the Mekong delta in Vietnam, where about 70 million m^3 are estimated to have been extracted over a decade. While more aggregate has been extracted from the Loire River, France, this extraction occurred over a period of 44 years (Latapie, et al., 2014). Large volumes were extracted over similarly long periods in rivers such as the Drôme in France, the Tedori in Japan, and the Brenta or Tagliamento in Italy.

Table 5-1. Summary of extraction rates for QSR papers

Paper	River	Mean annual extraction rate (x 10^3 m^3)	Total extracted (x 10^3 m^3)
Kondolf (1993)	Cache Creek, CA, USA	6,24	48,485
	Sacramento River, Ca, USA	-	5,400
	Stony Creek	260 - 730	-
	River Usk, Wales	5 - 8	-
Downs et al. (2013)	Lower Santa Clara River, CA, USA	1,700	28,900
Brunier et al. (2014)	Mekong Delta, Vietnam	~7,000	~70,000
de Leeuw, et al. (2010)	Poyang Lake, China	234,000	-
Kondolf, et al. (2007)	Lower Eygues River, France	400	8,000
Ratnayake, Silva, & Kumara (2013)	Kaluganga River, Sri Lanka	110	-
Kondolf, (1994)	Eel River, CA, USA	8 - 24	-
Podimata & Yannopoulos, (2016)	Alfeios River, Greece	43.5	435
Leeuw, et al. (2010) in Lai, et al., (2014)	Poyang Lake, China	236,000	1,888,000
	Arno-Garno River, Ethiopia	24.3	-

Paper	River	Mean annual extraction rate ($x 10^3 m^3$)	Total extracted ($x 10^3 m^3$)
Mingist & Gebremedhin, (2016)	Ribb River, Ethiopia	2.8	-
Liébault, et al., (2013)	Drôme River, France	250	~5,000
Dang, et al., (2014)	Tedori River, Japan	250	7,600
Moretto, et al., (2014)	Brenta River, Italy	240 - 320	6,000 - 8,000
Latapie, et al., (2014)	Loire River, France	1,890	83,000
Gumiero, et al., (2015)	Panaro River, Italy	310 average 730 peak	5,900
Sitzia, et al., (2016)	Brenta River, Italy	360	9,000
	Tagliamento River, Italy	1,100	23,100
Ortega-Becerril, et al., (2016)	Nogalte Stream, Spain	-	540
Sanchis-Ibor, et al., (2017)	Palancia River, Spain	15.3	138
Rempel & Church, (2009)	Fraser River, Canada	69	One off experimental extraction

5.6 Sand use

Only 35 of the studies reported the motivation behind the aggregate extraction, with 32 listing construction aggregate as the primary use for the extracted materials (Figure 5.6). Other motivations included improving the ecological health of the river (1), modifying the river's channel for navigational purposes (2), and extracting gold from alluvial sands (2). These findings are consistent with the information presented in Section 3 of this report, showing that the predominant use of extracted sand is for construction activities.

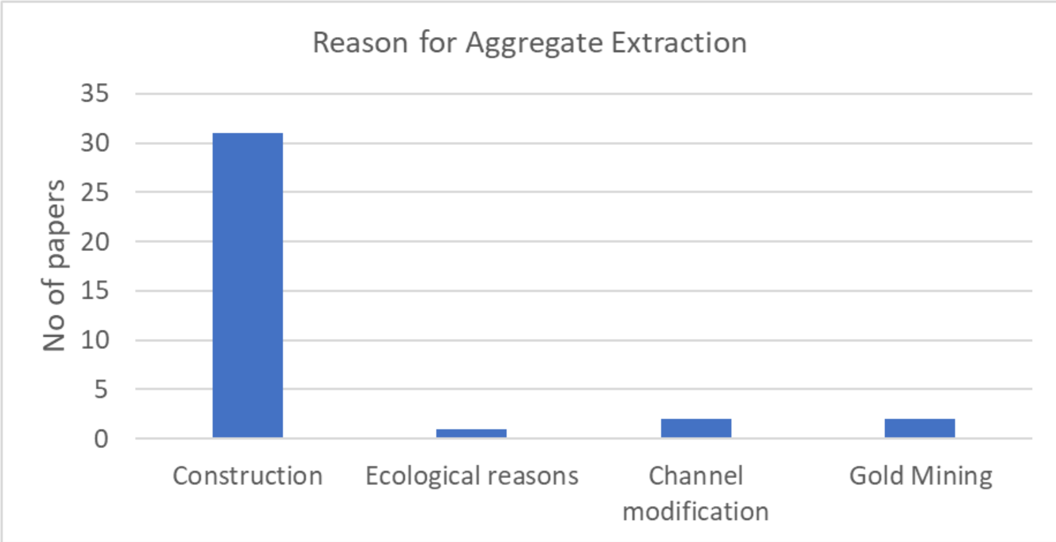


Figure 5.6. Uses of extracted aggregates in studies included in the QSR.

5.7 Geomorphic and ecological impacts of sand mining

Investigations tended to report the physical responses of rivers to aggregate extraction and suggest potential ecological impacts that may arise as a result, however few sought to determine if these changes were actually occurring. In the following discussion, the physical changes are described, and linked to ecological changes where the connection is straightforward. A number of investigations linked multiple physical changes to ecological changes or identified indirect pathways of change. These more holistic findings are presented after the discussion of physical impacts.

5.7.1 Physical impacts

A wide range of physical impacts associated with sand mining were documented in the QSR papers. It is possible that in other sand mining operations physical impacts were limited and no report or paper resulted, if so this is systematic bias in publications.

The recorded impacts can be broadly divided into the following categories: changes to the channel morphology, alterations to the composition and movement of sediment; changes to larger scale river features, alteration to the flow regime, and impacts on water quality. A summary of these physical responses is shown in Figure 5.7, with each grouping divided into a number of specific impacts. Impacts associated with changes to the availability of groundwater due to sand mining are discussed in Section 5.8.2, Social impacts.

A total of 107 different impacts were reported in the 46 QSR papers that documented physical impacts. Immediately apparent is the overwhelming predominance of channel morphology change, which was reported in 29 instances. Also apparent is that within most categories, opposite impacts were observed. For example, both channel widening and narrowing, sediment reductions increases (due to exposure and transport of fine-sediment during mining, and changed channel hydraulics), flow increases and decreases, and increased and decreased flood control were all documented. These two observations suggest that whilst sand mining is likely to induce channel incision, there is no one limited set of physical impacts associated with sand mining, with impacts being site-specific and variable. Given the highly variable nature of river systems, and range of extraction methods and volumes captured in the QSR papers, this is not a surprising finding.

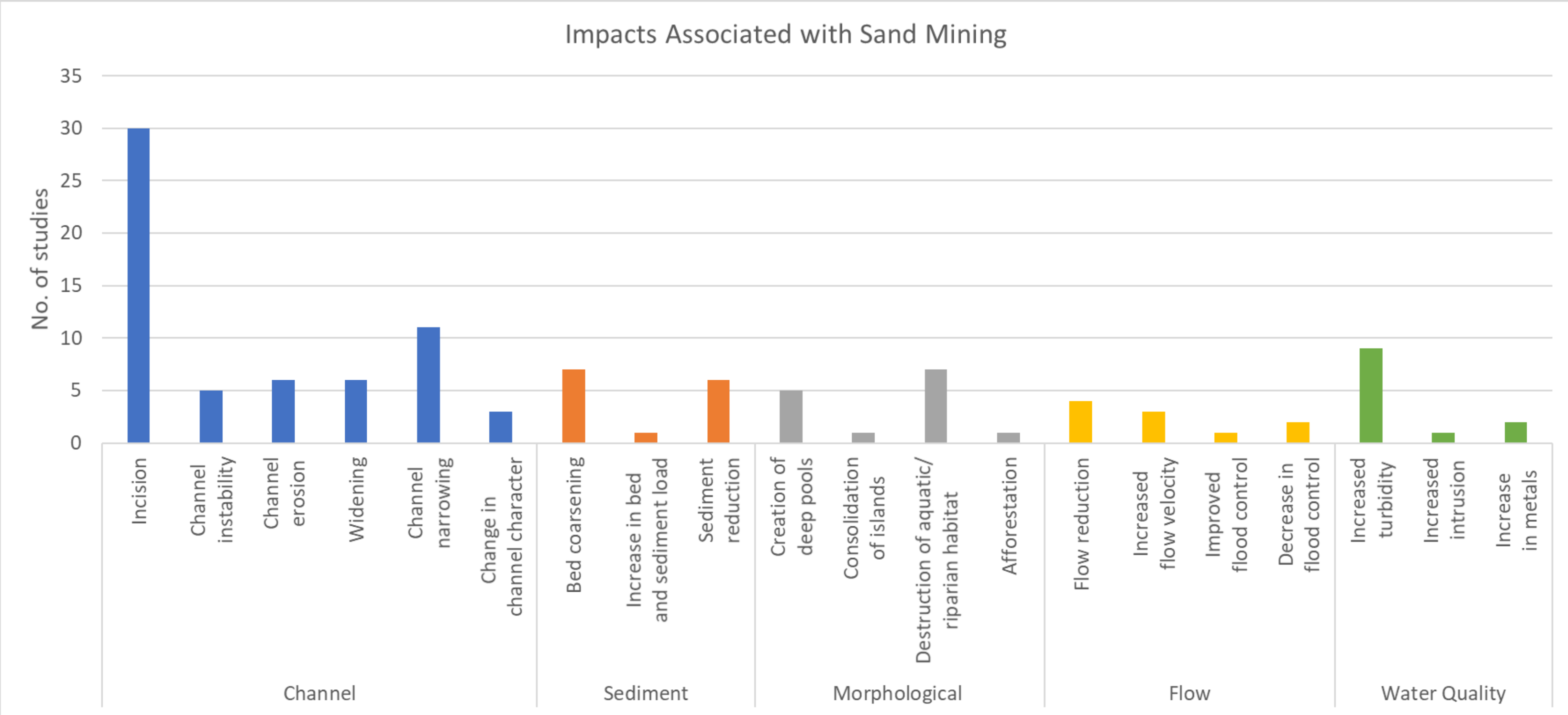


Figure 5.7. Summary of impacts recorded in QSR papers.

Incision

Channel incision was the most commonly reported impact associated with in-stream mining. The degree of channel incision in rivers was quantified in a number of papers, with reported ranges including: 0.5 to 3.5 m over a 40 year period in the Tedori River in Japan (Dang, et al., 2014); 2 to 4 m in an ephemeral river in Spain since the 1970s (Calle, et al., 2017); 3.5 m in montane rivers in Southern Poland (Skalski, et al., 2016); up to 5 m in the Brenta River in southern Italy (Figure 5.8, Moretto, et al., 2014); 10 m in the Panaro River in northern Italy (Gumiero, et al., 2015) to over 30 m in the Bachang River in Taiwan (Huang, et al., 2014). Substantial channel incision was generally associated with channel narrowing. The extreme case of 30 m incision was accompanied by the channel narrowing to 1/6th of its original width. Incision and channel narrowing was linked to bank erosion due to over steepening and destabilisation of banks (Ortega-Becerril, et al., 2016; Campana, et al., 2014).

The widths of several rivers in the Piedmont and Tuscany regions of Italy have decreased by over 50% as a result of incision (Surian & Rinaldi, 2002). This effect was viewed as advantageous in the past as it allows the former floodplain to be mined, developed for agriculture and to be used for infrastructure, however it also fundamentally altered the characteristic of rivers from braided to single channel.

In a delta setting, thalweg deepening of about 1.5 m and irregular deepening was documented over a 10-year period in the Mekong (Brunier, et al., 2014). The areas of incision did not reflect hydraulic conditions in the river and were attributed to sand extraction during the previous decade (Brunier, et al., 2014).

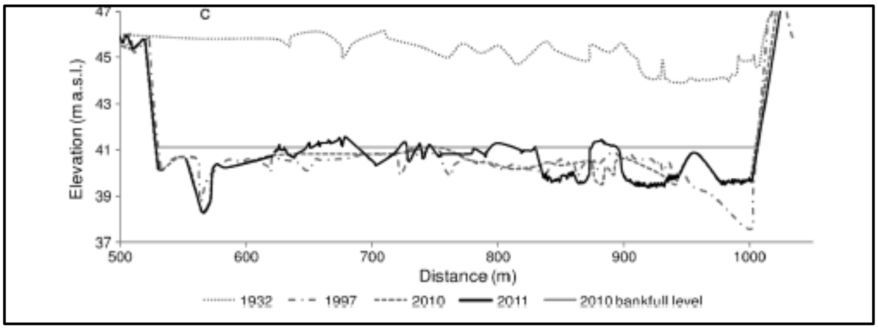


Figure 5.8. Channel incision in the Brenta River in Italy in 1932, 1997, 2010 and 2011. Bankfull discharge indicated by grey line (Moretto, et al., 2014).

Consistent with the geomorphic understanding of nick points (see Section 4.2) and incision resulting from aggregate extraction was documented propagating upstream from the mining activity, with distances of 11 km documented by Kondolf (1997, Figure 5.9) and 12 km by Isik, et al., (2008). Where nick point propagation was recorded, channel widening was also generally reported, suggesting that substrates that are susceptible to upstream propagation of disturbances are also susceptible to lateral erosion processes.

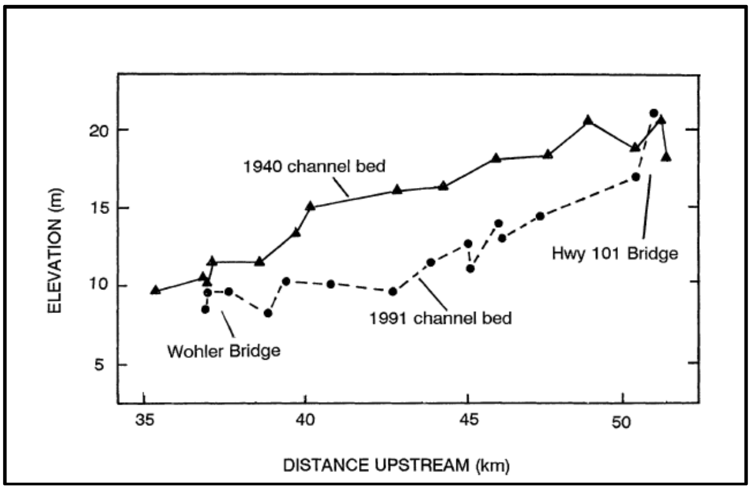


Figure 5.9. Channel incision in excess of 3 - 6 m over an 11 km length of the Russian River in California, USA (Kondolf, 1997).

Incision and channel widening was associated with increasing the braiding of rivers in gravel streams on the Ozark Plateau in central USA (Brown, et al., 1998) but an opposite response was observed in rivers in southern France, with decreasing braiding accompanying sand mining (Liébault, et al., 2013), however other catchment activities such as dams likely affect change as well as mining (Liébault, et al., 2013).

Other channel changes associated with incision included thalweg relocation (Meador & Layher, 1998), decreased floodplain connectivity (Kiss, et al., 2018; Wyżga, et al., 2009; González, et al., 2016). Decreases in the connectivity between the river and groundwater system were observed (González, et al., 2016) as were changes in the water table. Bayram, et al. (2014) documented decreases of up to 6 m in groundwater levels. Lower groundwater levels were linked to inhibiting the establishment of riparian vegetation on river banks impacted by sand mining in the lower Eygues River, France (Kondolf, et al., 2007), and were suggested as hindering efforts to restore impacted rivers. Decreases in the water table may also impact off-channel wetlands, tributaries, and alter the seasonal flow regimes of rivers (Neal, 2009). Groundwater extraction and associated ground subsidence combined with sand mining was identified as a driver of channel incision in the Nogalte stream, in SE Spain (Ortega-Becerril, et al., 2016).

Incision was also linked to bar scalping or skimming mining methods. The removal of the coarser armoured layer from river bars exposes the underlying finer layers of sediment to the river's flow. These finer sediments are mobilised by lower flows than coarser material, so erosion can increase, leading to the removal of the bars. Such collapses alter the hydrodynamic regime of the river, and so can have significant flow on effects on the riverine and riparian environments (Kondolf, 1993).

Erosion associated with gravel and sand mining in a salt marsh in the Potomac River estuary was recorded between 1930s – 1970s, with 55% of the surface area of the wetlands lost (Litwin, et al., 2013). Accelerated erosion was observed following the cessation of mining (1976-2012) with the ongoing impact was attributed to flooding and wave action on a highly altered coastal landscape.

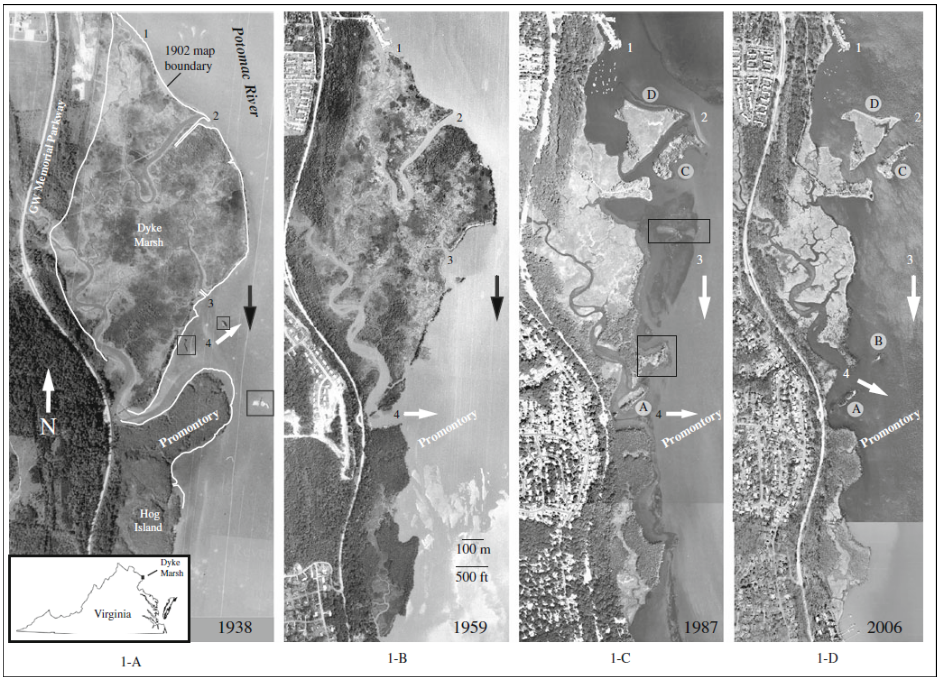


Figure 5.10. Extensive erosion of coastal wetlands in the Potomac estuary of Virginia, USA . Aerial photos show pre-mining (1-A), mining (1-B), and post-mining extent of marshlands (1-C, 1-D)

Sediment changes

Aggregate mining was found to affect sediment transport and the composition of riverbeds in a number of ways. A reduction in sediment loads was a common finding (González, et al., 2016; Mingist & Gebremedhin, (2016); Kondolf, 1997; Podimata & Yannopoulos, 2016), while increased sediment loads linked to increased channel stability were also reported (Sadeghi & Kheirfam, 2015). The selective removal of specific size fractions altered grain-size distributions in rivers (Mingist & Gebremedhin, 2016), and change the bed load to sediment load ratio (Sadeghi & Kheirfam, 2015). Fine sediments mobilised by mining disturbance were found to accumulate in hydraulically quiescent locations, thus changing the distribution of riverine habitats (Freedman, et al., 2013). Fine-sediments were also found to infill bed materials, changing rugose (irregular) sediment surfaces to indurated and embedded substrate (Duan et al. 2008). The same author found that this change dramatically decreased the macroinvertebrate taxa diversity and density of individuals.

The agitation and subsequent embedding of substrates was also linked to the of spread pollutants throughout river systems. Nasrabadi et al. (2016) found and attributed homogeneous heavy metal concentrations in the Haraz basin in Iran to intensive aggregate mining activities. Within such river systems metals are generally highly heterogeneous, and a change to homogeneous concentrations could result in all river organisms being constantly exposed to these harmful substances, and limit their ability to escape them by relocating.

Changes to morphology

Changes to channel shape, sediment composition and availability and the flow regime combine to alter larger scale river morphology and impact the distribution and availability of habitats. Mining was linked with the creation of new pools and lakes (Ronquim, et al., 2017; Mingist & Gebremedhin, 2016), the elongation of existing pools (Brown, et al., 1998), and a reduction in riffles (Brown, et al., 1998). On the floodplain of the Paraiba do Sul River in Sao Paulo State, Brazil, floodplain mining between

1985 and 2016 increased the number and area of lakes from 54 to 316, and 615 ha to 3,876 ha, respectively, reducing the area available for rice cropping (Ronquim, et al., 2017).

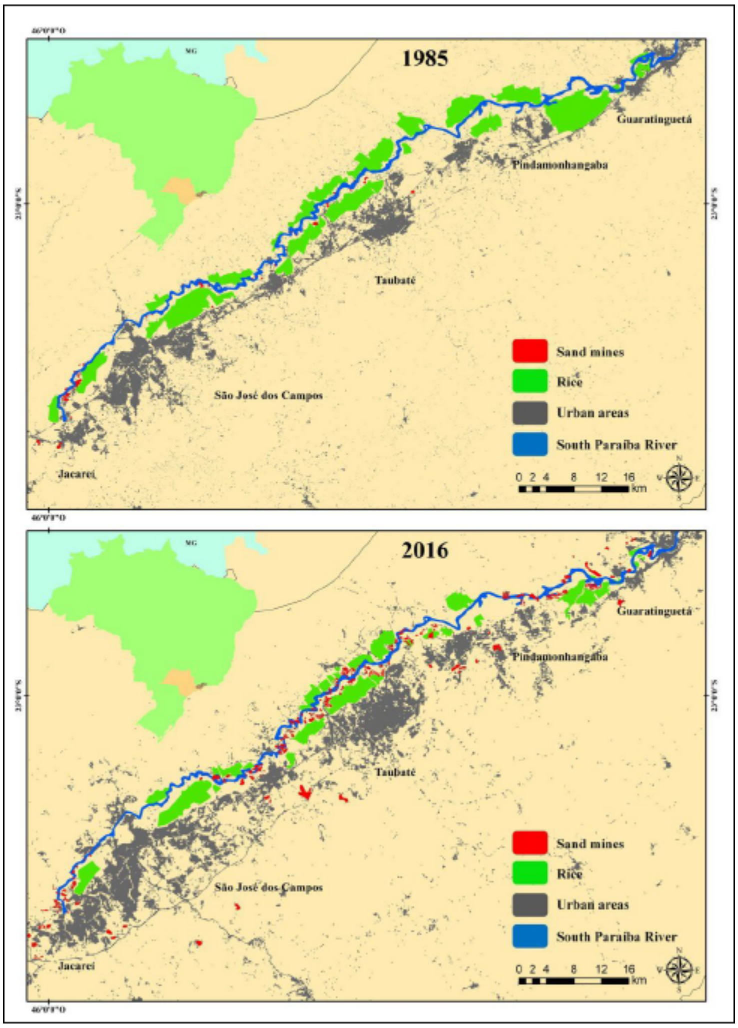


Figure 5.11. Floodplain changes along the Paraiba do Sul River, Brazil between 1985 and 2016 showing large expansion in the number and area occupied by sand mines (Ronquim, et al., 2017).

The creation, deepening, and widening of pools was found to impact Poyang Lake, China, with the creation of deep pools near the lake's outflow being a major driver for the increased discharge and historical reductions in lake water levels (Lai, et al., 2014). The lower water levels and increased frequency of low water levels were identified by the authors as a potential risk to the extensive wetlands that are renowned for their biodiversity and provide vital habitat for half a million birds, including the critically endangered Siberian Crane (Lai, et al., 2014).

Incision was also linked to a stabilisation of riverine islands and an increase in riparian forests (Picco, et al., 2012). Sand and gravel mining in conjunction with other catchment activities in Hungary was found to be responsible for a change in the frequency and morphology of levees along the banks of the Maros River, leading to the gradual disconnection of the river from the floodplain (Kiss, et al., 2018).

River discharge and water level changes

Locally changed river discharge and water level changes were recorded in response to the physical channel changes in many of the studies, although the direction of change was not uniform. For example, Kondolf (1993) found channel widening and a decrease in river level associated with bar scalping, due to the mining allowing the flow to spread across the entire river channel rather than being confined to one single channel during the dry summer months. In contrast, Mingist and Gebremedhin (2016) and Wyżga et al. (2009) documented increased flow rates, with the latter study attributing the higher rates to increased channel capacity. Within Poyang Lake, a reduction in lake water level was attributed to increased water flow at the lake's outlet (de Leeuw, et al., 2010).

Water quality

Water quality changes linked to sand and gravel mining include increases in turbidity, changes to water temperature, changes to the distribution and availability of habitats and increased pollutants and salt water intrusion.

As previously discussed, increased turbidity is linked with both in-stream mining and bar scalping (Kondolf, 1993). Changes in turbidity can impact macroinvertebrate communities by affecting drift, the process through which macroinvertebrates colonise new river sections, escape suboptimal habitats and avoid intraspecific competition (Brittain & Eikelan, 1988). Drifting invertebrates also act as an important food source for organisms ranging from fish to larger invertebrates (Brittain & Eikelan, 1988; Allan, 1978). Béjar et al. (2017) found that suspended sediment concentrations associated with sand extraction could be similar to those occurring during peak flow periods and had differing effects on different groups of macroinvertebrates.

Channel widening associated with bar scalping was linked to increases in water temperature where river velocities are low (Kondolf, 1993). These changes can reduce the availability of shelter and habitat for riverine species, while higher temperatures also result in lower dissolved oxygen concentrations and increases in the toxicity of pollutants such as heavy metals, insecticides, and natural toxicants. (Heugens, et al., 2008).

Impacts of gravel mining on water quality in the Harsit River in the Eastern Black Sea basin of Turkey were found to include increased temperature, turbidity, manganese, chromium and iron concentrations, associated with the extraction and washing of material, with the increase in metals correlated with suspended solids (Bayram & Önsoy, 2015). The study highlighted the potential for the water quality impacts to affect local groundwater, which is extracted at a rate of 5.5 million m^3/yr for domestic use in the city of Tirebolu.

Incision associated with sand mining has increased the extent of salt water intrusion to well beyond pre-mining levels in the Kaluganga estuary in Sri Lanka (Ratnayake, et al., 2013), in the Tweed River, Australia (Rinaldi, et al., 2005) and in the Mekong (Brunier, et al., 2014). In addition to altering water quality Ratnayake et al. (2013) found that previously clean sediments could become contaminated by chlorides diminishing their value. If used in construction, such aggregates can accelerate the corrosion of reinforcements (Kayali & Zhu, 2005) and cause salt efflorescence to occur (Anita, et al., 2010).

Other physical impacts

In addition to impacts affecting physical dimensions and conditions in the river channel, it was suggested in one of the QSR papers that noise associated with sand mining may affect the echolocation of the red listed finless porpoise that lives in Poyang Lake (Wen and Zhang, 2002, cited in de Leeuw, et al., 2010).

5.7.2 Ecological impacts

The following studies identified changes to ecosystems associated with sand mining but did not necessarily identify the physical mechanisms responsible for the observed impacts. Quantifying these linkages is difficult owing to the variable sensitivities of different ecological communities to change, the impact of stressors in addition to sand mining, and the time- and spatial-scales over which impacts may occur.

Fish communities

In total, 10 studies directly investigated the impacts of aggregate mining on fish but produced equivocal results.

Mingist & Gebremedhin (2016) found that aggregate mining had a number of negative impacts on local fish populations. By destroying spawning grounds, interfering with migratory routes and causing large scale fish kills, aggregate mining caused severe declines in local fish populations. These results were obtained qualitatively by surveying workers in sand mines on the Arno-Garno and Ribb rivers in Ethiopia, and were not supported with quantitative data.

The removal of riffle sequences from riffle-pool controlled gravel rivers due to mining and incision were linked to lentic species replacing lotic species and allowed generalist and invasive species to displace native-habitat-specialists (Freedman, et al., 2013; Paukert, et al., 2011).

Consistent with these findings, Paukert et al. (2011) observed an increase in abundance of lentic and non-native fish species in dredged areas, with these sites also having more variable species compositions. They proposed that the augmentation and creation of pools by aggregate mining, which resulted in decreased flow velocities and replaced riffles with pools, were responsible for the observed changes, however other anthropogenic stressors (dams, urbanisation) are likely to have impacted the system. Freedman, et al., (2013), Brown et al. (1998) and Harvey and Lisle (1998) reported similar increases in the abundance of lentic and invasive species after the disruption of natural riffle-pool-run sequences. They also found that generalist species had replaced habitat specialists, but attributed this change to the effects of dams on sediment flow.

Fish are directly threatened by suction dredging during their embryonic stages (Harvey & Lisle, 1998). Mortality rates vary dramatically between species (18% for *Oncorhynchus mykiss* compared to 100% for *O. clarki*), while juvenile and adult fishes are likely to avoid or survive passage through a suction dredge.

Rempel & Church (2009) found that dry experimental bar scalping in the Fraser River, British Columbia, Canada, had no discernible impact on the local fish community. They further found that mining temporarily changed both the abundance and diversity of invertebrates, however the mined section was immediately recolonised and differences in community composition between the mined and reference sites disappeared after a flood event. They concluded that the disturbance used in this study (extraction of 69,000 m^3 see Table 5-1) fell within the range naturally experienced by native organisms during flood events. Their results suggest that aggregate mining may have minimal ecological impacts if controlled volumes are extracted at low frequencies.

Meador & Layher (1998) summarised information presented at the 1997 midyear meeting of the Southern Division of the American Fisheries Society, and reported varying impacts of aggregate mining on fish communities. Gravel dredging in the Brazos River reduced the abundance of many sports fishing species, while floodplain mining in Alaska caused severe channel alterations that have been linked with the elimination of local fish populations. Conversely, there was no significant difference in fish abundance or community composition in dredged and nondredged areas of the Tennessee and Cumberland rivers.

Furthermore, the impact of mining on fish species composition and abundance varied between the Uphapee, Line, Cubahatchee and Mulberry creeks in Alabama, despite similar anthropogenic pressures and fish community health upstream of mining activities. At mined sites, the relative abundance of cyprinids, blacktail shiner and speckled chub increased, while the relative abundance of percids, and various darters, decreased (Meador & Layher (1998).

Additionally, Meador & Layher (1998) found that while there was some variation between species, turbidity of less than 25 ppm did no harm to fisheries, while chronic exposure to between 25 ppm-100 ppm could be tolerated. Higher levels had marked negative impacts, with sight feeders such as trout and bass more likely to be harmed than non-sight feeders such as catfish.

Through stable isotope analysis of $\partial^{13}C$ and $\partial^{15}N$, Freedman et al. (2013) revealed that fish from undredged sites obtained nutrients from the benthos, while fish in dredged areas relied on phytoplankton and terrestrial detritus. Fish from dredged areas also occupied lower trophic positions, indicating that aggregate mining changed the food-web structure. Similar impacts in food web structure were reported for Big Rib River, Wisconsin by Kanehl & Lyons (1992).

Freedman et al. (2013) suggested that fish species belonging to brood hider and substratum chooser reproductive guilds are more heavily impacted by aggregate mining than nest or open substratum spawners. Taxa in the brood hider and substratum chooser reproductive guilds require a rugose (wrinkled, corrugated) substrate to spawn, hence they are unable to spawn on the well embedded fine-grained substrates created by the settling of fine sediments agitated by aggregate mining. Such substrates favour nest spawners who can easily burrow into fine sediments, while open broadcast spawners are not strongly impacted by substrate type. In addition to damaging spawning habitats, fine sediments can directly impact silt-sensitive fish species (Brown, et al., 1998).

Aggregate mining can destroy spawning habitats by selectively removing sediments of a specific size (Harvey & Lisle, 1998). Fish such as salmonids build hollows to spawn in, and are only able to do so in sediments with grain sizes smaller than a certain proportion of their body length. Aggregate mining can remove these gravels, leaving behind cobbles that are too large for fish to move and hence hindering spawning (Kondolf, 1993; Kanehl & Lyons, 1992). Similarly, the rearrangement of bottom materials during aggregate mining could hamper fish reproduction by decreasing the stability of the resulting deposits. These deposits may appear attractive to salmonids, however they are more likely to move during high flows, killing embryos sheltering within these features (Harvey & Lisle, 1998).

Wyżga et al. (2009) investigated the impact of aggregate mining and channelisation on the fish communities of the Czarny Dunajec River in the Polish Carpathians. They found that the diversity and abundance of fish species was substantially greater in multi-channelled unmanaged cross-sections that had not undergone sand mining as compared to single channel, incised cross-sections. They found that the diversity and abundance of fish species increased linearly with increasing variation in depth within the multi-channelled cross-sections, and exponentially with improving hydromorphological river quality, but were not linked to habitat area. They concluded that the simplification of flow pattern and degradation of hydromorphological quality arising from aggregate extraction caused remarkable impoverishment of fish communities.

The effect of aggregate mining on groundwater levels was also linked to impacts on fish populations. Summer river temperatures are increasing in river systems acrosss North America, with these rises in temperatures likely to have negative impacts on cold blooded fish. Such fish may alleviate thermal stress by aggregating in cold water plumes created where groundwater seeps into rivers. By lowering the water table, aggregate mining can reduce the intensity of these seeps, therefore removing thermal refugia for cold blooded fish species (Kurylyk, et al., 2015).

Invertebrates

Investigations targeting organisms other than fish also identified a range of impacts associated with sand mining. Brown et al. (1998) found that impacts on macroinvertebrate assemblages varied between invertebrates of different sizes, and the magnitude and frequency of mining. The density of both large (*Corydalidae*, crayfish, and molluscs) and small invertebrates were significantly higher in unmined sites, while the biomass of large invertebrates also decreased in these areas. Such a decrease was not observed for small invertebrates. Functional group analysis revealed that the abundance of collector-gatherers was unchanged between dredged and undredged sites, while the number of collector-filterers decreased dramatically.

Kanehl & Lyons (1992) reported a decrease in invertebrate populations resulting from direct removal during mining activites, habitat disruption, and increases in sedimentation.

As discussed under 'water quality' in Section 5.7.1, changes in turbidity can impact macroinvertebrate communities by affecting drift, which affects the ability of macroinvertebrates to colonise, escape suboptimal habitats and avoid competition (Brittain & Eikelan, 1988). Affecting drift will also alter the availability of invertebrates as an important food source for organisms ranging from fish to larger invertebrates (Brittain & Eikelan, 1988; Allan, 1978). Béjar et al. (2017) found that suspended sediment concentrations associated with sand extraction could be similar to those occurring during peak flow periods and had differing effects on different groups of macroinvertebrates.

The impacts of aggregate mining on mussels have been investigated in the Amite River, Lousiana, United States. (Brown & Daniel, 2014) found that sand mining increased the risk of stranding and death for the Heelsplitter mussel (*Potamilus inflatus*) due to low water levels associated with incision. As most mussels have limited mobility, other species are likely to be similarly affected. Smith & Meyer (2010) examined the impact of aggregate dredging within navigational pools in the Allegheny River, Pennsylvania. The removal of sand and gravel and agitation of fine sediments had negative effects on both mussels and the fish that play an important role in their life cycles.

Riparian zones

The impacts of aggregate mining also extends to riparian zones. The creation of access roads and storage sites to support aggregate mining have fragmented riparian forests in the Lower Eygues River, France (Kondolf, et al., 2007). The lowering of the water table caused by aggregate mining related incision may also prevent the establishment of pioneer forest on previously cleared riparian habitats (Kondolf, et al., 2007).

Gumiero et al. (2015) linked observed vegetation types (e.g. mature *Potametea, Charetea fragilis*) with particular landforms (e.g. channels). Each landform was generally associated with a single vegetation type, however this relationship diminished in highly impacted river sections. Reaches that had undergone narrowing due to aggregate mining induced incision were colonised by a range of pioneer vegetation and had higher diversities as compared to the most pristine river sections which exhibited the least diversity in community composition (Gumiero, et al., 2015).

Asaeda and Sanjaya (2017) investigated the impacts of incision and aggradation on the colonisation of steep, gravelly river reaches by riparian vegetation. They found that deposited gravel layers contained little moisture and nutrients, and so colonisation of these areas was delayed. In river sections characterised by erosion (such as river stretches subjected to aggregate extraction) these gravelly sediment layers are removed, accelerating the establishment of riparian vegetation. Kanehl & Lyons (1992) reported changes in aquatic plant communities associated with increased scouring and changing substrate compositions caused by aggregate mining.

Skalski et al. (2016) investigated the effects of incision induced by aggregate mining on the structure of ground beetle assemblages in riparian settings. After measuring the abundance and diversity of beetles at three different elevations above both incised and vertically stable river stretches they found that only the structure of beetle assemblages on the lowest elevation were highly negatively impacted by river incision. Beetle assemblages and behaviors typical of undisturbed habitats were more prevalent on the highest elevation of incised stretches rather than vertically stable sections. Skalski et al. (2016) attributed this to the prevalence of riparian vegetation along these stretches, as more stable sections were more likely to be cleared for agriculture.

Kumar & Kumar (2014) conducted a phytosociological study of a riverine aggregate mine and its surrounding areas near Palri Bhoptan village, Rajasthan, India. The primary impacts of aggregate extraction was the direct removal of vegetation, however the act of mining and the dumping of tailings also altered soil profiles, changed the areas hydrology and topography, and altered the nutrient concentrations of the substrate. The changes in vegetation altered the rates of carbon and nitrogen cycling, the productivity of the ecosystem, and altered the structure of the microbial community.

5.8 Social impacts

Aggregate mining not only affects the physical state and ecology of rivers but also the societies within the river catchment. Within the QSR papers, 11 included discussions of the social impacts of aggregate mining, with the same number linking aggregate mining with depleted fisheries, loss of land, destroyed infrastructure and reductions in groundwater quality, all of which have social impacts. The studies that reported infrastructure damage and groundwater depletion generally cited multiple examples. This may suggest that these impacts are the most common social impacts of aggregate mining, although the limited number of studies considered prohibits such conclusions from being drawn with any certainty.

The QSR papers did not identify impacts on fisheries or other aquatic organisms as a social impact, but rather an ecological issue. This is probably related to the papers being predominantly derived from developed countries in North America and Europe, where communities are not directly dependent on waterways for food. In developing countries, where sand mining occurs extensively but appears infrequently in the literature, impacts to fisheries could represent a major social impact.

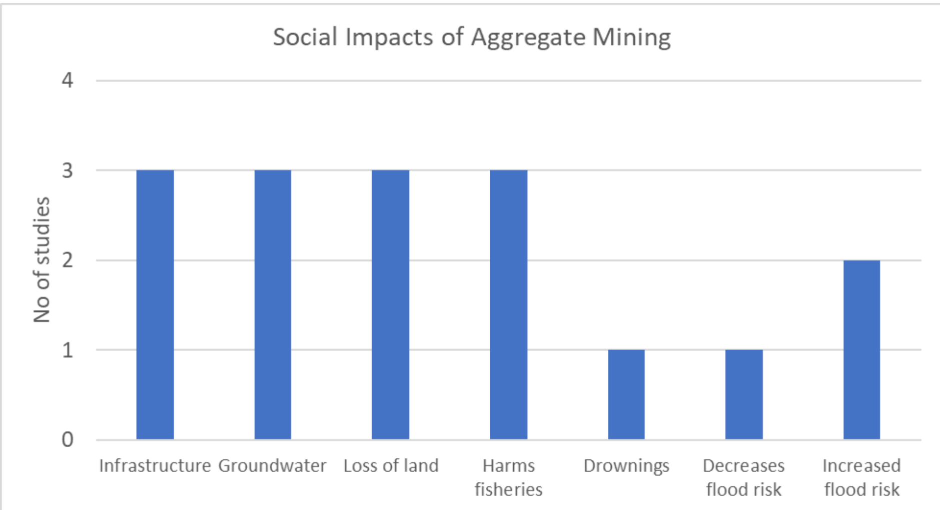


Figure 5.12. Social impacts of aggregate mining

5.8.1 Infrastructure

The impacts of aggregate mining on infrastructure, particularly bridges, was associated with incision leading to the undermining of support structures. Five bridges over the Bachang river in Taiwan failed, with four of these being caused by unexpectedly high rates of incision in the underlying sandstone bedrock attributable to a combination of sand mining and bank protection measures.(Huang, et al., 2014). Weirs were similarly undermined and require continuous maintenance which is unlikely to be feasible over the long term with mitigation options such as the installation of dams and devices designed to dissipate the river's energy being considered.

Bridges upstream of aggregate mines in California have suffered similar fates (Kondolf, 1993). In 1981 a bridge over the San Diego River on California Highway 67 had to be completely replaced at a cost of $3.3 million USD due to downstream sand mining, while damage caused by incision required a $700,000 USD repair of a bridge on California Highway 118. In 2018 dollars, these repairs would cost in excess of $5 million USD. The undercutting of bridges and weirs has also been reported for rivers throughout Italy, France, Spain, Poland and England (Rinaldi, et al., 2005). Damage to bridges can impact people's lives on a daily basis for long periods of time. In India, aggregate extraction caused the failure of a bridge downstream of the Farraka barrage and locals were forced to choose between using a slow ferry or taking a 50 km detour to cross the river.

It is not only bridges and weirs that can be impacted by incision. In some cases underwater cables and gaslines have been exposed, while the lowering of the river level associated with incision can render irrigation channels and pumps useless (Rinaldi, et al., 2005).

Ortega-Becerril, et al. (2016) linked gravel extraction to an increase in the severity and extent of flooding in the Nogalte Stream, Spain. The authors attributed increased river energy and an increase in the distribution of flood waters to a combination of a reduced sediment load and channel incision associated with gravel mining, and land subsidence associated with the extraction of ground water contributing to a reduction the base level of the river. Similarly, Nakayama & Shankman (2013) recognised that intensive aggregate mining near the outlet of Poyang lake increased the flood risk of the area, however they also suggested that strategically selecting sites for aggregate extraction could have the opposite effect and limit flood risk.

5.8.2 Groundwater availability and quality

The lowering of river levels associated with sand mining may also lead to a lowering of the surrounding water table. Such a decrease can limit the effectiveness of wells (Kondolf, 1993; Rinaldi, et al., 2005) and so threaten the water availability for both local people and agriculture, resulting in economic losses (Rinaldi, et al., 2005). The agitation and introduction of pollutants to rivers through mining may contaminate groundwater and threaten the health of those who use it. Bayram & Önsoy (2015) suggested this may be occurring within the city of Tirebolu, Turkey.

5.8.3 Eroding usable land

Aggregate mining can increase flow speeds and accelerate the erosion of banks, eliminating previously usable land. In the Lower Sakarya River, Turkey, erosion linked with aggregate extraction caused private land to be lost, and culminated with the landholders suing the mining company (Isik, et al., 2008). Harvey & Lisle (1998) discussed similar impacts of mining and pointed out that, once lost, this land was unlikely to be regained in the near future.

Aggregate mining can reduce the amount of land available for other uses in other ways. Aggregate extraction caused a dramatic increase in the number (54 to 316) and area (615 ha to 3,876 ha) of deep pools between 1985 and 2016 within the Paraíba do Sul basin in southeastern Brazil. In conjunction with increasing urbanisation, this increase in aggregate mining resulted in the area of land used for agricultural crops decreasing from 24,131.4 ha to 13,780.8 ha over the same timeframe (Ronquim, et al., 2017), impacting the livelihoods of local farmers.

In the Sakarya River in Turkey, sand mining has been linked to the loss of private land, negatively impacted fish spawning and increased drownings due to the change to the river channel and flow dynamics (Isik, et al., 2008). Legal action was taken against the miners as a result of these impacts.

Farahani & Bayazidi (In Press) surveyed communities near sand mining locations in the Tato River in north western Iran. The respondents rated environmental and social costs and benefits associated with sand mining on a scale of 1 to 5, with the average results showing that environmental and social costs were considered to exceed benefits, while economic costs and benefits were considered similar (Figure 5.13).

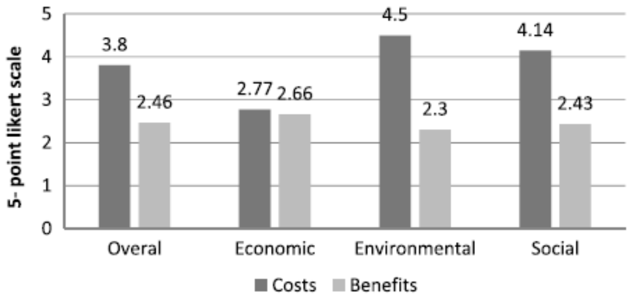


Fig. 1. Economic, environmental, and social cost/benefit of sand mining from point of respondents, average of 5-point Likert type scale. On a scale of 1–5 where 1 = very low and 5 = very high impacts. Bar chart showing the mean of Likert scale responses.

Figure 5.13. Average economic, environmental and social cost/benefit of sand mining based on survey of communities near sand mining locations. 1 = very low, 5 = high (Farahani & Bayazidi, In Press).

Other impacts

The increased intrusion of saltwater during high tides associated with aggregate mining can have impacts on society that extend beyond reducing the quality of construction materials. Such intrusion in the Mekong Delta has resulted in decreases in drinking water quality and salinisation of agricultural land in Southeast Asia's most important food growing region (Anthony, et al., 2015), while intrusion in Sri Lanka has reduced crop productivity (Pereira & Ratnayake, 2013).

While these social issues were mentioned in studies included within this QSR, they do not make up an exhaustive list. One social impact that went unmentioned in the QSR but was identfied in papers surveyed during a general literature review was the role aggregate mining may play in the spread of communicable diseases (Padmalal & Maya, 2014). For example, aggregate mining creates, enlarges and deepens pools, creating areas of stagnant water where disease vectors such as mosquitos may breed (Soleimani-Ahmadi, et al., 2013) and which have been linked with an increased incidence of the Buruli ulcer (Merritt, et al., 2010).

5.9 Interaction between sand mining and other stressors

Rivers impacted by aggregate mining typically flow through populated areas and are also subjected to other stressors such as dams, channel manipulations, land use changes, and industrial discharges Figure 5.14 separating the impacts of mining from those arising from other stressors is challenging. The difficulty in attributing observed changes to individual stressors is complicated by both the time frame and irregular rate at which rivers respond to changes.

Figure 5.14 shows that almost a third of the QSR papers reported dams as having a potential impact on the river systems with about a quarter of the investigations also reporting channel manipulations other than sand mining. Channel manipulations included flood control measures, modifications to improve navigation, straightening of rivers to allow for the development of floodplains and the diversion of river water for irrigation use.

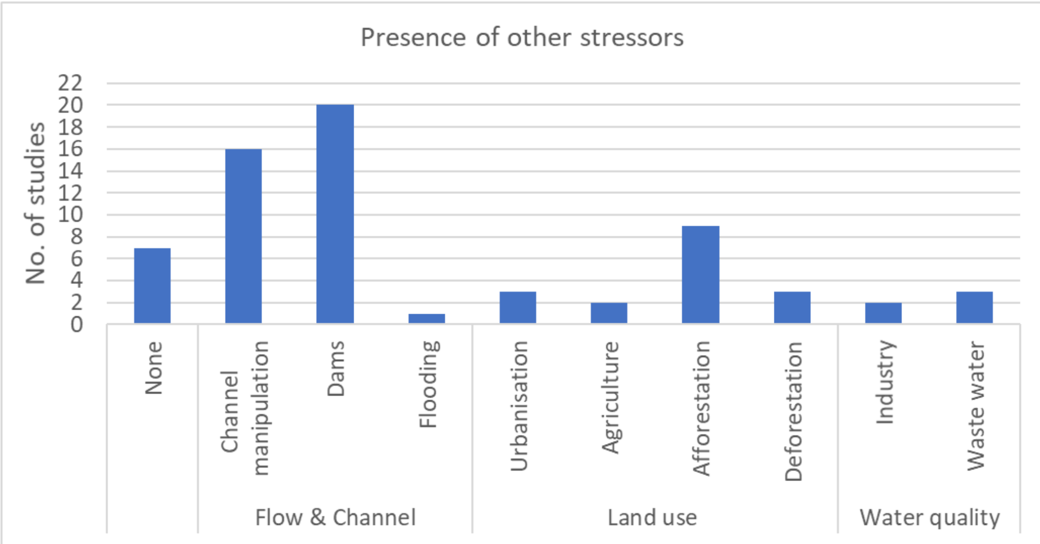


Figure 5.14. Anthropogenic stressors present on rivers.

Few of the investigations systematically or quantitatively evaluated other stressors, with most acknowledging the potential interaction and impact of these additional activities on the river morphology or ecosystem.

Several studies attempted to directly link stressors with impacts, but the investigations found differing and at times opposing responses. Latapie, et al. (2014) investigated channel changes in the middle Loire River in response to multiple stressors (e.g. flood embankments, groynes, bridges, dams, sand mining, changes in land use) over a 50-year period. The study concluded that historic sand mining exerted the major control on the river morphology with the observed channel changes reflecting the distribution of former sand extraction sites. In addition they found that bed aggradation increased following the cessation of mining, and regardless of the previous rate of extraction, bed stability was re-established within a 15-year period (Figure 5.15).

An investigation of the Ahr River in the Italian Alps arrived at a similar conclusion based on an analysis of planform (shape) and vertical changes between 1820 to 2011 (Campana, et al., 2014). The river experienced intense narrowing, incision and floodplain disconnection in the 1960s, and the study found that while changes to the sediment and flow regime in the early twentieth century contributed to the observed channel alterations, the main driver was gravel mining. The study's authors state their findings are consistent with those for other rivers in the Alps.

A third study, examining 31 alpine braided rivers in southern France attributed gravel mining as the main factor explaining degradation of braided channels (Liébault, et al., 2013). The work also developed an index to establish where a channel was in the recovery process after gravel mining ceased. For an ephemeral river in eastern Spain Calle, et al. (2017) concluded that climate and land use changes were present, but their effects were completely masked by in-stream gravel mining. Similarly Moretto et al. (2014) attributed major river changes to sediment mining, but highlighted the important role large floods play in shaping channels.

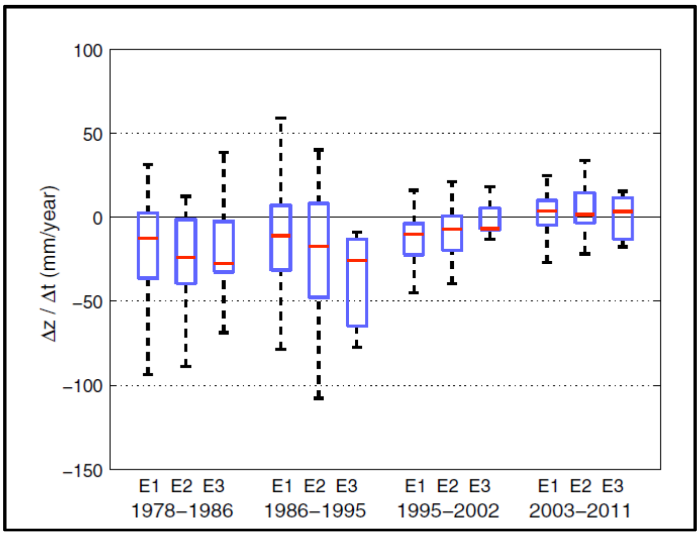


Figure 5.15. Changes to bed level during periods of sediment extraction (1978 to 1995) and following cessation. E1 – E3 indicate low (<1,000 tonnes/yr), medium (<100,000 tonnes/yr) and high (>100,000 tonnes/yr) extraction rates (Latapie, et al., 2014).

In contrast, Provansal et al. (2014) investigated the sediment balance of the lower Rhône River over 130 year period with the aim of establishing the impact of hydropower dams as compared to other factors. The investigation found that river engineering works combined with reductions in sediment input associated with a decline in rural agriculture and subsequent reforestation had a greater impact in geomorphologically transforming the Rhône as compared to dams or gravel mining (Provansal, et al., 2014).

An in-depth investigation of the Tedori River in Japan (Dang, et al., 2014) specifically investigated the relative contribution of sand and gravel mining, dredging and hydropower development on the observed morphological changes between 1950 and 2007. The results indicated that prior to the development of hydropower, sand mining caused channel degradation when sediment extraction rates exceeded sediment supply rates. Following the implementation of hydropower, the combination of dam operations and sediment mining produced widespread channel erosion, however the rate of channel erosion was reduced compared to the period of sediment extraction without hydropower. This was attributed to a reduction in the sediment carrying capacity of the river related to the revised flow regime. A similar change was observed following the cessation of sediment mining, with the river bed experiencing aggradation. The increased deposition in the channel was attributed to the reduced sediment transport capacity of the regulated flow regime, and also to an increase in in-channel vegetation (which is also attributable to reduced flooding). It was suggested that the increased vegetation stabilised the bed, slowed water velocities and trapped sediments. The study highlights the complextities, interdependencies and linkages of processes and demonstrates that changes to the flow regimes associated with damming exert as large a control on downstream impacts as the trapping of sediment.

These comprehensive studies highlight that the impacts of sand mining are likely to vary both between and within river systems, with alpine and low land reaches having different responses. The investigations also demonstrate that the impacts of aggregate mining, and processes of recovery or readjustment following the cessation of mining occur over time-frames of decades.

Other stressors that were found to contribute to river incision included bank protection works that restrict channel migration, and levees that limit the connectivity between the river and the floodplain (Kondolf, 1997). Channel infrastructure was also linked to positive impacts for aquatic ecosystems in rivers affected by sand mining and dredging. Freedman et al. (2013) identified areas downstream of dams and under bridges as having higher diversity of benthic fishes and mussels as compared to dredged sections of the Allegheny River, and attributed these differences to a ban on dredging in these areas of the river.

Afforestation was found to have a multi-faceted interaction with sand and gravel mining. As river channels narrow due to incision, riparian forests can expand into abandoned braided river channels and isolated floodplains (Kondolf, et al., 2007). Asaeda and Sanjaya (2017) suggest that riparian forests are more easily established once gravels are removed from a river, as finer-grained substrates contain more nutrients and can hold more water which are primary requirements for vegetation establishment.

An investigation in the Tajan River in Iran used a Multimetric Macroinvertebrate Index to evaluate the relative impacts of catchment activities (agriculture, aquaculture, dams sand mining, and other industrial activities) on the biological health of the river (Aazami, et al., 2015). The findings suggested that industrial activities such as pulping, papermaking or sand mining exerted a greater impact than agriculture and fish ponds, with the observed changes strongly related to sediment deposition and turbidity (which can be associated with both sand mining and pulp effluent).

In addition to exacerbating or minimising the physical impacts of aggregate mining, anthropogenic stressors can also change the ecological effects. Aggregate mining, waste water, and industrial plants can all pollute and warm rivers. In addition to reducing the oxygen content of rivers, warming increases the toxicity of many different types of pollutants. The presence of facilities such as factories or waste treatment plants on stretches of rivers already impacted by aggregate mining may therefore increase the negative effects experienced by aquatic organisms.

5.10 Synthesis of QSR

The QSR results for the evidence of the impacts of aggregate mining on ecosystem structure, process and biodiversity in rivers, floodplains and estuaries has provided a range of insights into the physical and ecological impacts of sand mining in world rivers. Important findings include:

- Most rigorous research on the impacts of sand and gravel mining on rivers has been conducted in North America and Europe, where sand mining has been prohibited in many rivers and is heavily regulated where it continues. The benefits of these studies include the identification of impacts, an indication of time-frames over which impacts and recovery occur, and interactions between sand mining and other catchment activities. Limitations of these results include:
    - The rivers are predominantly in temperate climates and the findings are not necessarily applicable to tropical rivers in monsoonal climates where sand mining is presently occurring at high rates;
    - Along with regulations for sand mining, other catchment activities that can affect rivers and interact with sand mining (agriculture, forestry, irrigation, etc.) are also regulated, such that the documented impacts from these rivers may not reflect the full spectrum of potential impacts in countries where regulation and / or enforcement is lacking.
- The QSR results consistently identify incision as a primary impact of sand mining. However, there is no uniform response with regard to how rivers respond to incision.

Channel narrowing was more commonly observed (10 studies) as compared to widening (6 studies), with a range of factors identified as influencing river response and nick point propagation, including: the nature of the substrate, the characteristics of the existing channel, river slope, nature and distribution of riparian and floodplain vegetation, presence and degree of river regulation and other river and land uses. This highlights the need to understand the underlying characteristics of rivers before appropriate management, mitigation or restoration approaches can be developed, or 'sustainable' mining targets developed;

- There is evidence, albeit limited, that rivers can sustain sand extraction if the extracted volumes are within the natural sediment variability of the system. Several studies identified floods as important factors in restoring and 're-setting' river channels and gravel bars impacted by aggregate extraction, suggesting that mining needs to be considered and managed like an extreme event in the context of geomorphology. This might include linking sand extraction rates or maximum extractable volumes to flood frequency, or duration;
- The interaction between sand mining and riparian vegetation is important and complex. Vegetation is a strong stabilising agent of river channels, and changes to substrate or channel characteristics will induce changes in the riparian vegetation that in turn have the potential to alter the river channel. A common example is the conversion of a braided river to a single channel river due to sand mining, followed by increased riparian forests on the abandoned banks and channels that in turn increase the stability of the narrow, incised channel form. Riparian vegetation and zones provide critical links between aquatic and terrestrial ecosystems and alteration of these zones can directly affect ecosystem processes;
- The documented impacts of sand mining on ecosystems are diverse with an increasing range of impacts being recognised over time. Sand mining leading to the loss of gravel beds and associated destruction of fish breeding habitat has long been recognised and is often cited. Disruption to migration and alterations to thermal regimes of rivers have also been documented. However, the impacts on species and communities are often inferred from observed habitat changes rather than quantified in biological measurement studies. Nevertheless, some research has recorded declines in native fish and invertebrate species and increases in invasive alien species. More recently studies have shown that larval drift can be affected by sediment plumes created by sand mining, and isotopic investigations show fundamental changes in the food webs in areas affected by sand mining. It is highly likely that sand mining has many additional impacts on riverine ecosystems that are not currently recognised in the existing literature;
- The interaction between sand mining and other catchment activities, including urbanisation, dam building, and floodplain development is widely recognised, but poorly quantified. The few studies that have attempted to quantify these relationships arrived at different conclusions with respect to the relative importance of sand mining, land use changes and dams. This again highlights the complexities of the system and highlights that there is no one model of sand mining impacts that is suitable to all river systems. An important aspect of these studies is that they addressed the relative impact of these activities on decadal to century time-scales, reflecting the time periods required for changes to manifest;

- A significant finding of the QSR is that the countries and rivers for which there is science-based evidence related to sand mining impacts are *not* the countries where extensive in-stream and floodplain mining are presently occurring. Exceptions include Lake Poyang in China, which is well represented in the QSR, and from which the largest documented volumes of material are being extracted on an annual basis (~235,000,000 m^3/yr) and by total volume (as of 2013 1,888,000,000 m3/yr, (Lai, et al., 2014), and the Mekong, where deltaic impacts are linked to large scale and often illegal mining (Anthony, et al., 2015). Articles cite examples of extensive legal and illegal mining in China, India, SE Asia (Cambodia and Vietnam), Indonesia and Malaysia, and more recently Bangladesh. This finding suggests that the scientific literature does not reflect the present status of global sand mining nor impacts.

5.11 Comments on limitation of QSR criteria

The QSR approach has been adopted to provide a robust assessment of the published scientific findings on the impacts of aggregate mining on **ecosystem structure, process and biodiversity** in rivers, floodplains and estuaries. This central question does not capture scientific papers that report only on the physical changes within river systems associated with sand extraction, of which there are many (See Section 4.2 and the references there in). Whilst these studies of physical changes may not provide direct linkage to ecosystem response, 85% of species on the IUCN Red List are threatened by habitat loss and degradation, making it the most significant risk to global biodiversity (IUCN, 2015). Similarly, the QSR approach does not capture investigations identifying changes to ecosystem structure, process or biodiversity that are linked to physical changes in rivers not caused by sand mining.

The impacts associated with sand mining may also be indirect, making investigation even more complex. The relatively low number of investigations that address both aspects of the question likely reflects the inter-disciplinary requirements of such an investigation, the different time-scales over which geomorphic and ecological processes may operate, and the fundamental complexities of linking physical and ecological processes. An example of this is where river bed incision due to sand mining increases channel capacity and reduces the duration and extent of floodplain inundation. Over time, these hydrologic and hydraulic change to the floodplain will affect the habitat structure. Similarly, a reduction in sediment delivery to a deltaic system will promote the sinking and shrinking of the delta, ultimately reducing and altering the availability of habitats. These changes may occur after the sand mining activity has ceased, thus complicating the ability to directly link the sand extractions with the ecosystem response.

In a broader, less structured literature review, a common approach would be to summarise the documented physical changes to river systems associated with sand mining, and summarise recognised ecosystem impacts arising from physical disturbance from any cause, and link the findings within the context of identifying ‘changes to ecosystems that could be caused by sand mining’. However, the aim of this investigation was to identify and quantify scientific investigations that directly link sand mining impacts with ecological impacts.

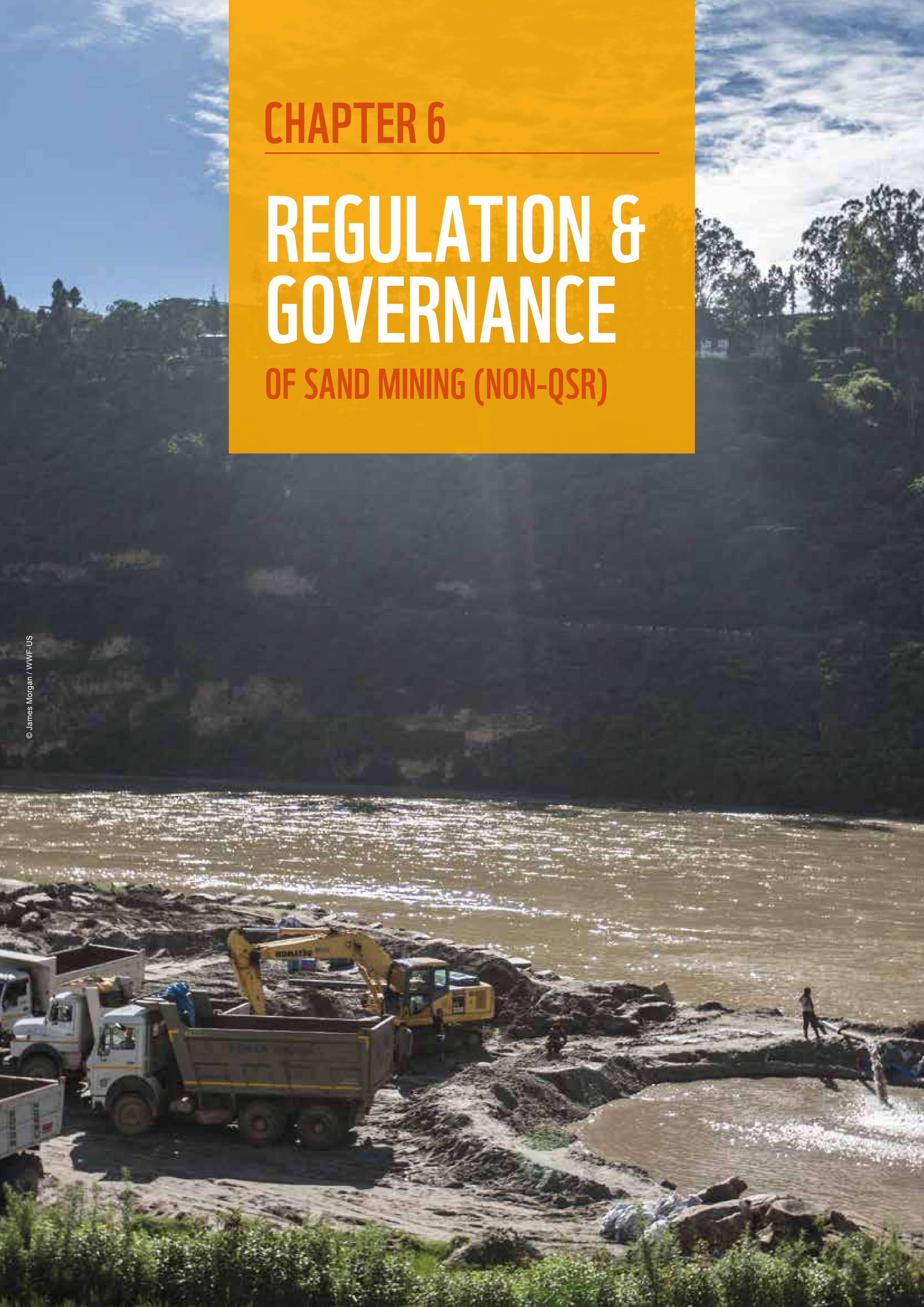
Another potential limitation of the investigation is restricting the search to the past 25 years, as the impact of sand mining in rivers has been well recognised and investigated for many decades. In western Europe and the US, the impacts of sand mining were recognised in the mid-1900’s, and the activity has been eliminated or highly regulated (Bravard, et al., 2013), resulting in little active research into the topic. Many of these older papers are included as references in papers included in the QSR (e.g., Provansal, et al., 2014; Liébault, et al., 2013).

The restriction of the QSR to papers published in English may have prevented the inclusion of relevant investigations published in other languages. Sand mining in world rivers is ubiquitous, and where sand mining is shown to impact local ecosystems it would be reasonable to publish this information in the local language, to promote dissemination of the findings to government, industry and the community. Many older geomorphic investigations of rivers in Europe were also published in non-English journals.

CHAPTER 6

REGULATION & GOVERNANCE

OF SAND MINING (NON-QSR)



6 Regulation and governance of sand mining (non-QSR)

6.1 Introduction

The regulation of sand and gravel mining from rivers was researched using a traditional literature review. An internet-based search was conducted using the name of a country followed by terms such as aggregate, regulation, rivers, sand mining, government, controls, and legislation. There was little information for some countries, while for others there were guidelines and some references to overarching legislation. For many of these countries there was also a plethora of articles related to illegal mining, suggesting that even where sand extraction in rivers is 'regulated' the regulations, such as limits on extraction volumes, are often not enforced.

The following sections provide overviews of the available information on a regional basis. The final section provides a summary and some observations about the findings.

6.1.1 Western Europe and North America

The developed countries of Western Europe and North America have effectively banned or drastically reduced in-stream mining due to its environmental impacts. Bravard et al. (2013) note that the impacts of sand and gravel mining were recognised in Italy as early as the 1950s, while in France, the activity was considered detrimental by the end of the 1970s, unsustainable in the 1980s and finally banned in the early 1990s. The authors conclude that regulations have been drafted and are now enforced in industrialised countries. This finding is consistent with information from the European Aggregate Association which states that 'pits' are the predominant source of sand and gravel, with no category for in-stream sources (EUPG, 2016).

In Europe a different situation exists with respect to Marine Aggregates (MA), which presently contribute a low percentage of material to the European market but whose share is projected to increase in the future (EUPG, 2016). A review of regulations related to the extraction of MA in the EU concludes that 'rules and procedures relevant to MA extraction vary considerably between the considered Member States' (Radzevicius, et al., 2010). In general, accurate, comprehensive, and up to date information relevant to MA extraction is not easily available making evaluation of compliance with international and European rules and regulations difficult (Radzevicius, et al., 2010).

Coastal sand mining has become a social and political issue in Brittany, France, where sand extraction is being proposed from a Natura 2000 site. A 15-year concession has been granted for the removal of up to 250,000 m^3/year of shell sand (Coastcare, 2016).

In the US a similar decline in in-stream mining has occurred. A final large decline in in-stream extraction was documented in the northwest of the US in the 1990s as awareness of the damage inflicted on salmon and steelhead habitat by in-stream mining increased (Fish, 2001). The web search did not find any overarching regulations directed at in-stream aggregate extraction in the United States, and regulations and policies that were applicable generally addressed one component, such as management of wash water under the Clean Water Act or impacts to river environments under the Endangered Species Act. A review of regulations associated with in-stream mining in the 1990s (Kondolf, 1994) found the activity was largely managed at the county and city level under the Surface Mining and Reclamation Act of 1975 (SMARA), but that other Federal Agencies, such as the Army Corp of Engineers, and State agencies also played a role, and that this fragmented approach prevented rivers from being managed at the catchment scale. Recent amendments to SMARA have focussed on the rehabilitation of mining pits following decommissioning, as they are considered environmental and safety issues (Fund, 2016).

In California, an agreement has been reached to close the last coastal beach mining operation in the lower 48 States by 2020 (lake beach mining occurs at Lake Michigan and in Hawaii). The closure reflects community pressure motivated by concerns about increased erosion and awareness regarding coastal the coastal sand budget (Weikel, 2017).

A similar situation appears to exist in Canada, with the British Columbia's Land Use Operation Policy for Aggregate and Quarry mines only listing aggregate extraction from rivers where the purpose of removing the materials is for public safety or flood mitigation, without any mention of in-stream material as a resource (Province of British Columbia, 2011).

Instances of articles or papers describing illegal sand mining in western countries were limited. The involvement of the Italian mafia in the illegal sand mining trade was referred to (Rege & Lavorgna, 2017), but it is unclear whether the sand is derived from rivers or other sources. The impression provided by the literature review is that in-stream sand mining is not a common or large-scale activity in most western countries anymore.

6.1.2 Countries recognised as having high rates of in-stream sand mining

Southeast Asian countries are overwhelmingly identified as locations where large volumes of sand and gravel are being extracted from rivers, floodplains and coasts, with much of this activity reported to be illegal. Governance of these resources was similar for some of these countries, with regulation delegated to the State or lower administrative level and non-binding guidelines being introduced to improve sand mining sustainability.

India

Under the Environmental Impact Assessment notification of 2006 issued by the Ministry of Environment, Forests and Climate Change (MoEFCC), which forms the legal basis for environmental impact assessment of development projects in India, mining of minerals with a lease area of less than 5 hectares did not require prior environmental impact assessment (EIA), until 2012 when the Supreme Court of India ruled that EIAs were mandatory for minor minerals, irrespective of the lease area. Pursuant to this, the MoEFCC, in response the increase in the EIA applications requiring scrutiny devolved the process of environmental clearance to the district level. This included amending the EIA Notification of 2006 to create District-level authorities for screening and evaluating EIAs for mining of minor minerals, including sand.

Since this directive was enacted, the National Green Tribunal and other courts have issued repeated directives to halt illegal sand mining, based on the environmental impacts arising from the activity. These have included a 2015 National Green Tribunal directive to ban sand mining in Madhaya Pradesh during the monsoon, but the ban was lifted within a month (SANDRP, 2016).

In 2016, the Union Ministry of Mines (Ministry of Mines, India, 2016) released a press release addressing the administrative responsibilities associated with legal and illegal sand mining in rivers, stating that:

- Sand mining is regulated at the state level under powers granted by the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act);
- States can grant mineral concessions for minor minerals and enact regulations to control these activities;
- The same Act empowers state governments to frame rules to prevent illegal mining, transportation and storage of mineral sands, and therefore the control of illegal activities is under the legislative and administrative jurisdiction of the state governments.

Sustainable sand mining guidelines in India have been developed by the Ministry of Environment Forest and Climate Change (MoEFCC, 2016). The guidelines are based on the premise that sand extraction from rivers is required for construction, but is also required for maintaining river health, The Guidelines recommend the following process be followed and included:

(a) Identification of areas of aggradation / deposition where mining can be allowed; and identification of areas of erosion and proximity to infrastructural structures and installations where mining should be prohibited. Use of satellite imagery for identifying areas of sand deposit and quantity be done.

(b) Calculation of annual rate of replenishment and allowing time for replenishment after mining in area.

(c) Identifying ways of scientific and systematic mining.

(d) Identifying measures for protection of environment and ecology.

(e) Determining measures for protection of bank erosion.

(f) A bench mark (BM) with respect to mean sea level (MSL) should be made essential to in mining channel reaches (MCR). Below which no mining shall be allowed.

(g) Identifying steps for conservation of mineral.

(h) Permanent gauging facilities (for discharge and sediment both) should be made compulsory for the sites having excessive mining in consultation with Central Water Commission or any competent State Agency.

(i) Implementing safeguards for checking illegal and indiscrete mining.

Under the guidelines, Districts are responsible for preparing comprehensive District Survey Reports that address the above process. The guidelines also contain a comprehensive list of potential impacts associated with sand mining, a hierarchy of sand mining locations in river valleys, and guidance for the rehabilitation of mined surfaces.

In March 2018, the Ministry of Mines launched a 'Sand Mining Framework' based on studies of sand mining in several states, consultation with institutions such as the National Council of Cement and Building Materials and the Cement Manufacture Association. The framework will provide a roadmap to States helping them to frame their policies and act as a check on illegal mining of sand (Ministry of Mines, India, 2018).

In India there are 707 Districts, so in effect sand mining is controlled by 707 separate entities within the country. Having such a large number of administrative entities limits / abolishes the possibility of managing rivers on a basin scale, and has the potential to reduce consideration of downstream, trans-district impacts when formulating plans or approving operations. It also makes determination of a 'replenishment rate' extremely difficult, as changes to the river in upstream Districts cannot be controlled and can be rapidly changed by upstream developments. An overarching limitation of the guidelines is that they were developed and issued at the Federal level, but sand mining is regulated at the State and District level. Hence, although the Guidelines recommend that these steps be required, there is no mechanism through which they can be mandatorily implemented unless enacted by the States.

A very large number of stories associated with illegal sand mining in India were identified during the web search.

Figure 6.1. Sustainable Sand Mining Management Guidelines for India, Malaysia and Cambodia.

Malaysia

Responsibility for regulating sand mining is devolved to State Governments in Malaysia via the National Land Code (Act 56) 1965. At the state level the Department of Irrigation and Drainage (DID) is responsible for sand mining within Malaysia, and guidelines covering the identification, management and monitoring of sand mining sites have been developed (DID, 2009).

The Malaysian Guidelines include a wealth of technical information describing geomorphic attributes of river systems, impacts to river systems associated with sediment extraction and the different impacts associated with different mining methods. The guidelines are based on the premise there is a replenishment rate for each river section, and sand volumes equivalent to this volume can be extracted on an on-going basis. Two approaches for determining replenishment rates are included, both of which require a high level of site-specific hydrologic, hydraulic and sediment information (Figure 6.3), with one based on sediment transport calculations and the other on hydraulic modelling using a freely available program (HEC-RAS). The licenced extraction rate from the river is to be based on the calculated replenishment rate, with the actual extraction rates monitored against the target (DID, 2009). There are also detailed recommendations on the depth of allowable mining within rivers and floodplains, and the size of set-backs (Figure 6.2).

The results from a study employing this approach were presented at the International Association for Hydro-Environment Engineering and Research conference (Teo, et al., 2017), emphasising its highly technical nature. The researchers endorsed the approach and recommended it for adoption, which suggests that although the guidelines were developed in 2009 they have not been widely implemented within the country.

The 'Guidelines' do not contain any information about how they are to be implemented, or how management plans or monitoring results are to be reported or used to guide future management. The complexity of calculation, and quantity and range of site-specific information required for implementation may pose a hurdle for adoption at the District level.

A very high number of articles describing illegal sand mining were identified during the web search. Many were related to the illegal export of sand from Malaysia to Singapore even though official bans on sand export have been in place for many years.

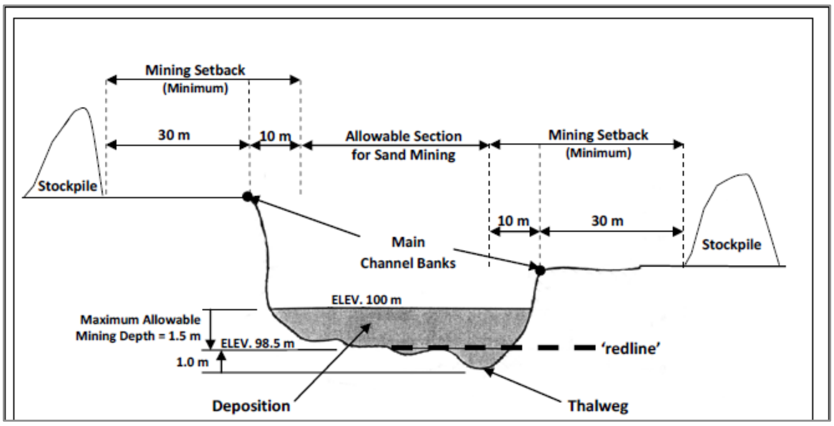


Figure 6.2. Example of setbacks for sand extraction from river systems provided by the Malaysian Sand Mining Guidelines (DID, 2009).

Cambodia

Since 2015, the Ministry of Mines and Energy (MME) has been in charge of the approval and licensing of sand extraction from the rivers of Cambodia. The Law on Mineral Resource Management and Exploitation (2001) governs mining in Cambodia and provides six categories of mineral extraction with two being applicable to sand mining.

- An Artisan Mining License may be issued that is limited to using locally available common instruments and their own labour or with the help of family or friends (maximum of 7). This includes the use of mining crafts that may exploit resources found in a loose state within a 1 Ha area, to a maximum depth of 5-m (e.g. equivalent to 50,000 m^3);

- A Pits and Quarries Mining License may be issued to exploit construction and industrial minerals obtained from pits and quarries.

Good Practices for River Sand Mining Guidelines were developed by the MME in 2015 (MME, 2015). The guidelines aim to 'support orderly and consistent decisions about sand mining on major rivers of Cambodia'. The Guidelines recognise two types of locations: those that are *'suitable'* for sand mining, and those that may require particular caution, that is, sand mining may be allowed at such locations, only if supported by a detailed assessment of the consequences (MME, 2015). For both types of locations, consideration of site-specific is required prior to initiating sand mining.

The objectives of the guidelines are to preserve the over-all planform (shape when viewed from above) of the river in general, prevent bank erosion, and to prevent damage to fish stocks, habitats and ecosystems, including dolphin habitat. It is stated that the guidelines are indicative, and the various stipulations are not mandatory and should be applied with regard to site-specific circumstances (MME, 2015).

The Guidelines draw on the Malaysian method of establishing replenishment rates based on sediment sampling, incorporating the same sediment-based flow sheet as contained within the Malaysian Guidelines (left side of Figure 6.3). Similar to other locations, even if management is based on this approach, the lack of consideration of the changing upstream sediment loads substantially impedes the ability of this approach to produce a 'sustainable' sand mining industry.

Media articles strongly suggest that this approach is not implemented within Cambodia, and there are a very large number of media articles reporting that illegal sand mining occurs within Cambodia. Illegal mining occurs in both riverine and coastal settings, with the subsequent illegal export of this sand to Singapore often reported.

China

National laws related to sand mining in China are listed below. The China Mineral Resource Law specifically permits individuals to mine building materials.

- China Marine Environmental Protection Law (2017 amendment), Article 46: strictly restrict sand and gravel mining along coastal line. Open-pit sand mining on seashore and seabed mineral mining must take effective measures to prevent marine pollution (NPC, 2017).
- Water Law of PRC (2016 amendment), Article 39: The State applies a licensing system for sand quarrying in river courses. Measures for implementing the licensing system for sand quarrying in river courses shall be formulated by the State Council. Where sand quarrying in areas under river course control that may adversely affect the stability of the river condition or endanger safety of the dykes, the administrative departments for water resources under the relevant people's governments at or above the county level shall delimit no-quarry areas or fix no-quarry periods, which they shall make known to the general public (NPC, 2016).
- China River Management Regulation (2017 amendment), Article 25: Sand mining, earth borrowing, gold mining, and disposal of sand or silt must be submitted to relevant authorities of river management for approval within the scope of river management; for other departments involved, the river authority shall approve with the relevant departments in collaboration (Baidu, 2017).
- China Mineral Resource Law, Article 35: The State applies the principles of vigorous support, rational planning, correct guidance and effective administration with regard to collectively-owned mining enterprises and privately-owned mining undertakings. It encourages collectively-owned mining enterprises to mine mineral resources within the areas designated by the State, and permits individuals to mine scattered and dispersed mineral resources, as well as sand, stone and clay that can only be used as ordinary building materials, and small amounts of minerals for their own use in daily life (NPC, 2017).

Specific regulations for sand mining in the Yangtze are governed by the Yangtze River Channel Sand Mining Management Regulations (Baidu, 2002), which includes requirements to establish the following:

- Forbidden mining areas and recoverable areas;
- Prohibited mining period and recoverable period;
- The total amount of annual sand control;
- The number of controlled sand mining vessels in the recoverable area.

Sand mining in the Yangtze is discussed in detail in Section 9.1 of this report.

The following information related to sand mining in China has been gathered from news articles, and demonstrates that illegal mining is occurring and of concern.

- In October 2015, the Vice Director of politics and law in the Ministry of Water Resources said there were a lack of national laws to stop illegal sand mining, with the highest punishment a fine of CNY 300,000 (approximately 50,000 USD) which he stated is only a small part of the illegal income and cannot deter illegal sand mining. The Vice Director intends to push illegal sand mining as a criminal offense, similar to other types of illegal mining or dangerous mining (note: it is assumed that sand mining is not regulated by the same provisions as hard rock mining,) (China Environment News, 2015);

- On 27 November 2015 the Fujian Province Standing Committee of the National People's Congress passed the "Fujian Province river protection regulations" which came into force on 1 Jan 2016. Under the regulations, illegal sand harvesting will be fined a maximum of 300,000 CNY (about 50,000 USD). A minimum fine of 100,000 CNY will be applied to extraction activities operating without a permit, and if found, 'large' operations will have their tools confiscated. Permits will be revoked from operators found to be outside of the designated zones. The maximum fine is an increase from the previous maximum fine of 100,000 CNY. The new regulations also clarified the responsibilities of government departments, and limited sand mining permits to a duration of 1-year. Motivation for the revised regulations stemmed from the repeated occurrence of illegal sand harvesting, and government inaction resulting from confusion over responsibilities (China Environment News, 2015);

- In August 2017 illegal sand mines in the upper reaches of the Yangtze River in southwest China's Sichuan province were closed to protect the local environment. The illegal mines lacked environmental protection facilities, failed to meet sewage standards and impacted the local agriculture. A government official said a total of 18 sand mines had been closed since April, but there were many more mines and that the government lacked the necessary law enforcement inspectors to enforce the ban. Seven mines are allowed to operate in the area, with a total maximum extraction of 300,000 m^3/yr (Xinhua, 2017).

6.1.3 Africa

South Africa

Sand mining is controlled by a complex regulatory system involving mineral, environmental and land use planning regulations (Green, 2012). Both Federal and Provincial governments exert powers with respect to environmental impacts of sand mining, but the overarching management of sand mining as a resource is governed at the Federal level by the Department of Mineral Resources (DMR). Historically, the regulatory system was skewed towards management under mineral regulation, with environment and planning having little input or control over activities. Legal cases challenging this lack of balance in 2010 – 2011 affirmed the applicability of Land Use planning legislation to sand extraction, but did not confirm the role of Environmental Legislation owing to changes in Environmental Law that occurred during the time of the legal action (Green, 2012). A 2014 Policy Briefing (Chevallier, 2014) highlights that this fragmentation continues, with as the DMR has national jurisdiction over sand mining, but there remaining a lack of clarity regarding which department is responsible for the environmental aspects of mining. Amendments to the mining legislation have sought to align requirements under the mining act with environmental legislation and from December 2014 a shift towards 'One Environmental System' was scheduled with the DMR issuing mining and environmental authorisations in addition to water licences (Chevallier, 2014).

A recent media piece highlights an increase in illegal sand mining in the Durban area, with sand suppliers acknowledging they cannot know whether the sand they buy is obtained legally or illegally (Pieterse, 2017).

Kenya

Under the Environment Management and Coordination Act, sand harvesting requires a proper environmental impact assessment and the approval of a technical sand harvesting committee (IRIN, 2012). However, a lack of resources and interference from political leaders has reportedly hindered these regulations (IRIN, 2012). A recently published investigative report into illegal sand mining and 'sand wars' in Kenya suggests that this situation continues, as the General Director of the National Environment Management Authority stated that new harvesting sites must undergo the EIA process, and 'The authority is not aware about these cartels; we have not received any incidents on violations based on our EIA regulations (Constable, 2017). Officials from the Federal Department of Environment refer enquiries regarding illegal mining to county governments, who hold jurisdiction over the activity (Constable, 2017).

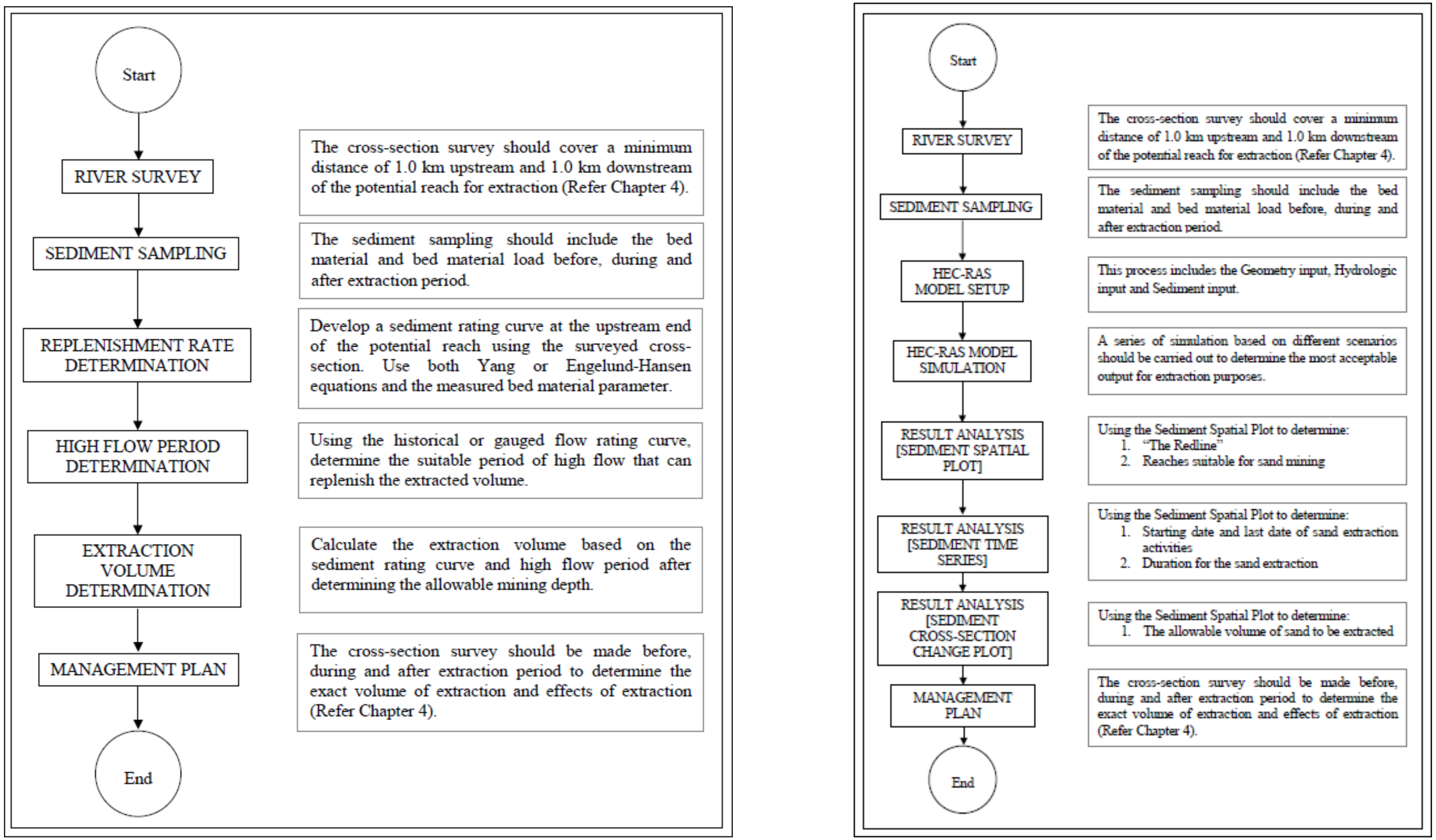


Figure 6.3. Flow charts for establishing the replenishment rate of bed material in rivers (DID, 2009). Flow-chart on left is based on a sediment rating curve, right chart is based on a channel modelling approach.

Other regions

Internet searches for sand mining regulations for countries in Eastern Europe and South America did not return detailed results. Relevant information obtained during the search includes:

- A summary of mining activities in Hungary (UN, 2008) indicated that extractive industries are regulated under the Act No 48 of 1993 Mining, and the Act covers the complete mining related activity chain. It does not however cover water, or ground water use, suggesting that in Hungary there may be similar issues with unclear jurisdictional responsibilities related to sand extraction. The search did not find any reference to illegal sand mining.

- In 2007, an entire artificial beach of sand (6,000 m^3) was reported as stolen during the off season from Mindszentas, a river-side resort on the Tisza River in Hungary. A popular destination in a land locked country, the sand was suspected of having been barged out of the country within the Shengen zone without detection following Hungary joining the EU. Subsequent reports in the Hungarian press suggest the sand was taken from the beach by a local contractor, employed to re-contour the beach, and used to create a bicycle path (Zsuzsanna, 2007).

- In Russia, there are numerous laws and agencies responsible for the issuance and regulation of the mining industry. However, the procedure for obtaining the right to develop a deposit of commonly occurring minerals, such as pebble or sand, differs from other mineral commodities, with the licences issued by the applicable regional authority under respective regional legislation, and tenders or auctions are not required (Josefson & Rotar, 2018). There are a few media reports of illegal sand mining in Russia related to small operations, but no large scale 'Sand Wars' were reported;

- Colombia has some of the oldest environmental laws in Latin America, with the Code of Natural Resources enacted in 1974. However, as reported by Forero Bonell (2000), the enforcement of environmental laws is complicated due to the large 'informal' sector, which is estimated to account for 65% of all aggregate extraction and 80% of the environmental impact.

6.1.4 Sand mining experience in countries where WWF operates

Surveys related to sand mining were distributed to WWF offices with responses received from Hungary, Malaysia, Croatia, Pakistan and the Ukraine. The following overview summarizes the responses, and is consistent with information derived from other sources.

- Sand mining was a major issue in Hungary in the past, but is now limited to maintenance of navigation channels;

- In Malaysia environmental issues associated with the mining of optical silica from the floodplain are increasing;

- In the Ukraine, illegal mining is wide spread in the rivers of the Carpathian Mountains. Illegal extractions from the rivers and floodplains have been occurring for decades, with the activity intensifying in the mid-1990s after the breakup of the Soviet Union due to an increase in demand;

- The governance of sand mining varies between the locations, with some areas managed locally, and others subject to multi-level EIA processes such as Natura 2000 sites;

- In several places legal 'loop-holes' were identified that allowed sand mining from rivers for flood or navigation improvement, with the material extracted and sold by private companies. For example, in the Ukraine, it is illegal to extract gravel or sand from rivers or floodplains, however 'river bed forming' and 'river bed cleaning' activities connected to flood control are allowed. These activities require a permit, but do not require an EIA;
- Malaysia has developed River Sand Mining Management Guidelines (2009). These non-binding guidelines inform operators about sediment transport processes and promote extraction at a sustainable replenishment rate;
- Illegal sand mining was identified as a concern in the Ukraine, but complaints to the local regulators resulted in limited action. In 2015 and 2016, 47 prosecutions for illegal mining were recorded in one oblast (administrative region), but the actual number of occurrences is considered much higher;
- There is no information available regarding the volumes of materials extracted in the countries completing the surveys.

In Suriname, WWF has supported an extensive investigation into the impact of sand mining on beaches in the country, with a focus on Braamspunt beach, a major turtle-nesting beach on the east bank of the Suriname River (Anthony, 2016). The investigation documented a complex interaction between mud banks, mangroves, *cheniers* (beach ridges) and the coastal plain. The *cheniers* are very efficient natural dissipaters of wave energy, protecting the coast from erosion. The sandy, elevated *cheniers* also provide cultural, recreational and ecological functions and services in Suriname, including nesting sites for turtles and habitat for shorebirds and other wild life. Extensive mining of the deposits for use in the road and building industry has occurred which has affected the downdrift of material, reducing the resilience of the beach structure and reducing beach nesting sites for turtles. Recommendations from the work include re-focussing of the sand mining industry to alternative sand sources, and restricting coastal mining to the most inland *cheniers*.

WWF has also under taken detailed investigations of sand mining in the Mekong River between the Chinese border and the Vietnamese delta, providing an integrated picture of the impacts of sand mining in conjunction with other catchment activities on a large river system. A summary of these investigations are included as a case study in Section 9.3 of this report.

6.2 Summary of regulation and governance

This web-based review of sand mining regulations has identified a number of similarities between countries with respect to how sand mining is regulated. At a national level, sand mining activities span the legislative requirements of numerous acts and ministries. The mineral extraction part of operations is generally governed by mining acts and regulations, whereas land use, environmental and water aspects of sand mining typically fall within other jurisdictions. However, the gathered information suggests that mineral and mining agencies have historically held the exclusive power to licence and regulate sand mining activities, and it is only recently that environmental considerations are being incorporated into regulatory regimes.

The lack of one clearly defined entity with the responsibility to oversee and regulate the mineral and environmental aspects of sand extraction is a major short-coming. The initial inclusion of aggregate extraction under mining acts by governments was understandable given the previous lack of environmental legislation that persisted until relatively recently. As environmental legislation increased in scope mining discharges were recognised and regulated, but the environmental impacts arising from a pit or an excavated river bed were afforded the same importance.

Compounding the fragmented nature of regulation is the general devolvement of regulatory powers from the Federal Government to lower tiers of government (State, Province, and county). This action results in a large number of entities having responsibility for the same activity within a country. As a result, it is likely that inconsistencies between jurisdictions with regards to the interpretation and implementation of mining controls will arise, leading to a high risk of inconsistent management and outcome. This approach is particularly deleterious in the context of river systems, as the managing entity has no control, or possibly even knowledge, about the river system upstream or downstream of their area of jurisdiction. This prevents the management of rivers at the basin scale and complicates management approaches based on an understanding of riverine processes, such as replenishment rates, as inputs can change due to changing conditions upstream. Lower tiers of government also tend to have reduced technical capacity and resources as compared to Federal agencies, making development of site-specific plans and management strategies a challenge. This is particularly relevant to management strategies based on replenishment rates, as the accurate determination of these rates requires an in depth understanding of riverine processes, and with large amounts of accurate geomorphic, hydrologic, hydraulic and sediment information required over long timeframes.

These regulatory gaps undoubtedly contribute to the poor governance on sand mining operations, however, the main issue identified while researching mining regulations is the widespread occurrence of unregulated, illegal sand mining activities that occur in response to the high and increasing global demand for sand. 'Sand Wars' are a widely reported phenomenon in many countries, involving highly organised gangs or 'mafias' operating with the complicity of regulators and immunity from prosecution. Sand gangs are being widely reported as operating in India, Vietnam, Cambodia, Malaysia, Indonesia, Bangladesh, Morocco, South Africa, Nigeria, Jamaica, Kenya, and Mozambique. With few exceptions, these activities and their impacts are not described or quantified in the scientific literature due to the difficulties and risks associated with investigating and documenting them, while the random and transient nature of the extraction making controlled investigations impossible.

One exception is Lake Poyang in China where there is recent evidence regarding the environmental impacts associated with sand mining. In a correspondence published in Nature Letters in October 2017, scientists familiar with the environments in the Yangtze River and associated lakes described the destruction caused by large scale sand mining driven by development, and appealed to the Chinese government to 'clamp down on this wholesale destruction of aquatic organisms' habitat and to promote ecologically friendly building substitutes' (Chen, 2017). The letter also noted that although a strict management plan for sand mining in the Yangtze River was established in 2012, operations involving colossal vessels are increasing, often illegally in the Yangtze's mainstem, tributaries and the connecting Poyang and Dongting lakes. There were seven signatories of the letter, including four members of the Chinese Academy of Science.

Non compliance with regulations has also been documented in Bali, Indonesia, where permits for aggregate mining includes requirements to restore land following mining activities. A lack of enforcement has resulted in 70% of aggregate miners not obtaining permits, while those that do often create deeper and wider pits than their permits allow with impunity (Beiser, 2015). In India, a sediment audit for the Chaliyar River in the Malappuram and Kozhidode District states that 'Illegal mining of Sand and the lack of governance, in a big way is causing land degradation and threatened its rivers which face ultimate extinction' (Centre for Social and Resource Development, 2014).

A study focussing on the social impacts of sand mining in Bangladash documented sand approved for mining for government projects being diverted to private uses, mining that did not comply with required enviornmental regulations, lack of river bank stabilisation following mining as required and the illegal infilling of low-lying paddy fields with illegally obtained sand (Rege & Lavorgna, 2017). The same study noted that most of the officials at the district level who were interviewed for the study 'regretted that legal regulations had little practical effect and that administrative formalities became a mere name'. The study concluded that due to the 'external factors such as industrialization allying with power structure in local society, the residents who were at risk of the loss of their property by riverbank erosion were put in the most unfair circumstances' (Rege & Lavorgna, 2017).

6.3 'Sand Wars' in the media

Investigative journalism is the primary source available for current information related to illegal mining. Articles typically focus on the social and individual impacts of illegal activities on communities, often introducing the topic with examples of violent encounters between community members or others and sand mafias – which often result in death. The articles then tend to focus on how and why sand is important to economies, how under-recognised its importance is by societies, and how inexpensive the resource remains in spite of shortages. These facts are presented with a sense of shock and horror, suggesting the journalists themselves have never previously thought about sand, and expect that their readers haven't either.

The articles go on to highlight the huge and growing global demand for sand driven by urbanisation, the inability of the industry to distinguish between legal and illegal sources of sand, the lucrative nature of the illegal sand trade (including providing income for some of the worlds' most marginalised communities), the environmental damage that has occurred and is expected to occur in the future due to aggregate extraction activities, the **lack of regulation, the lack of enforcement of regulations where they do exist and the complicity of regulators and government officials with the illegal operations.** There is strong consensus between the reports that 'Sand Wars' are not caused by a lack of regulation relating to the industry but rather caused by a breakdown in the implementation and enforcement of regulations.

Articles describing 'Sand Wars' have featured in mainstream newspapers (e.g. Beiser, 2015; 2017), magazines (e.g. Owen, 2017) and books such as *Sand* (Welland, 2012), with another book *The World in a Grain* by Vince Beiser due out in August 2018. The increasing impacts of coastal sand mining on beaches was the topic of an award-winning documentary film by Denis Delestrac in 2014. Some of the assertions contained in various articles include:

- Illegal aggregate mining is known to occur in over 70 countries, and in addition to enviornmental damage has been linked with social problems ranging from child labor (Quérouil & de Viguerie, 2015) to increasing the damage caused by natural disasters (Illangasekare, et al., 2006).

- India is notorious for having the largest, most wide-spread and most violent illegal sand mining groups in the world. Driven by the rapid increases in aggregate demand 'sand mafias' have emerged over the past two decades and now operate illegal mines in 12 Indian states (Bliss, 2017). Attempts to shut down these mines and bring the perpetrators to justice have met with little success. There have been reports of police inaction following the filing of complaints, and of police tipping off mine operators when raids are imminent. Attempts to confront this problem at a legislative level have also been largely fruitless, and it is widely believed that government officials are being bribed by, or are actively involved with, illegal mining groups.

- Efforts to curb illegal aggregate mining operations elsewhere have also been met with violence. In 2013 Palerum Chauhan was shot and killed in his bedroom in the middle of the day following a 10 year campaign to shut down an illegal aggregate mining operation in India (Beiser, 2015), and he is one of hundreds of people thought to have been killed during conflicts between and against sand mafias (Ward, 2015). Journalists , activists, and police opposing aggregate miners have been threatened, maimed and murdered (The News

Minute, 2017; Beiser, 2015), with several of these acts thought to have been tacitly approved by members of local governments (Abdulali, 2012). Similar levels of corruption have been reported in other countries, such as Bangladash (Khan & Sugie, 2015).

- Those involved in the sand mining industry as miners or drivers recognise that sand mining is having a deleterious impact on the waterways on which they and their community depend, but the lack of alternative jobs and the relative high paying nature of the illegal trade makes it difficult to forego involvement (Hawkley, 2017).

- Figures from the UN database for trade (ComTrade) and Singapore Customs data shows that Singapore imported approximately USD$725 million of sand from Cambodia since 2007, but figures reported to the UN from Cambodia show an export of only about USD$5 million (Dara, 2016). The attention caused by this revelation resulted in Cambodia banning international exports of construction sand in July 2017, even though a ban on exports had been previously issues in 2009. The export of silica sand is still permitted (Roeun, 2017).

- Vietnam has announced that it will run out of construction sand by 2020 if the present rate of consumption is maintained. The Ministry of Construction announced that 691,516 million cubic meters of sand and gravel had been approved for mining by the end of 2016, and there predicted demand between 2016 and 2020 was 2.1 – 2.3 billion m^3, while the country's total sand reserves are estimated at just over two billion m^3 (Tuoi Tre News, 2017).

The overall picture provided by these mainstream articles is of a dire situation, with little chance of change given the ever-increasing demand for sand combined with its diminishing availability, and a high financial incentive to engage in illegal mining.

(left) Source: https://d1u4oo4rb13yy8.cloudfront.net/e3da54fe-0b30-404a-8de0-d7692630d574.jpg; (right) (Global Witness, 2010)

CHAPTER 7

CHALLENGES, RESEARCH & COMMUNICATION NEEDS

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7 Challenges, research and communication needs

7.1 Overview

Mitigating the environmental and social harm caused, or inferred to be caused, globally by sand mining will require a multi-faceted set of issues to be addressed. The QSR results clearly indicate that research quantifying the physical changes associated with sand mining and linking them to ecological impacts is lacking. This is somewhat extraordinary considering sand mining is one of the oldest and most widespread activities / industries in the world. Accurate global information about the distribution and scale of sand mining is also scarce, however the mainstream media overwhelmingly reports that it is occurring on a massive, unsustainable and largely unregulated scale, that may be pushing ecosystems and communities to the brink destruction.

The increased reporting of sand mining and 'sand wars' reflects a nascent but increasing awareness of the issue in the west, but it is an issue that has not been recognised within the global scientific community. US scientists who have formed a working group to provide an integrated perspective on the issue stated that (Torres et al., 2017):

This problem is rarely mentioned in scientific discussions and has not been systemically studied. Media attention drew us to this issue. While scientists are making a great effort to quantify how infrastructure systems such as roads and buildings affect the habitats that surround them, the impacts of extracting construction minerals such as sand and gravel to build those structures have been overlooked.

This view is applicable to the western scientific community, but scientists and organisations operating in large Asian Rivers have recognised the scale and complexity of the issue for years, as evidenced by WWF's investigations in the Mekong. Unfortunately, recognising the issue is one thing, but being able to conduct robust scientific investigations is another. It is not easy nor even possible at times to investigate sand mining in countries where governments are complicit in the illegal extraction and trade of sand.

Scientific research into sand mining impacts alone is unlikely to directly alter the attitudes of governments worldwide or improve the governance to the levels required for sand mining to be reined in, or drive the research needed for alternative materials. However, scientific research, to underpin formulation of sound policies, combined with increasing the awareness in the global community of the scale and associated impacts of illegal mining is a potential pathway to addressing the problem. Given the present situation of highly reported although scientifically undocumented impacts associated with sand extractions, raising awareness, improving governance of existing regulations and promoting a precautionary approach to sand mining whilst completing additional research is a sound strategy.

Decreasing societies' dependence on sand derived from unsustainable sources will necessitate enormous changes over decades, requiring leadership from governments (e.g. changes in land use regulations, urban planning, transport systems, building codes, natural resource management, tax regimes, etc.) and large-scale changes in the private sector (supply chain from raw materials to finished projects, design and architectural industry). Governments and industries tend to be very slow to change or respond to 'scientific research' unless there is also strong community pressure and a willingness by the community to embrace change. This is evidenced by leading scientists reporting the danger of rapid and serious global climate change caused by humans since the early 1970s (American Institute of Physics, 2017), but eliciting little response from governments until social pressures increased.

The recently published mainstream media articles about unsustainable sand mining have all drawn upon the same limited set of primary references – global production and trade of sand as recorded by the USGS, and the UN, the facts and figures contained in the UNEP Global Environmental Alert Service (2014), and some basic construction statistics about how much sand is required to build a road, building or house. These same numbers, frequently without attribution, appear in most of the pieces, suggesting the media is highly interested and willing to disseminate the story, but there is a shortage of 'facts' upon which to rely. This raises both opportunities and poses constraints for future research. Research that quantifies extraction volumes, and environmental and social impacts in a way that the results can be captured by the media can provide important scientific credibility to campaigns and actions and can be used to increase public awareness. Without a credible science base, the debate is merely gainsaying and exchange of unsubstantiated claims and counter-claims. Equally robust, but not as media 'friendly' research will increase understanding, but likely receive limited attention.

The following sections provide some thoughts about both research and communication. They are intended as a starting point to generate discussion.

7.2 Research needs

Quantifying the scale of river extraction

The volume of sand being extracted from rivers, floodplains and the coast in the world today is unknown. The data sets upon which estimates of extraction of aggregate have been based are generally limited to pre- 2012, and include all sources (terrestrial, riverine, marine). The often-cited statistic of China using as much cement in three years as the US used in the 20th century is based on consumption in China between 2011-2013, a period not included in many metrics (Figure 7.1). Economic growth in China has slowed from ~ 12% in 2010 to ~7% in 2017 (Trading Economics, 2017), suggesting that the rapid increase in cement demand may be slowing, but other economies in Asia are expanding at rapid rates. It is notable that the fastest growing economies of SE Asia (Table 7-1) correlate with the countries where widespread illegal sand mining is most widely reported.

In addition to defining the scale of the aggregate business, determining which sources this sand is sourced from is vitally important. Knowing the volumes and proportion of sand extracted from rivers would better allow for the magnitude of this issue to be assessed. Establishing quantities being extracted from coastlines would also be of value, as this is emerging as an issue in western countries where extraction from rivers has been largely discontinued. Developing regions such as Africa, South America and Eastern Europe, warrant special attention, as these regions are likely to experience increased growth in the future, leading to increased pressure on sand for construction.

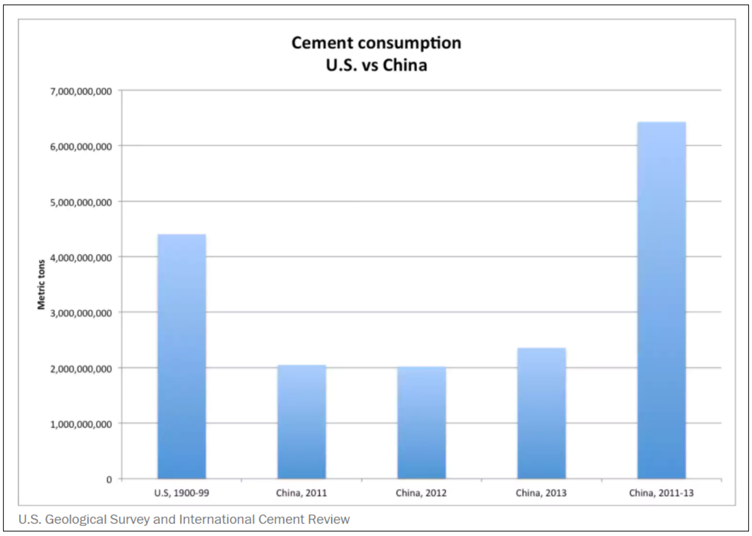


Figure 7.1. Cement consumption in China based on USGS and International Cement Review figures. Graph from (Swanson, 2015)

Table 7-1. GDP growth forecasts for SE Asia (Asian Development Bank, 2017).

Country	2017[f]	2018[f]
Brunei Darussalam	0.0	1.0
Cambodia	7.1	7.1
Indonesia	5.1	5.3
Lao People's Democratic Republic	6.9	7.0
Malaysia	5.4	5.4
Myanmar	7.7	8.0
Philippines	6.5	6.7
Singapore	2.7	2.7
Thailand	3.5	3.6
Viet Nam	6.3	6.5
Average	5.0	5.1

The most common approach to estimating aggregate usage has been examining economic and trade information. Perhaps these types of data sets could be interpreted on a regional rather than global basis to provide a more detailed understanding of where sand is being extracted and consumed and allow these processes to be linked to parameters such as urbanisation. Economic models that enable the response of sand extraction to different economic or social incentives would be a useful for exploring future management options.

Other approaches, such as GIS and satellite imagery could be used to quantify the number and distribution of river barges operating within river reaches to assist in the interpretation of trade and economic results.

Understanding impacts on river basin

The impact of sand extraction varies between and within river systems. Undertaking rapid geomorphic and ecological assessments of rivers experiencing mining provides a snapshot of the present status of these systems, indicates how rivers are responding to sand extraction and provides information about natural values that may be under threat. Conducting these investigations in river systems where there are known species at risk, and for which there is an understanding of life cycles and habitat needs would allow a holistic picture of sand mining impacts to be gained in a short time period. Ideally such studies should be in river basins suffering limited impacts from other pressures, such as dams, to permit definition of cause-effect relationships. Understanding the sand 'issue' with respect to endangered species could assist in identifying management actions that might be applicable to individual rivers or reaches.

While short-term 'river blitzes' may elucidate the immediate impacts of sand mining on particular species, they will not provide a thorough understanding of how rivers will be affected by sand mining. Rivers often respond to large changes over time periods, ranging from years to decades, hence short-term studies will not necessarily allow the future behaviour of rivers to be predicted. For both short and long-term studies a multiple-lines of evidence approach will likely be required to quantify the impacts of sand mining on systems, as there is background information available to provide a context or baseline for most rivers systems undergoing sand mining.

A general understanding of geomorphic and ecological responses to changes in flows, hydraulics and sediment movement can be gained through rapid investigations, but establishing long-term response and rates of change is far more difficult. Insights into these longer-term processes and impacts can be gained using ecosystem models to compare scenarios where there is limited information. In the Gulpur River, Pakistan the *Drift* model was applied to different management scenarios to investigate which minimised environmental impacts associated with the combined impacts of gravel mining and hydropower development (Hagler Bailly Pakistan, 2014). Different rates of sediment removal and catchment management strategies were used to assess the relative impact on trophic levels within the ecosystem. These types of models can integrate site-specific data, information from the scientific literature, local knowledge and expert opinions to provide insights into river functioning. They are also useful education tools to demonstrate how changes in 'sand' can impact entire ecosystems. The value of these ecosystem models improves as the availability of site specific scientific information increases, again highlighting the need for robust and targeted research.

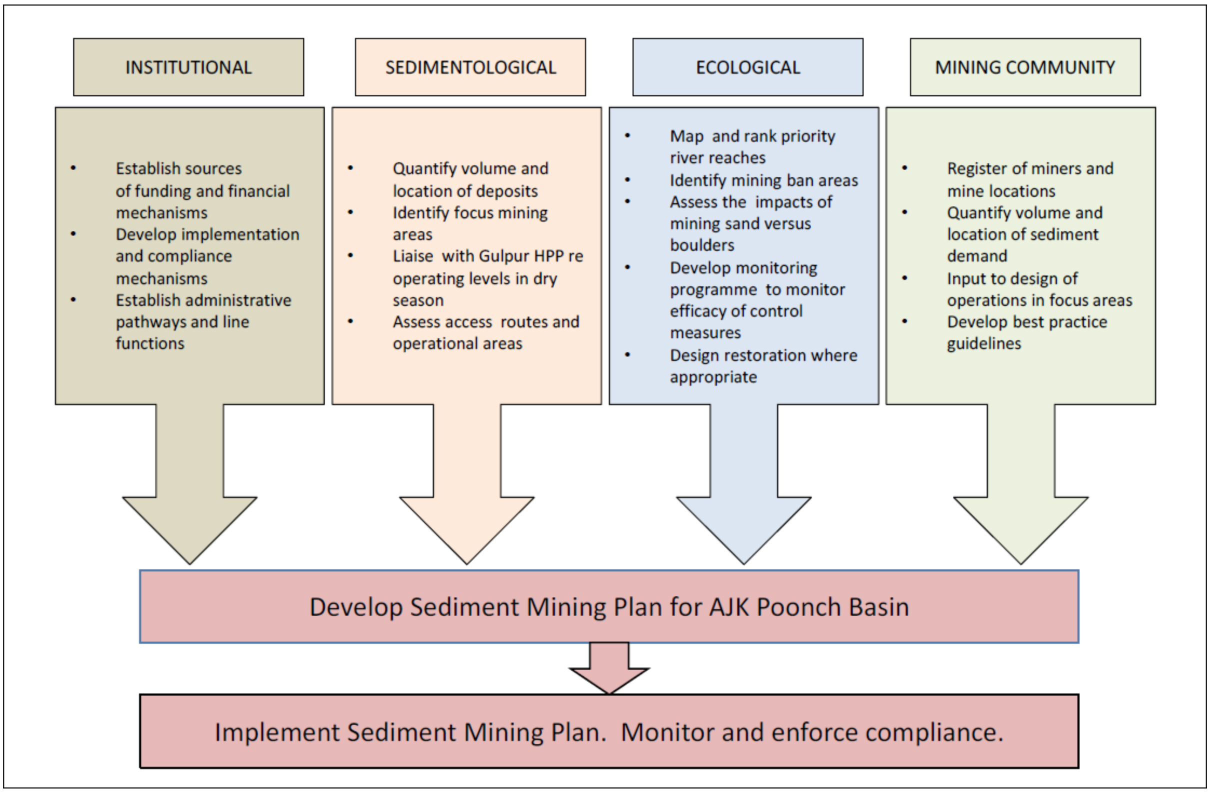


Figure 7.2. Elements of a sediment management plan to improve ecological condition in the Poonch River Pakistan based on ecological modelling (Hagler Bailly Pakistan, 2014).

Reducing consumption / moving towards sustainable sand sources

Research into the potential for economic or social approaches to reduce consumption and / or shift supply towards legal and sustainable sources is vital but lacking. These approaches can be risky, however, as increasing the cost of sand to encourage the uptake of other building materials may lead to an increase in the illegal sand trade due to an even higher differential in price between the legal and illegal commodity.

A potential research opportunity is to gauge the potential, challenges and risks of establishing a certification program for sand sources similar to the Forest Stewardship Council (FSC). Gauging whether industry and consumers would support this approach would also provide an indication of whether 'sand' is perceived as an environmental issue.

Alternative building materials, building codes, substitutes, etc. and how to increase market uptake

As highlighted in the previous section, there is extensive research on using alternative materials, especially waste products, as a substitute for aggregate. There is very limited information about the uptake of these materials. Research into what is preventing the construction industry from adopting new materials, and ways to increase uptake would be informative.

Research into new materials, methods and uptake by the construction industry

Large amounts of research into new materials is occurring, but there is little evidence that these materials are being adopted by the construction industry. Understanding the hurdles to implementation would assist in developing incentives that could increase the rate of uptake. The film 'Sand Wars' highlights that universities are full of architects developing and interested in adopting new materials, techniques and methodology but the construction industry's experience and equipment is based on concrete and is reluctant to change. There is also a huge industry in the provision of equipment and materials to build with concrete and steel.

CHAPTER 8

POTENTIAL MANAGEMENT AND MITIGATION APPROACHES

8 Potential management and mitigation approaches

Addressing the environmental and social impacts associated with legal and illegal sand mining is not easy. Sand and concrete are as ingrained in modern societies and economies as fossil fuels, and similarly will require a global change in attitude and practices if river systems are to be preserved. Sand's accessibility and extremely low cost combined with the widespread use of concrete in the construction industry make decreasing demand or finding alternative supplies a challenge. The following sections describe some management and mitigation strategies for reducing sand mining and associated impacts identified during the QSR and literature review.

8.1 Improved governance

Without improved governance in the countries experiencing high rates of in-stream sand mining, the over extraction at licenced sites and the prevalence of unlicensed sites will continue. In many of these countries the issue of governance is not limited to sand mining in rivers, but to the general management of natural resources as well as other aspects of trade and industry.

Investigating methods to improve governance at a national level in developing countries is beyond the scope of this investigation, and few recommendations regarding this issue were offered in the literature surveyed. US academics have formed a working group that is looking at all aspects of the sand supply chain using a systems integration approach to better understand socioeconomic and environmental interactions over distances and time. The group suggests that international conventions similar to the 2030 Agenda for Sustainable Development and the Convention on the Biological Diversity are needed to regulate sand mining, and the use and trading of aggregates. They also identify the needed to develop regional and global sand budgets (Torres, et al., 2017).

8.2 Sustainable extraction of river sand

In theory, sand and gravel mining in rivers should be sustainable if the quantity of material extracted is within the volume 'replenished' by the system, and sufficient sand and gravel remains in the system to maintain downstream river beds, deltas and coastal environments. This was indirectly supported by the findings of Rempel and Church (2009) who concluded that an experimental extraction of gravel from bar surfaces had only a short-lived impact on the ecosystem due to the extracted volumes being within the variability of the sediment load of the river. The investigation established the replenishment rate based on site specific flow and sediment information (Figure 8.1). This study was based on a one-off extraction of material during the driest part of the year, so it is unknown if the findings hold for multi-year periods or when extraction is sustained over longer durations. Furthermore, this study considered a single river and the results may not be applicable to other locations.

One documented account of this approach being applied in practice was found in the literature (Kondolf, 1994), related to a river in California where replenishment rates were calculated at 110,000 – 150,000 m^3/yr and sand extraction was limited to an average of 100,000 m^3/yr to allow the incised river bed to recover. Kondolf (1994) noted that this approach does not recognise the high variability in annual sediment transport rates and does not take into account the continuity of the river. Although sediment may be replenished from upstream, the extracted material is not available for transport downstream, hence while this approach may preserve the mined regions, the risk of downstream impacts remains. The interactions between land use and sediment delivery and how these can change as land use changes (perhaps through construction using the extracted sand) must also be considered when employing this approach. The Guidelines developed by Malaysia are strongly reliant on this method, however as previously discussed this technique requires a high level of technical expertise and extensive data sets. There is no evidence in the literature that they have been successfully implemented as a management tool for aggregate extraction.

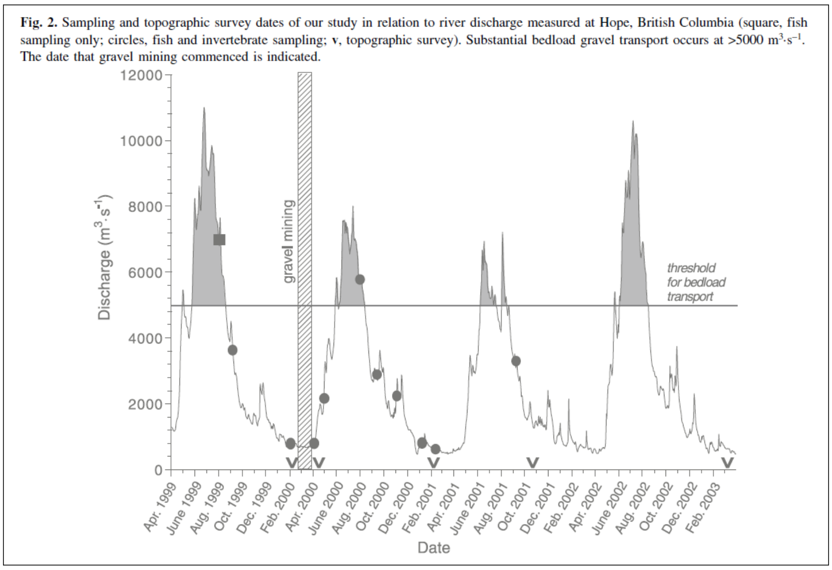


Figure 8.1. River hydrograph showing periods of potential gravel transport that can be used to estimate potential replenishment rates. From Rempel & Church (2009).

8.3 Alternatives to river sand

Alternatives sources to river sand have been identified and adopted by most western countries, and similar shifts in developing countries could reduce pressure on the resource. However, without improved governance changing the primary sources of construction materials is difficult as alternatives are likely to cost more due to additional handling, processing and transport costs. Any increase in the cost of 'legal' sand as compared to illegally derived river sand drive an increase in illegal activities. Alternative sources and substitutes for sand in concrete is an area of active research. A literature review found the following examples.

- Dry mining of floodplains or other deposits where mining does not intercept the water table or affect active river systems. Floodplains tend to be dominated by fine-grained silt and clay-sized material that is unsuitable for construction purposes. However, the presence of abandoned river channels, ancient valley fill and estuaries, glacial outwash and meander scars are examples of sedimentary environments that tend to contain sand and gravel.

  An example of this approach is the Orca quarry on Vancouver Island that is exploiting a Pleistocene glacial outwash deposit. The deposit is not near any rivers. The operation ships and sells the sand and gravel to the San Francisco Bay area, with the ship terminal functioning as a 'virtual' quarry near the heavily populated San Francisco Bay area, reducing the need to identify sand sources near the high-density population centres. The operation is developed on First People's land, and incorporates benefit sharing and hires local people (Bridge, 2017).

- Recycling of concrete for use as road bases (Smith, 2018);

- Development of bacteria and fungi that can produce calcium carbonate and be used to repair existing concrete structures, increasing their lifespans. This may be particularly useful when applied to the huge highway systems of the world that are requiring repair or replacement (Smith, 2018);

- Replacement of sand with other materials, with a focus on the recycling of waste materials. It is notable that a web search of this topic returned many recent articles by Indian researchers, all of which highlight the need to identify replacement materials to diminish sand mining and its related environmental impacts. Examples (not all from India) include:
    - Backfilling of mining voids using fly ash composites in place of river sand in India due to a decrease in the availability of river sand. Finding an alternative use for fly ash is also desirable as it would reduce landfill (Mishra & Karanamk, 2006);
    - Use of walnut shell and PET-fibre as a replacement for aggregate in lightweight shotcrete suitable for roadway or mine support (Cheng, et al., 2017);
    - Use of fly ash and polypropylene or steel fibres to produce high quality concrete (Raut & Deo, 2017);
    - Use of rubber tyres and copper slag as aggregate in concrete (Blessen, et al., 2012)
    - Replacing aggregate with recycled concrete sand in masonry and mortar design for indoor use (Fernandex-Ledesma, et al., 2016);
    - The use of residual materials such as kaolinitic waste, sewage sludge, schist fines and wasted glass to create light weight granules suitable for light concretes, road engineering and waste water treatment (Kanari, et al., 2016);
    - The use of crushed oil palm shell as a replacement for aggregated in concrete. Investigations have found that replacement rates of between 50% and 75% can be used to produce a lightweight concrete for use in non-load bearing structures, and structural concrete can be created at replacement rates of about 25% (Muthusamy, et al., 2013);
    - The replacement of river sand with manufactured (crushed) sand. Manufactured sand is a by-product of the production of coarse aggregate and has historically been used for road bases and land fill. Replacement of river sand with manufactured sand at a rate of 75% was found to produce concrete with properties suitable for use as high-performance concrete (Prasanna, et al., 2017);
    - Replacement of river sand with crushed waste stone, dust and polish slurry generated by the production of dimension stone (stone quarried and cut to specific sizes or shapes, e.g. ornamental stone). Replacement of 100% of river sand in concrete by 85% stone waste and 15% slurry waste resulted in a very high-quality concrete product (Rana, et al., 2017);
    - Use of iron-ore tailings to replace sand in concrete. The inclusion of the tailings reduced the workability of concrete, but all other strength modulus of elasticity data were consistently higher than conventional replacement at all levels of replacement (25% to 100%). The use of tailings is recommended to minimise environmental problems, cost and natural resource depletion (Shettima, et al., 2016). Note, this approach would not be suitable for tailings containing sulphides.

Whilst research into alternatives is promising, the identification of sustainable replacement materials requires a holistic consideration of the environmental and social costs and benefits of the options, with the long-term stability and suitability of the material, energy use required for production and transport, potential waste generation and disposal issues over the life-cycle of the material and any other potential social impacts evaluated.

The development of alternatives is an active area of research, but there is little information about the rate of uptake or performance of concrete containing sand substitutes outside of a laboratory setting. One practical development is occurring in Vietnam, where a set of standards on the use of ash and plaster as replacement materials for sand is being development by the Ministry of Construction in Vietnam and are due for release this year (Tuoi Tre News, 2017).

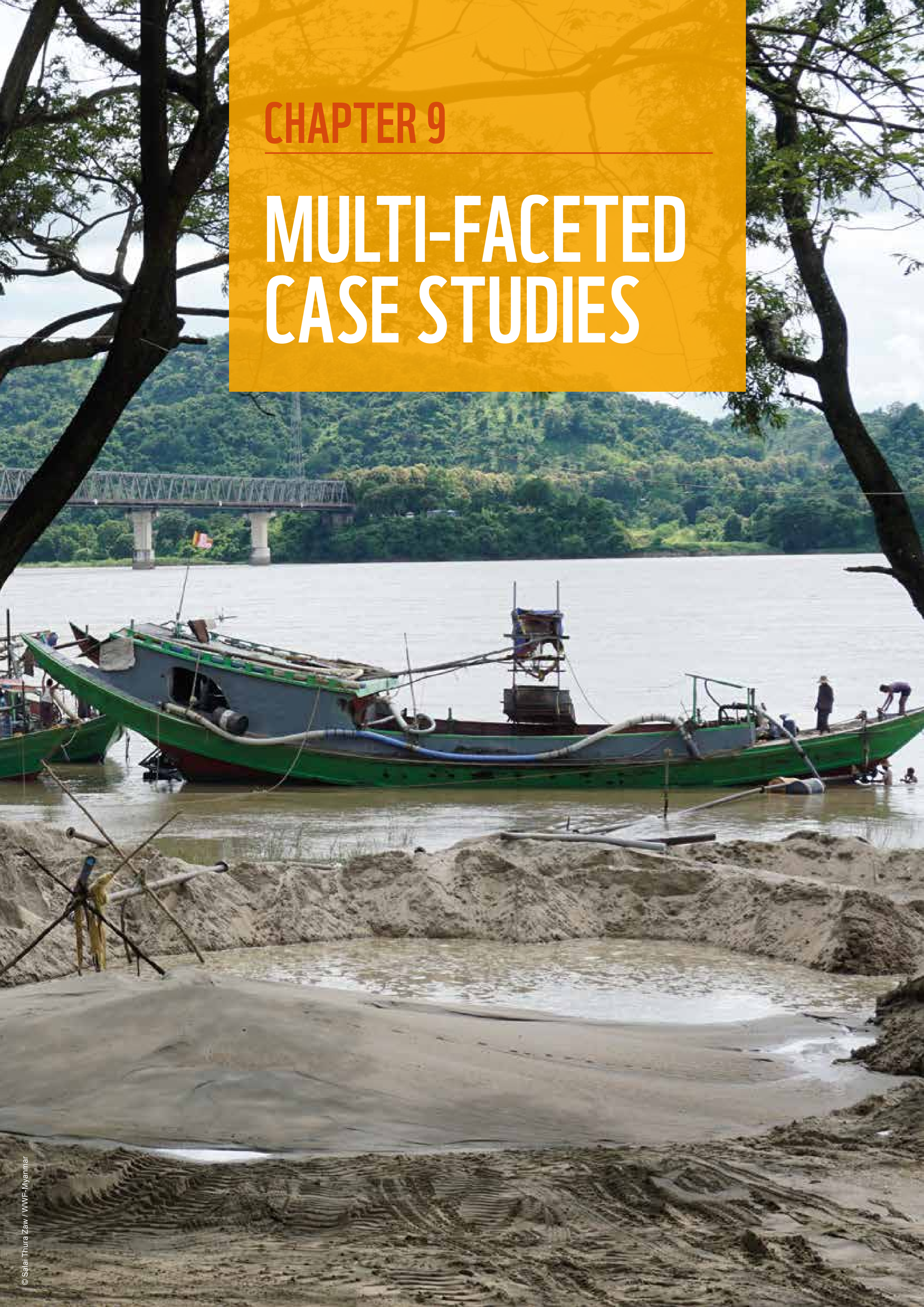
8.4 Changes to design and construction approaches and methods

Altering how buildings are designed and constructed is a fundamental way to change the dependence on concrete. As concrete is currently the most widely used building material on earth this would require fundamentally altering the construction industry and would not be an easy process. In the film 'Sand Wars', it was noted that universities are full of architectural students designing and working with alternative materials, but the construction industry is not interested in change.

The following approaches to reducing concrete uses during construction are described in an article by Smith (2018):

- Lighter weight concrete panels produced by 3D printers that use less concrete and are applicable to light weight construction;
- Construction designs that rely on the strength provided by tight-fitting light weight blocks;
- 3D printing of concrete moulds from reusable wax (FreeFab) to produce more efficient shapes with respect to concrete use, faster. This technique is being used in the London Crossrail project (Figure 8.2).

Figure 8.2. Concrete panels created using FreeFab 3D printing . Panels to be used in London's CrossRail project (image from https://3dprint.com/181956/freefab-3d-printing-crossrail/)



CHAPTER 9

MULTI-FACETED CASE STUDIES

9 Multi-faceted case studies

This section presents summaries of four multi-faceted case studies that highlight the impacts and challenges associated with sand mining in rivers. They could also form the basis of awareness raising campaigns, or guide future research or ecosystem intervention projects. Three of the studies focus on freshwater environments, with the fourth highlighting large concrete intensive infrastructure projects that are planned.

9.1 Lake Poyang, China

The factors that make Lake Poyang a good case study include:

- The largest sand mine in the world in terms of documented annual extractions and total volume of extracted material;
- The sand extraction is impacting both riverine and lake environments;
- The lake hosts numerous endangered species and is an important part of migratory routes for birds;
- Management plans for the site have been developed and implemented in the last two years, but no improvement has been reported in scientific literature;
- The Scientific community has recognised the impacts and there are calls for the Chinese Government to intervene;
- There are good satellite images capturing changes in the lake's morphology over time.

History

Located in the Jiangxi province of China, Lake Poyang is part of the Yangtze River system and is the country's largest freshwater. It is also believed to be the world's largest sand mining operation, with extractions conservatively estimated at 236 million m^3 for 2005 – 2006 (de Leeuw, et al., 2010).

The lake naturally experiences a large annual change in volume and surface area, increasing water level by approximately 10 m and increasing area from ~1,000 km^2 to ~4,000km^2 creating an ephemeral wetland system of approximately 3,000 km^2 (Mei, et al., 2015). The timing and magnitude of water level fluctuations has been affected by the construction of the Three Gorges Dam, with a higher frequency of low water levels, and a shortening of the wet season by about 1 month (Mei, et al., 2015).

Little sand mining occurred within Lake Poyang until the turn of the century, with sand miners concentrating their efforts on the main stem of the Yangtze. These operations had become so prevalent that vessels associated with them were blocking river traffic (Beiser, 2016). Sand mining was linked to the collapse of river embankments within Jiangxi Province that protected a large, populated plain (Beiser, 2016). These concerns led to all forms of sand mining being banned within the Yangtze's main stem in 2001 with all associated mining facilities to be dismantled (Lai, et al., 2014). While small amounts of sand extraction continued, this ban did dramatically reduce the prevalence of sand mining within the river's main stem. The demand for aggregate that created these mining operations did not disappear however, and instead of disbanding, many of these mining operations relocated to Lake Poyang, resulting in the extraction of aggregate from the lake increasing dramatically throughout the 2000s (Beiser, 2017).

Importance of Lake Poyang

Lake Poyang is important ecologically and socially to both the people living around it, and those who reside downstream. People in villages surrounding the lake rely on fishing for sustenance and livelihoods, while the lake is an important transport route (Thibault, 2012). Water flowing out of the lake is used for irrigation and provides drinking water for up to 44 million people who live downstream (Mei, et al., 2015).

In addition to being economically and socially important, Lake Poyang also fulfils many environmental roles. Both the hydrology and level of the lake experience dramatic seasonal changes, with these variations producing a wide range of different habitats (Li, et al., 2004) that support rich biodiversity and maintain two distinct ecological phases. During the summer, production is dominated by sub-tropical vegetation, while temperate vegetation accounts for the majority of the growth in the cooler winter periods (Zheng, 2005).

This habitat diversity and year-round productivity plays a large role in the bird life for which Lake Poyang is famous. Every winter, an average of 425,000 birds migrate to Lake Poyang, with a maximum count of 726,000 birds in 2005. Species that visit the lake include the vulnerable Swan Geese (*Anser cynoides)* and vulnerable White-naped Cranes (*Gus vipio*), and the critically endangered Siberian Crane (*Leucogeranus* leucogeranus).

Figure 9.1. Siberian cranes migrate to Lake Poyang every weinger. Photo by Ji Weitao

Lake Poyang also hosts numerous mammals, such as the critically endangered Yangtze finless porpoise (*Neophocaena asiaeorientalis ssp. asiaeorientalis*) and water deer (*Hydropotes inermis*) (Living Lakes, 2009). Fish such as the critically endangered Chinese Sturgeon (*Acipenser sinensis*) and critically endangered Chinese Paddlefish (*Psephurus gladius*) are among the 122 fish species recorded within Lake Poyang (Wu & Ji, 2002).

Sand mining and other impacts

Sand mining within Lake Poyang has had dramatic impacts on this vital environment. In recent dry seasons, the lake has contracted to smaller areas than associated with the natural variability (Thibault, 2012), with the increased decline in surface area being directly linked to sand mining, due to increased discharge from the lake associated with an increase in the channel capacity at the mouth of the lake (Lai, et al., 2014). Much of the sand mining occurring within Lake Poyang has been and continues to be located in the Hukou Waterway, which links the lake with the Yangtze River. Sand mining at the outlet has been attributed with lowering the bed of the by an average of 59 cm/yr since 2001 (Lai, et al., 2014). River cross-sections of the Hukou Waterway have increased by 75% to 120%, with the increase in channel volume consistent with the estimated volume of 236 x $10^6 m^3$/yr of sand extracted from the area (de Leeuw, et al., 2010). While initially attributed to the construction of the Three Gorges Dam upstream of Lake Poyang and drought, sand mining is now recognised to have played a key role in increasing the discharge ability of the lake at low water levels by a factor of 1.5-2 (Lai, et al., 2014). This allows the lake to drain both faster and lower than it otherwise would, thus exacerbating the impacts of flow regulation from the Three Gorges. These hydrologic changes decrease the resilience of the area to drought by limiting its storage capacity, and directly threatens the continued existence of Lake Poyang's vital wetlands.

This large decline in area and volume of the water body has forced fisherman to find other jobs, limited the water available for agriculture both around the lake and downstream, and prevented transport through certain areas (Thibault, 2012).

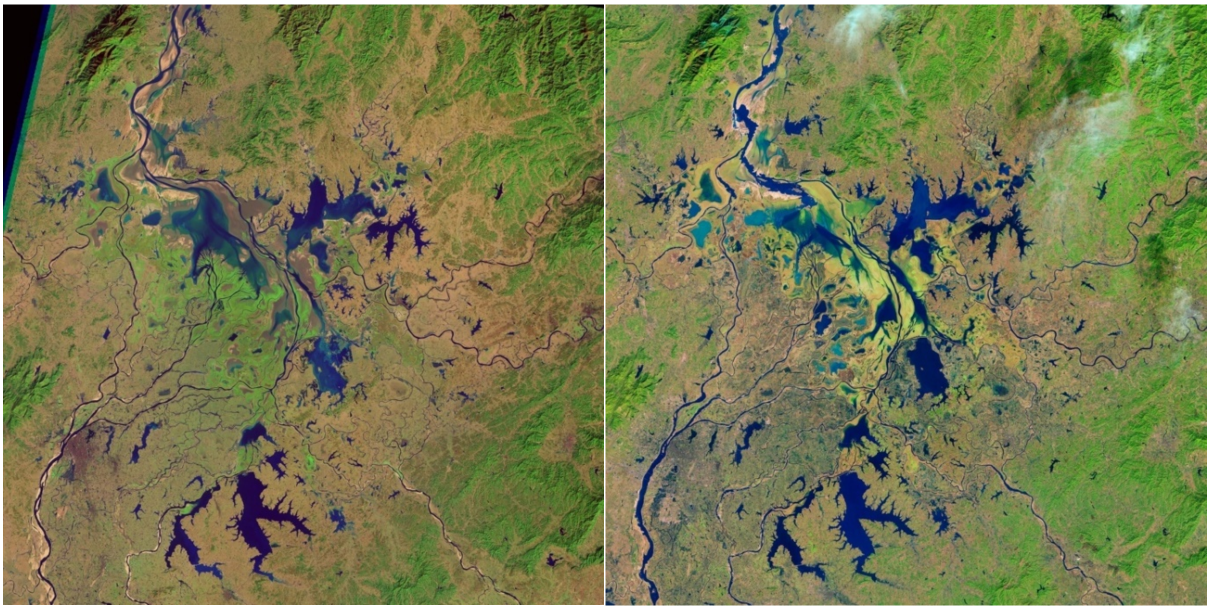


Figure 9.2. Lake Poyang in 1995 (left) and 2013 (right). To better compare the images, visit: https://earthobservatory.nasa.gov/IOTD/view.php?id=87663. Images from Nasa Earth Observatory.

The loss of these wetlands would have negative impacts on many species that utilise them as part of annual migration pathways. Of particular concern is the impact this would have on the critically endangered Siberian Crane, 90% of which are believed to frequent Lake Poyang's wetlands, and on vulnerable swan geese and white-naped cranes (Harris & Hao, 2010). If these environments are destroyed, additional pressure will be exerted on the species for survival.

Low water levels associated with sand mining have been linked with dwindling populations of the Yangtze finless porpoise. The global Yangtze finless porpoise population is estimated at 1,012, with around 450 individuals living within Poyang lake. As the lake shrinks, finless porpoises are forced into the main channel, increasing the likelihood of being struck by boats or propellers (Dong, et al., 2014). Sand mining also increases the turbidity of the lake, hampering the ability of porpoises to hunt, while pollution and overfishing have decreased their food supply so drastically that Chinese officials added 50,000 carp to the lake in 2012 in an attempt to provide food (Platt, 2012). The grim outlook for finless porpoises led to the relocation of several of the species to newly created sanctuaries, which have thus far been successful, albeit on a small scale (Aldred, 2015).

The hydrology of Lake Poyang could be further modified by a dam proposal that has been considered since the 1990s. Justifications for this dam have included restoring lake levels and securing water resources for surrounding communities, however the proposed plans have been heavily criticised by conservation groups (including the WWF) and experts as there has been little consideration of how the proposed constructions would impact the lake's environment and complex hydrology.

The plight of the lake has been recognised by scientists within China, with a Correspondence from eight scientists published in Nature (Figure 9.3, Chen, 2017).

Communication potential

The plight of animals such as the Yangtze finless porpoise and Siberian crane offer opportunities to raise the awareness of sand mining throughout the world. Conservation efforts focusing on the protection of other cetaceans have gained a strong foothold in the minds of the general public, suggesting that creating similar efforts centred around the finless porpoise may be possible. A campaign these 'popular' animals could be expanded to include the story and plight of other species under threat.

Recognition of Lake Poyang's importance has led to several conservation groups seeking to protect it. The Living Lakes Network, an international program of the Global Nature Fund has worked with the Promotion Association for Mountain-River-Lake Regional Sustainable Development (MRLSD), a non-governmental, non-profit conservation organisation, and the Jiangxi Academy of Sciences to research and implement management solutions (Global Nature Fund, 2013). A recent project aiming to protect avian biodiversity while taking into account the needs of local communities was carried out by the Paulson Institute in conjunction with the International Crane Foundation and the Poyang Lake National Nature Reserve. This project involved conducting basin-wide waterbird surveys, tracking the movements of visiting birds, and running educational programs on the importance of wetlands for local communities (Paulson Institute, 2015). These groups may have valuable contacts or suggestions relevant to conservation efforts in the region.

nature
International journal of science

Construction: limit China's sand mining

Sand mining in China has been massively stepped up over several decades to make the concrete and cement needed for the country's boom in urbanization infrastructure. The scale of this activity in the Yangtze River basin, for example, has destroyed crucial spawning, feeding and rearing grounds for its aquatic organisms, contributing to the demise of unique species such as the now-extinct Yangtze river dolphin (*Lipotes vexillifer*) and the endangered Yangtze finless porpoise (*Neophocaena asiaeorientalis* ssp. *asiaeorientalis*).

Although the Chinese government set out a strict management plan for sand mining in the Yangtze River basin in 2012, our field investigations over two years from August 2015 indicate that operations are increasing, often illegally. Colossal vessels are mining sand outside the permitted areas and times in the Yangtze's main stem and its tributaries, and in the huge connecting lakes Poyang and Dongting.

The impact of sand mining on the river's ecology is exacerbated by many mega-dam developments upriver that obstruct sand replenishment downstream (B. Hu *et al*. *Hydrol. Earth Syst. Sci.* **13**, 2253–2264; 2009). We appeal to the Chinese government to clamp down on this wholesale destruction of aquatic organisms' habitat and to promote ecologically friendly building substitutes.

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Figure 9.3. Correspondence published in Nature regarding ecological impact of sand mining.

9.2 India

India is an interesting case study because of the following factors:

- Widespread legal and illegal extraction of sand from rivers occurs throughout the country. Illegal extraction is run by highly organised and often violent sand 'mafias';
- Impacts of sand mining include river bank collapse, depletion of ground water, and loss of habitats with IUCN red listed species affected;
- Social impacts of sand mining include the loss of infrastructure and destruction of coastal mangroves leading to an increase in flooding in Mumbai and other coastal locations;
- Sand mining has been banned in some catchments due to zero sand being available above the dry season water level;
- Large profits and poor governance combine to drive the illegal trade, but there are attempts being made to reign in the activity;
- Demand in the country is likely to increase over the coming years due to increasing population and rapid development and urbanisation;
- There is potential to use this situation to raise awareness, and potentially engage in catchments where endangered species are at risk, such as the Chambal, and other places where sand mining is impacting on wildlife corridors of key species including tigers and elephants.

Background

India has the second largest population globally and is expected to become the most populous country in the next five to ten years. The population growth, economic development and urbanisation are driving the demand for sand, including plans to construct 60 million new low-income houses by 2024 (Balachandran, 2017). Construction in India is the largest economic sector, accounting for almost 8% of the GDP and the second largest provider of employment (Bliss, 2017). The demand for sand exceeds supply, with the resources of many large rivers depleted. Demand for sand in the Kerala region is anticipated to reach 60 million tonnes (Bliss, 2017), and 1,430 million tonnes nationally by 2020 (Kukreti, 2017) driving the illegal trade, which is valued at at 2.3 billion USD (Economist, 2017).

A sand audit completed for the Chaliyar River in Kerala identified poor governance, rampant corruption and the State Government exempting sand mining from Federal legislation on conservation of environment and mineral resources as underlying factors in the illegal trade (Centre for Social and Resource Development, 2014). Identified Impacts associated with the mining include:

- Loss of biodiversity of fish, turtles and birds like the rare Indian Skimmer (Bliss, 2017), including the critically endangered gharial (*Gavialis gangeticus*) and numerous other red listed species;
- Decreases in ground water levels affecting water supply and quality, including drinking water and irrigation water for important rice growing areas (Centre for Social and Resource

Development, 2014). In the Godavari River, Maharahsta State drinking water wells have dried up and villagers have to rely on tanker water.

- Channel deepening (Figure 9.4) and impacts to the aquifers of perched lakes and wetlands (Pitchaiah, 2017). In spite of regulations liming excavation to 1 m depth in the river, up to 7 m of sand is extracted (Centre for Social and Resource Development, 2014);
- Erosion of agricultural land (Bliss, 2017).

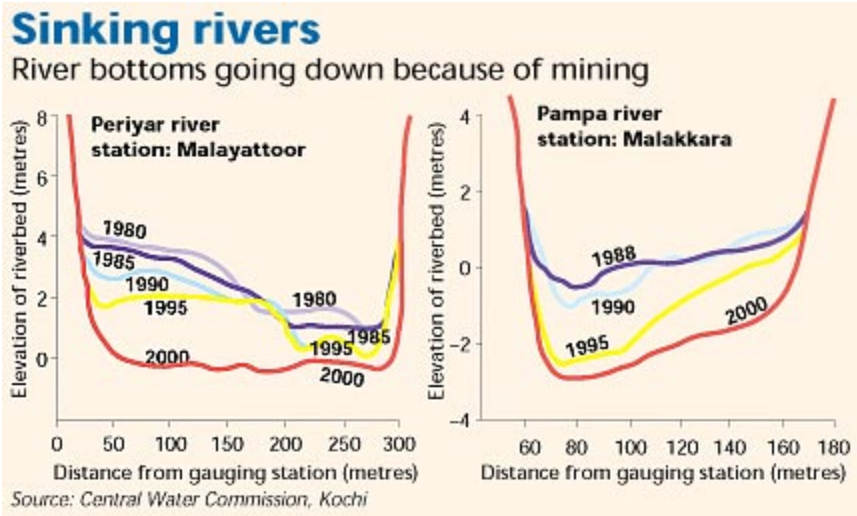

Figure 9.4. Channel deepening in the Periyar and Pampa Rivers, Kerala State, India. http://www.indiaenvironmentportal.org.in/files/images/20040531/33-graph.jpg

Attempts to deal with the illegal trade

Numerous approaches have been adopted by District, State and the Central Government to attempt to curb the illegal mining and the associated environmental, ecological and social impacts, including:

- Development of sustainable sand mining guidelines (see Section 6.1.2). The guidelines provide detailed information and recommendations on how to extract sand sustainably, but they are non-binding;
- Completion of sediment audits to identify sustainable sediment extraction limits. This approach was applied to the Kerala in 2015 and resulted in the banning of sand mining from 6 rivers with severe restrictions placed on others (Figure 9.5);
- The establishment of a complaint cell to receive and investigate complaints regarding sand mining. Legal authorities have been instructed to conduct raids, seize vehicles that engage in the illegal activity and take custody of illegally mined sand for subsequent sale at government rates, and to provide armed police to provide protection for revenue squads (Jha, 2013);
- Prosecution of illegal sand mining activity (Figure 9.6), with over 99,000 prosecutions for illegal mineral mining reported in 2014 – 2015, with collected fines totalling almost 50 million USD, suggesting an average fine of ~$500 USD (Kukreti, 2017).

Unfortunately, there is widespread reporting that these steps are insufficient to control the illegal trade, owing to the varying regulations within and between states, and a lack of enforcement. The monetary penalties are considered insufficient to discourage the activity (see Section Countries recognised as having high rates of in-stream sand mining6.1.2). A compilation of issues associated with sand mining in the States of India highlights the disparity of uniform regulations and the extend of illegal activities (Bliss,2017, Figure 9.7).

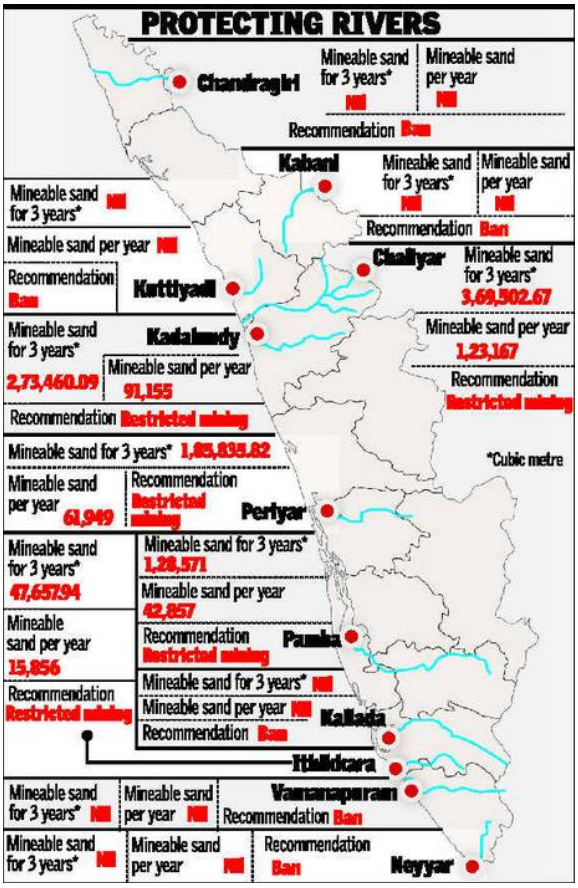

Figure 9.5. Sand mining ban in 6 rivers and restricted in 5 others in the Kerala in 2015 (Hindu, 2015)

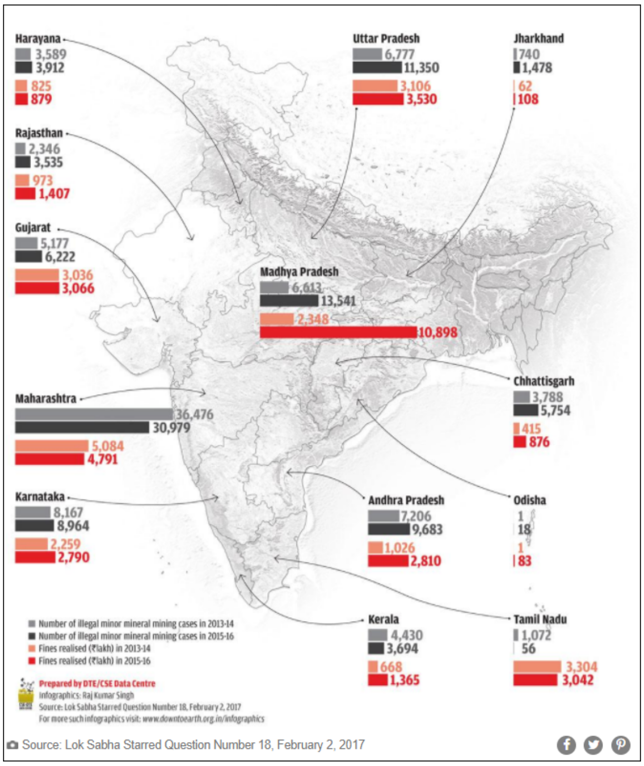

Figure 9.6. Number of illegal minor mineral mining cases in 2013-2014 and 2014-2015 (light and dark grey) and fines realised (pink and red) (Kukreti, 2017)

Illegal sand mining on rivers in 12 Indian States, their different laws and regulations

Note some rivers run through a number of states. This makes law enforcement difficult as states have different laws on sand mining. Should there be a national law? Would this solve the problem?

1. GUJARAT: Rivers Ambika, Purna, Kaveri, Tapi and Khapra are severely affected by illegal sand mining. It is forming cavities in the riverbed and accelerating water salinity. This is resulting in diminishing agricultural produce.

2. MAHARASHTRA: Sand mining needs environmental clearance. The creeks at Thane**,** Navi Mumbai, Raigad and Ratnagiri are most affected by mining

3. KARNATAKA Uniform Sand Mining Policy does not allow mining in Coastal Regulation Zones and prohibits use of machinery. The rivers affected are Cauvery, Lakshmanateerta, Harangi, Hemavathi, Nethravatai and Papaganii

4. KERALA Kerala Protection of River Banks and Regulation of Removal of Sand Act, 2001, permits mining in areas managed by a committee. The rivers affected are Bharatapuzha, Kuttiyadi, Achankovil, Pampa, Manimala, Periyar, Bhavani, Siruvani, Thuthapuzha, Chitturpuzha

5. TAMIL NADU Policy ensures quarrying in government poramboke land and private patta land can only be undertaken by the government. The rivers affected are Cauvery, Vaigai, Palar, Cheyyar, Araniyar, Kosathalaiyar, Bhavani, Vellar, Vaigai, Thamiraparani and Kollidam

6. ANDHRA PRADESH Policy allows only manual labour and bullocks for mining. Rivers affected are Godavari, Tungabhadra, Vamsadhara, Nagavali, Bahuda and Mahendratanaya

7. ODISHA Despite public agitation, sand is mined extensively. Districts like Jaipur are constantly in the grip of sand miners and contractors.

8. WEST BENGAL: Ruled by the mafia, stone quarrying in Birbhum's Mohammad Bazaar is widespread

9. BIHAR: Illegal mining rampant in Bhagalpur, Banka, Munger, Jamui, Lakhisarai, Sheikhpura, Patna, Bhojpur, Saran, Rohtas, Bhabhua, Aurangabad, Buxar, Gaya, Nalanda, Navada, Siwan, Jehanabad, Gopalganj, Muzaffarpur, Vaishali, Bettiah, Supaul, Motihari, Madhubani, Kishanganj, Saharsa and Madhepura

Map: http://cdn.downtoearth.org.in/dte/userfiles/images/25_20120430.jpg

10. UTTARAKHAND: Illegal sand mining along Ganga near Haridwar is a worry for inhabitants of Matri Sadan ashram.

11. NAGALAND: Sand mining along the Dansari River in Dimapur. Dansari is largest river in the state and has highest concentration of sand

12. MADHYA PRADESH: State exempts sand mining from environmental clearance. Mining areas are not demarcated. Therefore, mining far exceeds the allotted area. A strong nexus between contractors, politicians and bureaucrats facilitates illegal mining. It is rampant in the rivers Chambal, Narmada, Betwa and Ke

Figure 9.7. Summary of illegal sand mining activities on 12 rivers in India (Bliss, 2017)

Opportunities for communication

Without improving the regulation and governance of sand mining in India, there are limited opportunities for improvement. It is possible to use the current situation in India to increase public awareness, and promote the identification of alternative materials or building methods. There are also opportunities to engage in ecologically important catchments like the Chambal. The area contains more than 30 IUCN Red Listed species including the Ganges River dolphin and the largest remaining population of gharial. A large area of the river was declared a gharial sanctuary in 1979 with sand mining ban (Kukreti, 2017). The sanctuary has been the site of numerous conflicts between sand miners and State Armed Forces assigned to protect the sanctuary, including an officer being crushed to death by a sand-laden tractor (Chakravartty, 2014).

9.3 Mekong

The Mekong is considered a suitable case study because of the following factors:

- The Mekong is a transboundary river, with large volumes of sand extracted in Cambodia and Vietnam, with smaller quantities mined by Lao PDR and Thailand; with expected increase demand according to economic growth projections
- The countries are recognised as having poor governance and the trade is widely reported to have high rates of illegal sand mining activities;
- The impacts of sand mining are being exacerbated due to the river undergoing a phase of intense hydropower development, which is greatly reducing the sediment load of the river;
- The ecosystems being impacted include the Tonle Sap, the Mekong Flooded Forest and the Mekong delta, which are ecologically and socially important;
- Vietnam has announced they are likely to run out of sand by 2020, and are developing guidelines to use alternative materials;
- There are scientific papers quantifying sand extraction and providing a good example of a multiple lines of evidence approach. This is the only catchment for which this level of information currently exists;
- The investigations have provided a wealth of information that could be integrated and presented as an information package for the media to raise awareness;
- There is potential to build on existing knowledge with additional investigations.

Background

Legal and illegal sand mining in the lower Mekong River countries of Cambodia and Viet Nam is a major industry. Sand is extracted for domestic and international sale, and for land reclamation (Figure 9.9). Mekong River sand is advertised on the internet, with providers stipulating minimum order sizes ranging from 20,000 to 200,000 tonnes, and stating monthly supply capabilities of between 150,000 m^3/month and 1,000,000 m^3/month (Figure 9.8). This trade continues despite Vietnam and Cambodia officially banning sand exports in 2009 and 2017, respectively.

WWF identified the Mekong River as an ecological hotspot, with the river supporting over 800 species of fish, including 165 long distance migratory species and one of the three largest remaining populations of the freshwater Irrawaddy dolphin. The river and associated Tonle Sap system supports the world's largest inland fishery providing a critical food source for the 60 million people living in the catchment. A search of the IUCN Red List using the term 'Mekong' returned a list of 17 species including fish, snakes, stingray and turtle, with several species identified as data deficient highlighting how little is known about the ecosystem of the river. Habitat destruction is a threat for many of the species, suggesting sand mining is a risk.

The Mekong River is undergoing a phase of intense hydropower development. Over the past decade mega-dams have been developed on the mainstream in China with many additional dams developed or in the construction phase in tributaries in Lao PDR, Cambodia and Vietnam. Collectively, these dams are disrupting the sediment supply of the river, with virtually all dams trapping sand, and the larger dams trapping silt as well. The Mekong River is an area of focus for the Belt Road initiative, the largest infrastructure program in history (WWF & HSBC, 2018), thus possibly the largest future user of sand.

Sand mining in the lower Mekong may have higher risks associated with it as compared to other river systems due to the hydraulic balance between the mainstem Mekong and the Tonle Sap. The variability of river level in the main river drives the unique reversal of the Tonle Sap system, and determines the area of inundation of the lake. Altering the characteristics of the river channel through sand mining near the bifurcation of the Mekong and Tonle Sap has the potential to alter the timing and size of flow entering or exiting the lake, which can impact habitats and migration cues. Similar changes in delta channels can affect the hydraulics of the river (velocity, depth) and the extent and duration of salt water intrusion.

Governance of river and coastal sand mining has been under the spotlight in Cambodia for years. Global Witness (2010) found the sand mining industry was controlled by two Senators in Cambodia, with a lack of transparency regarding the issuance of permits and international trade, with Singapore was identified as the prime recipient of sand (much of which is derived from coastal sources). UN trade figures for 2007 to 2015 show that Singapore reported the import of $725 million in sand from Cambodia, but Cambodian trade figures showed only $5 million being exported (Dara, 2016). Exposure of this discrepancy increased pressure on the Government and a sand exports were banned in 2017.

Rapid growth in the region has increased the demand for construction materials and driven up costs. In Vietnam, the price for construction sand increased up to 4-fold in 2017, which in turn has driven an increase in illegal sand mining. The Director of Vietnam's Department of Construction Materials under the Ministry of Construction announced Vietnam could run out of sand by 2020 if domestic demand continues to exceed the country's reserves (Tuoi Tre News, 2017). The Ministry estimates that 2.1 – 2.3 billion m^3 of sand will be required between 2016 and 2020, with estimates of the resource at just over 2 billion m^3.

Quantifying the issue

In 2009 there was little understanding of the magnitude of sand extraction or the impact the activity was having on the rivers. WWF in collaboration with the Mekong River Commission (MRC) and with funding from Finland, France and Germany developed a range of investigations to fill these information gaps. This multiple-lines of evidence approach aimed to understand sand transport in the river, quantify sand volumes being extracted by mining, and document physical changes to the river and delta. The investigations included:

- Suspended and bedload monitoring in the mainstem Mekong and data analysis and interpretation of the results;
- An investigation into the distribution of sand in the Mekong channel and the transport mechanisms under which it was deposited and how these relate to the stream energy of the river;
- A quantitative survey of the volumes of aggregate extracted from the Mekong River, and the locations, longevity and trends within the industry;
- An examination of the morphological changes in the main channels in the delta between 1998 and 2008 to quantify changes in bed level and channel morphology;
- An analysis of changes to the delta front between 2003 and 2011 based on satellite imagery and field investigations; and,
- An analysis of temporal and spatial trends in the composition and distribution of the Mekong River plume in coastal waters.

Item specifics

Port: HCM | FOB Price: US $ 6.8 / | Minimum Order Quantity: 200000 Ton/Tons

Specifications

sand mekong river sand campuchia sand vietnamese sand
Our company recently have resources of Mekong river sand and salty sand.
We pleasure in sending you the details that we can supply as follow:
Specifications:
Module of sand : up from 1.6
Ability of providing: 500.000 m3 to 1.000.000 m3 per month.
Origin:
Our constructive sand have origin of Mekong river.
Our salty sand (smooth) have origin of Central part of Vietnam.
Partial shipment & Trans - shipment : allowed
If you have demand for our sand, please contact us as email following:
We look forward to hearing from you as soon as posible.
Thanks and best regards.
Vu Ngoc Cuong

Product Details | Company Profile | Inquiry Records(14)

Item specifics

Natural Sand Type: River Sand | Type: Sand | Fineness: Fine

Specifications

We supply River sand used for construction and reclamation. Price resonable.
Cambodia river sand can be used in both construction and reclamation.
Test Certificate: SETSCO
Capability: dredging and loading and transporting 8000 CBM per fine day.
Duration: 10 years of dredging permit and concession of exporting awarded by government
Transportation: Barge & tug, vessel

Coarse river sand from Cambodia

FOB **Reference** Price: Get Latest Price

20000 Metric Ton/Metric Tons (Min. Order)

Supply Ability: 150000 Metric Ton/Metric Tons per Month
Port: Cambodia

Contact Supplier

Chat Now!

Payment: This supplier also supports L/C payments for offline orders.

In addition, there are two other kinds of sands available.
1) Cambodia Reclamation Sands. - CIF to Singapore USD27 per metric cubic.
2) Concrete Sands from Malaysia. - Buyer will just bring transportation (Trucks) to buyers appointed wharf. Seller will transfer sands from his barge to his trucks in SINGAPORE. SGD33 per metric cubic.

Figure 9.8. Sand for sale from Vietnam and Cambodia.

Figure 9.9. Infilling of floodplain with sand mined from the Mekong in Cambodia. Google Earth Image from May 2012

Integrating the information gained from the investigations provided an estimate of the overall sediment budget for the Mekong and insights into how the impacts of sand mining and hydro development are affecting sediment transport.

It was estimated that a maximum of 30 million tonnes per year of sand was being transported by the Mekong. The results from the sand extraction surveys conducted in 2011 in Cambodia, Laos and Thailand and 2012 in Vietnam), showed that 55million tonnes per year of sand was being extracted from the river, resulting in a deficit of at least 25 million tonnes per year. The survey results are conservative, as under-reporting by some operators is likely, and not all operators were included in the survey, notably none of the ones operating on tributaries.

The other investigations highlighted the episodic movement of sand and documented the distribution of sand over the height of the river channel, demonstrating its importance in the creation and maintenance of riparian and aquatic habitat. Work in the delta showed that river channels had deepened by an average of 1.4 m between 1998 and 2008, with the changes not attributable to changes in flow or hydraulics (Brunier, et al., 2014). The delta front had experienced extensive change between 2003 and 2010, with most areas recording erosion the changes consistent with the reduced delivery of sediment (Anthony, et al., 2015). The coastal sediment plume showed decreasing concentrations of of suspended particulate matter and nutrients over the same time-period, with the decrease averaging about 5% per year (Loisel, et al., 2014).

The integrated results provided the first quantitative view of how sand mining and dams were affecting the sediment budget, and the geomorphology of the river. A large reduction in sediment delivery due to dams and sand extraction was leading to a deficit of at least 20 million tonnes per year in the sand budget of the river, and the rate of reported sand extraction comprised ~75% of the total sediment load (sand, silt and clay). The channel deepening and erosion of the delta front are consist with a highly starved river system. The capture of silt as well as sand in hydropower dams is also consistent with the observed reduction in the coastal sediment plume.

Take home messages

1. The interdisciplinary investigations are an excellent example of how different approaches can be combined to provide a holistic understanding of river systems. The use of historical satellite imagery and bathymetric surveys allowed processes that occur at time-scales of years to decades to be captured over a short period. Simple survey techniques to quantify sand mining extraction volumes and trends is a transparent and inexpensive way of providing an estimate of extraction. This work can be used to guide the development and implementation of similar studies in other river systems. It could also be useful to re-visit the Mekong situation, as awareness of the issue is increasing and there is additional information related to land subsidence related to ground water extraction, sea level rise and sediment transport.

2. The integrated understanding of how sand mining is directly impacting the Mekong and how it interacts with impacts associated with hydropower development could be used to develop communication materials to increase awareness regarding sand mining in large tropical rivers. Producing graphic models of the river showing sediment transport routes, habitat distribution, extraction volumes and areas of impact could provide a visual message of rivers and sand mining.

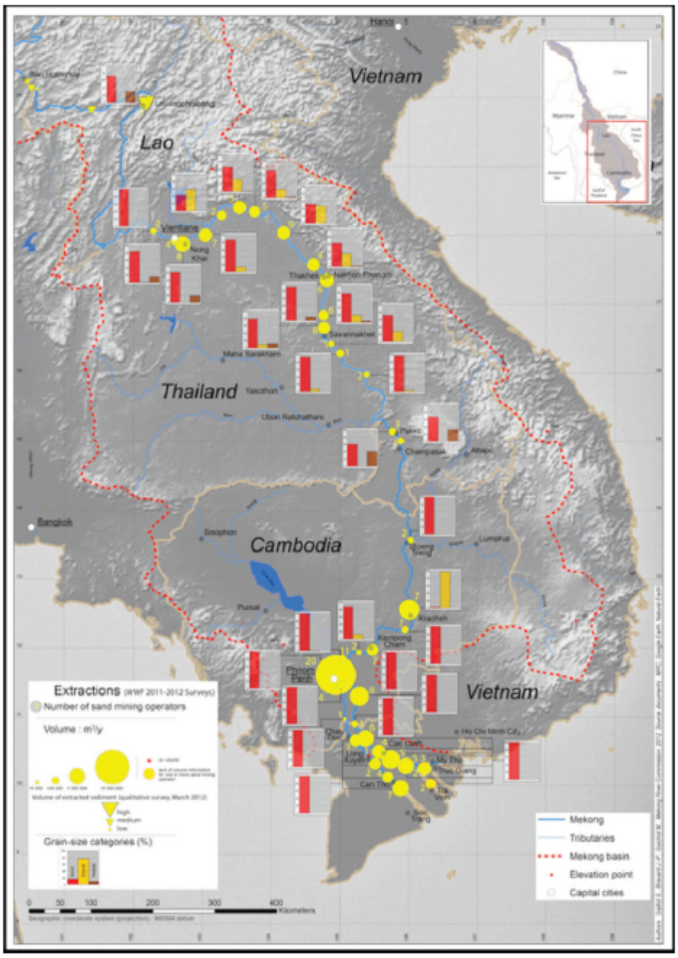

Figure 9.10. Map of sand, gravel and pebble extraction along the Mekong River based on the results of the sand extraction survey (Bravard, et al., 2013).

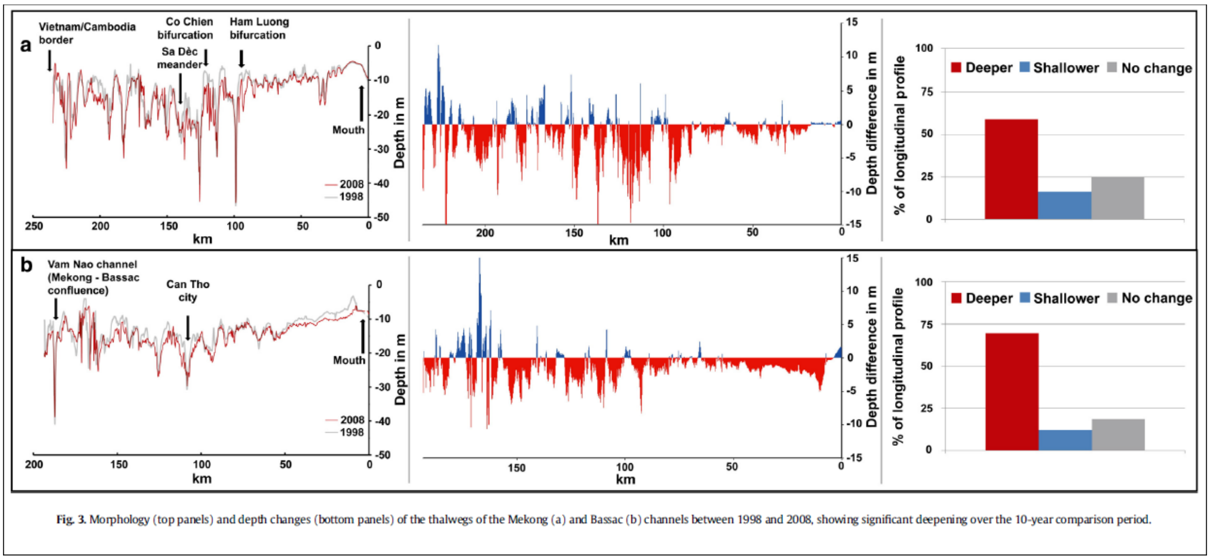

Figure 9.11. Morphology (top) and depth changes (bottom) of the thalwegs of the Mekong (a) and Bassac (b) channels between 1998 and 2008 , showing significant deepening over the 10-year period (Brunier, et al., 2014)

9.4 Mega-Projects

Mega-projects that consume large volumes of concrete increase employment and economic development, but also place local sand resources under pressure, increasing the risk of over extraction and illegal mining. There is little information available regarding the projected sand needs associated with these projects, or where and how these resources will be obtained. The list is intended to provide an overview of where some future sand mining 'hotspots' may occur.

Belt Road Initiative

China's Belt Road Initiative (BRI) is the largest group of infrastructure projects being planned in the world. The Chinese led plan could potentially cost US$1.3 trillion plan, involve over 60 countries and include the development of roads, railways, telecommunications, energy pipelines, and ports (Habib & Faulknor, 2017). The extent of the envisioned network is shown in Figure 9.12.

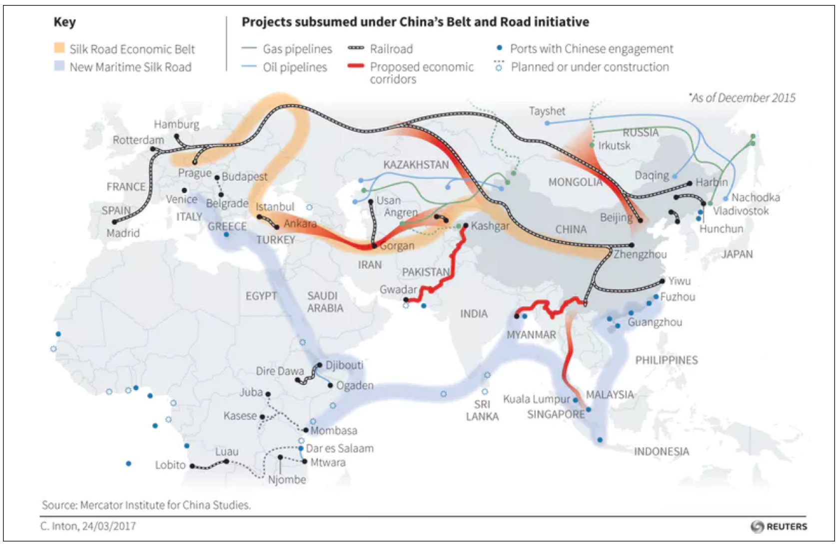

Figure 9.12. Infrastructure projects included in the Belt Road Initiative (Habib & Faulknor, 2017).

A motivating factor for the BRI is to utilise China's industrial over capacity, especially steel and cement production (Habib & Faulknor, 2017). The BRI combined with the rapid development of Asian countries could is projected to increase demand for cement to 580 million tons annually, which is about double the current capacity of the region (Bloomberg Brief, 2017). One large Chinese cement producing alone is aiming to increase exports by 50 million tonnes per year

This increased demand for cement will manifest as an increase in demand for sand, gravel or other aggregate. The increase in demand will increase the potential for impacts associated with unsustainable mining methods. Chinese financing is available for many of these large projects, and concerns have been raised about the 'minimal political conditionalities' required by China as compared to finance from the International Monetary Fund, World Bank or Asian Development Bank (Habib & Faulknor, 2017). It is plausible that this lack of requirements could extend to environmental regulations associated with a much-needed sand resource.

An analysis by BHP Billiton (Balhuizen, 2017), suggests that implementation of the BRI could drive up the demand for construction materials, with the demand for steel projected to increase by up to 150 million tonnes over the course of the BRI. The same study projects that 80% of the steel would be used in structures and reinforced concrete. This increase spread over a 10-year period would effectively double the growth rate of steel demand in the BRI region since 2011 (Balhuizen, 2017).

The implementation of such a wide-reaching array of projects in an already rapidly developing area of the world has the potential to increase the demand for sand to unprecedented levels throughout the BRI region.

South to North Water Diversion Project – China

The South to North water diversion project will take 50 years to construct and when completed, will divert 44.8 billion cubic metres of water annually from the south to the populous areas of northern China. It will link the four major river basins of the Yangtze, Yellow, Huihe and Haihe. The cost estimate for the project is $USD 62 billion, which is twice the cost of the Three Gorges Hydroelectric Project (Technology, undated). The 2,400 km Eastern and Central routes are complete, but the 1,300 km Western canal remains to be constructed (Kaiman, 2014). The estimated concrete usage for construction of the Eastern route is 15.7 million m^3, with an additional 950Mm^3 of soil / rock consumed (Liu, et al., 2015). No material estimates were found for the yet to be completed Western route.

The operation of the diversion scheme also has the potential to alter flooding in the Lake Poyang region increasing risks to an ecosystem already threatened by sand mining.

Figure 9.13. South-North Water Diversion plan.

Figure 9.14. The Caohe aqueduct project is the largest in China. Source of aggregate may be the mountains in the back of the photo?

Mega Airports

The Al Maktoum International Airport in Dubai and the Daxing International Airport in Beijing, China are both under going huge construction phases.

The Daxing International airport witll include up to seven runways, have the capacity to accommodate up to 100 million passengers a year, and cost USD$12.9 billion (Bloomberg News, 2017). Additional infrastructure will include new roads and train lines to link the airport to Beijing. The project will have a foot print of 1.17 millin m^2, with the terminal occupying 700,000 m^2. Each runway is planned to have a length of 3,800 m (CAPA, 2018). No information was found as to what companies are involved.

The Al Maktoum Internatioanl Airport in Dubai is undergoing a huge expansion, and is designed to be the largest airport in the world, capable of accommodating 220 million passengers within a decade (Airport Technology, 2018). Developed in two phases, the facility will ultimately include two new 385,000 m^2 satellite concourses, capable of servicing 65 million passengers each, four new 4.5 km runways, and twelve new trainlines and 10 train stations (Airport Technology, 2018). Contracts for the project have been awarded to UAE based Al Jaber LEGT Engineering & Contracting (ALEC), with financing provided by Uxport credit agency UK Export Finance (UKEF).

Figure 9.15. Artists impression of Daxing Airport (left, CAPA (2018)) and Al Maktour International Airport, Dubai (right, Airport Technology, (2018)).

Mega Housing Developments

In 2014, South Africa announced it would embark on a program of construcing mega-housing projects, with 1.5 million units to be built by 2019 (Harrison, 2017). Instead of providing housing within existing cities, these mega housing projets would develop completely new cities, with 46 projects initially identified (Groundup, 2016). An example is the $US 7 billion Modderfontein New City Project beign built near Johannesburg by Chinese company Shanghai Zendai. Upon completion it will house over 10,000 residents (AFK Insider (2016),)

Figure 9.16. Artists impression of Modderfontein mega-housing project outside of Johannesburg (AFK Insider, 2016).

The Indian Government has also embarked on an ambitious plan to upgrade the quality of housing in the country, with the planned construction of 60 million houses by 2024 (Balachandran, 2017). In February 2017, the affordable housing sector was provided with 'infrastructure status' which will incentivise and subsidise the project, provide tax benefits, and attract international investment (Balachandran, 2017).

To meet this huge demand for housing, alternative construction methods and materials are becoming more popular, with the traditional 'brick and mortar' being replaced by prefab structures and materials (MoneyToday, 2012). No other information about construction materials was obtained during the web search.

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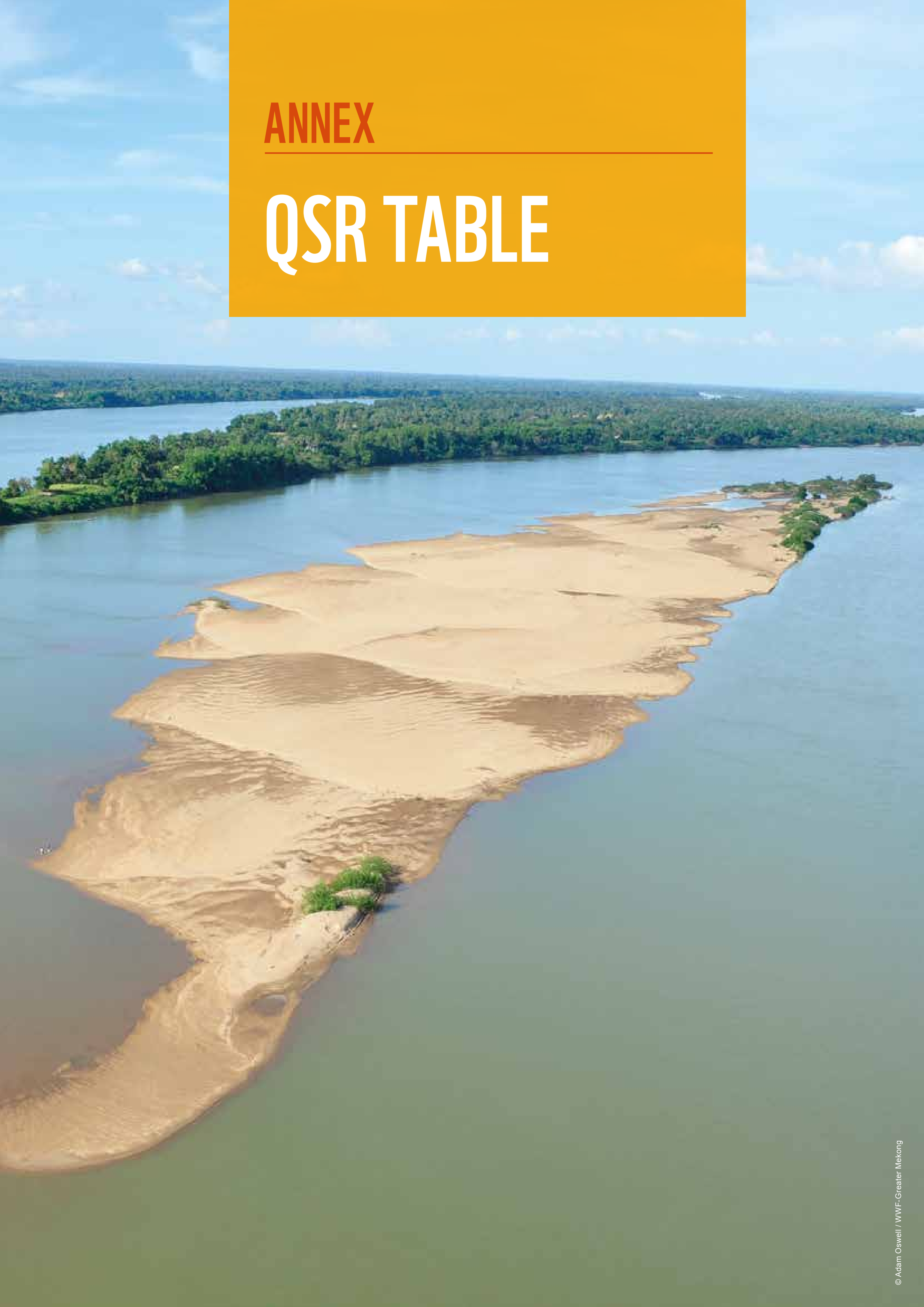
ANNEX

QSR TABLE



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No.	Author	Source	Title	Date obtained	Publication Date	River
1	Kondolf, G	SCOPUS	Geomorphic and environmental effects of in-stream gravel mining	4-Jan-18	1993	Numerous
2	Downs, P., Dusterhoff, S., Sears, W	SCOPUS	Reach-scale channel sensitivity to multiple human activities and natural events:Lower Santa Clara River, California, USA	4-Jan-18	2013	Lower Santa Clara River
3	Brunier, G., Anthony, E., Goichot, M., Provansal, M., Dussouillez, P	SCOPUS	Recent morphological changes in the Mekong and Bassac river channels, Mekong delta: The marked impact of river-bed mining and implications for delta destabilisation	4-Jan-18	2014	Mekong Delta
4	Macaire, J-J., Gay-Overjero, I., Bacchi, M., Cocirta, C., Patryl, L., Rodrigues, S.	SCOPUS	Petrography of alluvial sands as a past and present environmental indicator: Case of the Loire River (France)	4-Jan-18	2013	Loire River
5	de Leeuw, J., Shankman, D., Wu, G., Frederik de Boer, W., Burnham, J., He, Q., Yesou, H., Xiao, J.	SCOPUS	Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China	4-Jan-18	2010	Poyang Lake
6	Kondolf, G., Piégay, H., Landon, N	SCOPUS	Changes in the riparian zone of the lower Eygues River, France, since 1830	4-Jan-18	2007	Lower Eygues River
7	Daityari, S., Yawar Ali Khan, M	SCOPUS	Temporal and spatial variations in the engineering properties of the sediments in Ramganga River, Ganga Basin, India	4-Jan-18	2017	Ramganga River
			Chloride contamination in construction			

No.	Author	Source	Title	Date obtained	Publication Date	River
			Mining on River Channels			
10	Kowalska, A., Sobczyk, W	SCOPUS	Valuable Deposits of Sand and Gravel in the Valleys of Carpathian Rivers (Poland) VS Protected Areas	4-Jan-18	2014	Carpathian Rivers
11	Cheng, C-C., Hsu, H-M.,Lin, Y-H	SCOPUS	Price Investigation of Sand and Gravel from River Dredging as a Form of Public Works	4-Jan-18	2013	
12	Kurylyk, B., MacQuarrie, K., Linnansaari, T., Cunjak, R., Curry, R.	SCOPUS	Preserving, augmenting, and creating cold-water thermal refugia in rivers: concepts derived from researchon the Miramichi River, New Brunswick (Canada)	4-Jan-18	2015	Miramachi River
13	Kondolf, G	SCOPUS	Environmental planning in regulation and management of instream gravel mining in California	4-Jan-18	1994	Numerous
14	Podimata, M., Yannopoulos, P	SCOPUS	A conceptual approach to model sand-gravel extraction from rivers based on a game theory perspective	4-Jan-18	2016	Alfeios River
15	Brown, K., Daniel, W	WoS	The Population Ecology of the Threatened Inflated Heelsplitter, Potamilus inflatus, in the Amite River, Louisiana	4-Jan-18	2014	Amite River
16	Wyzga, B., Amirowicz, A.,Radecki-Pawlik, A., Zawiejska, J	WoS	Hydromorphological conditions, potential fish habitats and the fish community in a mountain river subjected to variable human impacts, the Czarny Dunajec, Polish Carpathians	4-Jan-18	2009	Czarny Dunajec River
17	Kumar, N., Kumar, A	SCOPUS	Floristic Diversity Assessment in River Sand Mining near Palri Bhoptan Village, Kisangarh Tehsil, Ajmer District, Rajasthan, India	8-Jan-18	2014	Palrl Bhoptan village

No.	Author	Source	Title	Date obtained	Publication Date	River
18	Isik, S., Dogan, E., Kalin, L., Sasal, M., Agiralioglu, N	SCOPUS	Effects of anthropogenic activities on the Lower Sakarya River	8-Jan-18	2008	Lower Sakaraya River
19	Ma, X., Lu, X., van Noordwijk, M., Li, J., Xu, J.	SCOPUS	Attribution of climate change, vegetation restoration, and engineering measures to the reduction of suspended sediment in the Kejie catchment, southwest China	8-Jan-18	2014	Kejie Watershed
20	Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., Jiang, J.	SCOPUS	Sand mining and increasing Poyang Lake's discharge ability: A reassessment of causes for lake decline in China	8-Jan-18	2014	Poyang Lake
21	Aazami, J., Sari, A., Abdoli, A., Sohrabi, H., Van den Brink, P.	SCOPUS	Assessment of Ecological Quality of the Tajan River in Iran Using a Multimetric Macroinvertebrate Index and Species Traits	8-Jan-18	2015	Tajan River
22	Mingist, M., Gebremedhin, S	SCOPUS	Could sand mining be a major threat for the declining endemic Labeobarbus species of Lake Tana, Ethiopia?	8-Jan-18	2016	Lake Tana
23	Ronquim, C., Cordeiro, G., de Amorim, M., de C. Tesxeira, A., Leivas, J., Galdino, S	SCOPUS	Competition between agricultural, urban and sand-mining areas at the Paraíba do Sul basin in southeastern Brazil	8-Jan-18	2017	Paraiba do Sul River Basin
24	Venson, G., Marenzi, R., Almeida, T., Deschamps-Schmidt, A.,Testolin, R., Rörig, L., Radetski, C	SCOPUS	Restoration of areas degraded by alluvial sand mining: use of soil microbiological activity and plant biomass growth to assess evolution of restored riparian vegetation	8-Jan-18	2017	Itajaí-açú river basin
25	González, E., Masip, A., Tabacchi, E	SCOPUS	Poplar plantations along regulated rivers may resemble riparian forests after abandonment: a	8-Jan-18	2016	Garonne River

No.	Author	Source	Title	Date obtained	Publication Date	River
			comparison of passive restoration approaches			
26	González, E., Masip, A., Tabacchi, E., Poulin, M.	SCOPUS	Strategies to restore floodplain vegetation after	8-Jan-18	2017	Middle Ebro River and Tributatires
27	Wyzga, B., Zawiejska, J., Radecki-Pawlik, A., Hajdukiewicz, H	SCOPUS	Environmental change, hydromorphological reference conditions and the restoration of Polish Carpathian rivers	8-Jan-18	2012	Carpathian Rivers
28	Finkl, C., Khalil, S., Andrews, J., Keehn, S., Benedet, L.	SCOPUS	Fluvial Sand Sources for Barrier Island Restoration in Louisiana: Geotechnical Investigations in the Mississippi River	8-Jan-00	2006	Lower Mississippi river
29	Campana, D., Marchese, E., Theule, J., Comiti, F	SCOPUS	Channel degradation and restoration of an Alpine river and related morphological changes	8-Jan-18	2014	Ahr River
30	Freedman, J., Carline, R., Stauffer, J	SCOPUS	Gravel dredging alters diversity and structure of riverine fish assemblages	8-Jan-18	2013	Allegheny River
31	Nakayama, T., Shankman, D	SCOPUS	Impact of the Three-Gorges Dam and water transfer project on Changjiang floods	8-Jan-18	2012	Poyang Lake
32	Bayram, A., Önsoy, H., Kankal, M., Kömürcü, M	SCOPUS	Spatial and temporal variation of suspended sediment concentration versus turbidity in the stream Harşit Watershed, NE Turkey	8-Jan-18	2013	Harşit watershed
33	Liébault, F., Lallias-Tacon, S., Cassel, M., Talaska, N	SCOPUS	Long profile responses of alpine braided rivers in SE France	8-Jan-18	2013	Numerous
34	Litwin, R., Smoot, J., Pavich, M., Oberg, E., Steury, B., Helwig, B., Markewich, H., Santucci, V., Sanders, G	SCOPUS	Rates and Probable Causes of Freshwater Tidal Marsh Failure, Potomac River Estuary, Northern Virginia, USA	8-Jan-18	2013	Dyke Marsh, Potomac River Estuary
35	Dang, M., Umeda, S., Yuhi, M	SCOPUS	Long-term riverbed response of lower Tedori River, Japan, to sediment extraction and dam	8-Jan-18	2014	Lower Tedori River

No.	Author	Source	Title	Date obtained	Publication Date	River
			construction			
36	Bayram, A., Önsoy, H	SCOPUS	Sand and gravel mining impact on the surface water quality: a case study from the city of Tirebolu (Giresun Province, NE Turkey)	8-Jan-18	2014	Harşit watershed
37	Picco, L., Mao, L., Rigon, E., Moretto, J., Ravazzolo, D., Delai, F., Lenzi, M.	SCOPUS	Medium term fluvial island evolution in relation with flood events in the Piave River	8-Jan-18	2012	Piave River
38	Moretto, J., Rigon, E., Mao, L., Picco, L., Delai, F., Lenzi, M.	SCOPUS	Channel adjustments and island dynamics in the Brenta River (Italy) over the last 30 years	8-Jan-18	2014	Brenta River
39	Latapie, A., Camenen, B., Rodrigues, S., Paquier, A., Bouchard, J., Moatar, F	SCOPUS	Assessing channel response of a long river influenced by human disturbance	8-Jan-18	2014	Middle Loire River
40	Chapuis, M., Dufour, S., Provansal, M., Couvert, B., Linares, M	SCOPUS	Coupling channel evolution monitoring and RFID tracking in a large, wandering, gravel-bed river: Insights into sediment routing on geomorphic continuity through a riffle–pool sequence	8-Jan-18	2014	Durance River
41	Huang, M-W., Liao, J-J., Pan, Y-W., Cheng, M-H	SCOPUS	Rapid channelization and incision into soft bedrock induced by human activity — Implications from the Bachang River in Taiwan	8-Jan-18	2014	Bachang River
42	Provansal, M., Dufour, S., Sabatier, F., Anthony, E., Raccasi, G., Robresco, S	SCOPUS	The geomorphic evolution and sediment balance of the lower Rhône River (southern France) over the last 130 years: Hydropower dams versus other control factors	8-Jan-18	2014	Lower Rhône River
43	Sadeghi, S., Kheirfam, H	SCOPUS	Temporal Variation of Bed Load to Suspended Load Ratio in Kojour River, Iran	8-Jan-18	2015	Kojour River

No.	Author	Source	Title	Date obtained	Publication Date	River
44	Gumiero, B., Rinaldi, M., Belletti, B., Lenzi, D., Puppi, G	SCOPUS	Riparian vegetation as indicator of channel adjustments and environmental conditions: the case of the Panaro River (Northern Italy)	8-Jan-18	2015	Panaro River
45	Nasrabadi, T., Ruegner, H., Sirdari, Z., Schwientek, M., Grathwohl, P	SCOPUS	Using total suspended solids (TSS) and turbidity as proxies for evaluation of metal transport in river water	8-Jan-18	2016	Haraz Basin
46	Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L., Lenzi, M	SCOPUS	Relationships between woody vegetation and geomorphological patterns in three gravel-b e d rivers with different intensities of anthropogenic disturbance	8-Jan-18	2015	Brenta, Piave, Tagliamento
47	Ortega-Becerril, J., Garzón, G., Béjar-Pizarro, M., Martínez-Díaz, J	SCOPUS	Towards an increase of flash flood geomorphic effects due to gravel mining and ground subsidence in Nogalte stream (Murcia, SE Spain)	8-Jan-18	2016	Nogalte Stream
48	Picco, L., Comiti, F., Mao, L., Tonon, A., Lenzi, M.	SCOPUS	Mediumand short termriparian vegetation, island and channel evolution in response to human pressure in a regulated gravel bed river (Piave River, Italy)	8-Jan-18	2017	Piave River
49	Skalski, T., Kędzior, R., Wyżga, B., Radecki-Pawlik, A., Plesiński, K., Zawiejska, J	SCOPUS	Impact of incision of gravel-bed rivers on ground beetle assemblages	8-Jan-18	2016	Czarny Dunajec, Bialy Dunajec, Bialka Rivers
50	Farahani, H., Bayazidi, S	SCOPUS	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	8-Jan-18	2017	Tatao River
51	Calle, M., Alho, P., Benito, G	SCOPUS	Channel dynamics and geomorphic resilience in an ephemeral Mediterranean river affected by gravel mining	8-Jan-18	2017	Rambla de la Vidua

No.	Author	Source	Title	Date obtained	Publication Date	River
52	Asaeda, T., Sanjaya, K	SCOPUS	The effect of the shortage of gravel sediment in midstream river channels on riparian vegetation cover	8-Jan-18	2017	Arakawa, Sagami, Kurobe, Kuzuryu, Kizu, Hii, Karasu rivers
53	Sanchis-Ibor, C., Segura-Beltrán, F., Almonacid-Caballer, J	SCOPUS	Channel forms recovery in an ephemeral river after gravel mining (Palancia River, Eastern Spain)	8-Jan-18	2017	Palancia River
54	Béjar, M., Gibbins, C., Vericat, D., Batalla, R	SCOPUS	Effects of suspended sediment transport on invertebrate drift	8-Jan-18	2017	River Cinca
55	Kiss, T., Balogh, M., Fiala, K., Sipos, G	SCOPUS	Morphology of fluvial levee series along a river under human influence, Maros River, Hungary	8-Jan-18	2017	Maros River
56	Smith, T., Meyer, E	SCOPUS	Freshwater Mussel (Bivalvia: Unionidae) Distributions and Habitat Relationships in the Navigational Pools of the Allegheny River, Pennsylvania	17-Jan-18	2010	Allegheny River
57	Paukert, C., Schloesser, J., Fishcer, J., Eitzmann, J., Pitts, K., Thornbrugh, D	SCOPUS	Effect of Instream Sand Dredging on Fish Communities in the Kansas River USA: Current and Historical Perspectives	17-Jan-18	2011	Kansas River
58	Harvey, B., Lisle, T	SCOPUS	Effects of Suction Dredging on Streams: a Review and an Evaluation Strategy	17-Jan-18	1998	
59	Milner, A., Piorkowski, R	SCOPUS	Macroinvertebrate assemblages in streams of interior Alaska folling alluvial gold mining	17-Jan-18	2003	
60	Brown, A., Lyttle, M., Brown, K	SCOPUS	Impacts of Gravel Mining on Gravel Bed Streams	17-Jan-18	1998	Ozark Plateau
61	Rempel, L., Church, M	SCOPUS	Physical and ecological response to disturbance by gravel mining in a large alluvial river	17-Jan-18	2009	Fraser River

No.	Author	Source	Title	Date obtained	Publication Date	River
62	Meador, M., Layher, A	SCOPUS	Instream sand and gravel mining	17-Jan-18	1998	Numerous
63	Kanehl, P., Lyons, J	SCOPUS	Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey on the big rib river, Marathon County, Wisconsin	17-Jan-18	1992	Big Rib River

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
1	Kondolf, G	USA	Rivers	Review	Review	Wet pit, dry pit, bar skimming	Numerous magnitudes
2	Downs, P., Dusterhoff, S., Sears, W	USA	River system	Comparison of historical data	Channel Sensitivity measured by comparing historical data	In-stream	0.8-2.5 Mt per yr, 1.7 Mt mean from 1960-1977
3	Brunier, G., Anthony, E., Goichot, M., Provansal, M., Dussouillez, P	Vietnam	Delta	Comparison of historical data	Thalweg evolution	In-stream	~70 Mm^3 over 10 years
4	Macaire, J-J., Gay-Overjero, I., Bacchi, M., Cocirta, C., Patryl, L., Rodrigues, S.	France	River	Comparison of sand composition	Spatial and temporal changes to sand composition	NA	NA
5	de Leeuw, J., Shankman, D., Wu, G., Frederik de Boer, W., Burnham, J., He, Q., Yesou, H., Xiao, J.	China	Lake	Observation	Number of barges exiting lake	Not specified	236 Mm^3 per yr
6	Kondolf, G., Piégay, H., Landon, N	France	River	Comparison of historical data	Historical maps/photos/field surveys		8 Mm^3 over 20 years
7	Daityari, S., Yawar Ali Khan, M	India	River	Engineering properties of sand	NA	NA	NA
8	Ratnayake, N., Silva, K., Kumara, I	Sri Lanka	Estuary	Observation	Salinity values	NA	110,000 cubic meters
9	Kondolf, G	USA	Rivers, beaches	Review	Review	In-stream, flodplain pit	Numerous magnitudes

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
						mining	
10	Kowalska, A., Sobczyk, W	Poland	Rivers	Review	Review	Not specified	250 Mt in 2011
11	Cheng, C-C., Hsu, H-M.,Lin, Y-H	Taiwan	Not discussed	Price Analysis	Prices obtained through interviews	Not specified	Not specified
12	Kurylyk, B., MacQuarrie, K., Linnansaari, T., Cunjak, R., Curry, R.	Canda	River	Summary	NA	Not specified	Not specified
13	Kondolf, G	USA	Rivers	Review of regulations and management	NA	In-stream	Variety of cases
14	Podimata, M., Yannopoulos, P	Greece	Rivers	Conceptual game theory modelling	Model outcomes	In-stream	435,228 m^3 in case study
15	Brown, K., Daniel, W	USA	Rivers, beaches	Observation	Comparison of disturbed and pristine sites	Not specified	Not specified
16	Wyzga, B., Amirowicz, A.,Radecki-Pawlik, A., Zawiejska, J	Poland	River	Observation	Fish abundance and diversity, hydromorphological river quality	In-stream gravel mining, illegal cobble mining	Not specified
17	Kumar, N., Kumar, A	India	River	Observation	Importance Value Index	River sand mining - not specified in any more detail	Not specified
18	Isik, S., Dogan, E., Kalin, L., Sasal, M.,	Turkey	River	Comparison of	Comparison of flow,	In-stream	Not specified - lots

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
	Agiralioglu, N			historical data	sediment and cross section data from pre- and post-1975 periods		is unregulated, making scale determinations difficult
19	Ma, X., Lu, X., van Noordwijk, M., Li, J., Xu, J.	China	Catchment	Comparison of historical data with models	Modelling	In-stream	Not specified - mines are illegal and hence do not report extracted volumes
20	Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., Jiang, J.	China	Lake	Comparison of historical data	Differences in flow, water level and channel morphology		236 x 10^6 m^3 per yr (2002-2009)
21	Aazami, J., Sari, A., Abdoli, A., Sohrabi, H., Van den Brink, P.	Iran	River	Observation	Multimetric Macroinvertebrate Index	In-stream	Not specified
22	Mingist, M., Gebremedhin, S	Ethiopia	Lake	Observation and questionnaires		Filtering (wet season) and digging (dry season)	24 384 m^3/2816 m^3 per year at different sites
23	Ronquim, C., Cordeiro, G., de Amorim, M., de C. Tesxeira, A., Leivas, J., Galdino, S	Brazil	River basin	Observation	LANDSAT images	Floodplain mining	
24	Venson, G., Marenzi, R., Almeida, T., Deschamps-Schmidt, A.,Testolin, R., Rörig, L., Radetski, C	Brazil	River basin	Observation	Microbiological enzyme activity	NA	NA
25	González, E., Masip, A., Tabacchi, E	France	River	Observation	Recolonization of vegetation in	In-stream	Not specified, occurred from 50s

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
					abandoned hybrid poplar plantations		to 80s
26	González, E., Masip, A., Tabacchi, E., Poulin, M.	Spain	River and tributaries	Observation	Composition and health of reforested locations	In-stream and floodplain	Not specified
27	Wyzga, B., Zawiejska, J., Radecki-Pawlik, A., Hajdukiewicz, H	Poland	Rivers	NA	NA	NA	NA
28	Finkl, C., Khalil, S., Andrews, J., Keehn, S., Benedet, L.	New Orleans	River	Geotechnical investigation		Not important	Not important
29	Campana, D., Marchese, E., Theule, J., Comiti, F	Italy	River	Comparison of historical data	Changes in river course/width	In-stream	Not specified
30	Freedman, J., Carline, R., Stauffer, J	USA	River	Observation	Ecological metrics and stable isotope analysis	In-stream	Not specified
31	Nakayama, T., Shankman, D	China	Lake	Modelling			
32	Bayram, A., Önsoy, H., Kankal, M., Kömürcü, M	Turkey	River	Observation	Suspended sediment concentrations and turbidity	Not specified	Not specified
33	Liébault, F., Lallias-Tacon, S., Cassel, M., Talaska, N	France	Rivers	Observation	Modern and historical profiles and cross sections	In-stream and floodplain	250 000 m^3 per year in the 70s and 80s from the Drôme River
34	Litwin, R., Smoot, J., Pavich, M., Oberg, E., Steury, B., Helwig, B., Markewich, H., Santucci, V., Sanders, G	USA	Tidal Marsh	Observation	Historical images	Not specified	Not specified

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
35	Dang, M., Umeda, S., Yuhi, M	Japan	River	Comparison of historical data	Sediment volumes, river topography, comparison of aerial photos	In-stream	7.69 x 10^6 m^3 from 1962-1991, 2.1 x 10^6 m^3 from 1949-1963
36	Bayram, A., Önsoy, H	Turkey	River	Observation	Water quality indicators (T, EC, DO, pH, SSC, WH, Al, Mn, Cr, Fe)	In-stream	
37	Picco, L., Mao, L., Rigon, E., Moretto, J., Ravazzolo, D., Delai, F., Lenzi, M.	Italy	River	Observation	Historical indicators	Not specified	Not specified
38	Moretto, J., Rigon, E., Mao, L., Picco, L., Delai, F., Lenzi, M.	Italy	River	Observation	Historical images	In-stream and floodplain pit mining	6-8 million m^3 from 1953-1977
39	Latapie, A., Camenen, B., Rodrigues, S., Paquier, A., Bouchard, J., Moatar, F	France	River	Observation/modelling	Aerial photographs, modeling	In-stream, flodplain pit mining	83 × 10^6 m^3 of sediment was extracted between 1949 and 1992
40	Chapuis, M., Dufour, S., Provansal, M., Couvert, B., Linares, M	France	River	Field measurements/ observations/modelling	Analysis of recorded changes on scour chains, particle tracking, channel surveying,	In-stream	Not specified
41	Huang, M-W., Liao, J-J., Pan, Y-W., Cheng, M-H	Taiwan	River	Historical comparisons	Historical topographic maps and aerial photographs from last 100 years	In-stream	Not specified

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
42	Provansal, M., Dufour, S., Sabatier, F., Anthony, E., Raccasi, G., Robresco, S	France	River	Historical map comparisons	Comparison of historical maps and GIS analysis over 130 years	In-stream	84 Mm^3 total 0.83 Mm^3/yr over the Rhone basin (mainstem and tributaries)
43	Sadeghi, S., Kheirfam, H	Iran	River	Observation	Bed load-suspended load ratio	Not specified	Not specified
44	Gumiero, B., Rinaldi, M., Belletti, B., Lenzi, D., Puppi, G	Italy	River	Observation	Vegetation distributions and presence of indicator species	In-stream	Minimum of 59 x 10^5 m3 were extracted between 1962 and 1980
45	Nasrabadi, T., Ruegner, H., Sirdari, Z., Schwientek, M., Grathwohl, P	Iran	Basin	Observation	Total Suspended Sediments/turbidity and Ni, Pb, Ca, Cu, Zn, Co, As, Sr concentrations	In-stream	Not specified
46	Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L., Lenzi, M	Italy	Rivers	Observation	Geomorphic conditions, presence/absence of woody species	In-stream	Brenta: 360, 000 m^3 per yr (from 1953-1977), Piave: Unavailable, Tagliamento: 1.1 Mm^3 per year (from 1970-1991)
47	Ortega-Becerril, J., Garzón, G., Béjar-Pizarro, M., Martínez-Díaz, J	Spain	Stream	Observation	Channel measurements, flood stage indicators, sedimentary sections, morphologic features,	In-stream	5.4 x 10^5 m^3 - total volume from one site

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
					aerial photos, LiDAR-derived DEM, ground deformation measurements		
48	Picco, L., Comiti, F., Mao, L., Tonon, A., Lenzi, M.	Italy	River	Observation	Historical aerial photographs, LiDAR data, repeated topographic surveys	In-stream	Unknown
49	Skalski, T., Kędzior, R., Wyżga, B., Radecki-Pawlik, A., Plesiński, K., Zawiejska, J	Poland	Rivers	Observation	Ground beetle collection	In-stream	Not specified
50	Farahani, H., Bayazidi, S	Iran	River	Survey of 282 out of 1054 households households in villages	Statistical analysis of survey results	Not specified	Not specified-but indicated as increasing in both legal and illegal activities due to increasing demand
51	Calle, M., Alho, P., Benito, G	Spain	Ephemeral river	Observation	Comparison of historical images and LiDAR data	In-stream	Not specified
52	Asaeda, T., Sanjaya, K	Japan	Rivers	Observation	Aerial photographs, field surveys of tree species diversity/abundance	Not specified	Not specified
53	Sanchis-Ibor, C., Segura-Beltrán, F., Almonacid-Caballer, J	Spain	Ephemeral river	Observation	Aerial photographs	In-stream	Unknown for 70s. The total volume extracted during the period from 1980–

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
							1988 is 137,925 m3
54	Béjar, M., Gibbins, C., Vericat, D., Batalla, R	Spain	Tributary	Observation	Suspended Sediment Load and invertebrate drift	In-stream	Not specified - lots is unregulated, making scale determinations difficult
55	Kiss, T., Balogh, M., Fiala, K., Sipos, G	Hungary	River	Observation	LiDAR	In-stream	Not specified
56	Smith, T., Meyer, E	USA	River	Observation	Mussel diversity and abundance	Not specified	Not specified
57	Paukert, C., Schloesser, J., Fishcer, J., Eitzmann, J., Pitts, K., Thornbrugh, D	USA	River	Observation	Fish abundance and diversity	Dredging	Not specified
58	Harvey, B., Lisle, T	North America	Rivers	Review	Review	Suction dredging	Not specified
59	Milner, A., Piorkowski, R	USA	Streams	Observation	Abundance, dominant taxon, mean total biomass	Rerouting river	Not specified
60	Brown, A., Lyttle, M., Brown, K	USA	Gravel bed streams	Observation	Morphological changes, changes in fish and invertebrate abundance/densities	Not specified	Unknown
61	Rempel, L., Church, M	Canada	River	Observation	Diversity, abundance, species richness, % salmonids, Simpson's diversity, Simpson's evenness, %EPT, total and EPT richness	Dry bar scalping	69 000 m^3

No.	Author	Country	System type	Method of Study	Method of inference	Type of extraction	Scale of mining
62	Meador, M., Layher, A	USA	Rivers	Review	Review	Various	Various
63	Kanehl, P., Lyons, J	USA	River	Observation	Habitat characteristics, Index of Biotic Integrity (IBI)		

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
1	Kondolf, G	No	Roads, highways, pipelines, septic systems, concrete	Historical data, sediment budgets	Incision, channel widening, destruction of aquatic and riparian environment, bed coarsening, channel instability, undermining and exposure of infrastructure, increased turbidity, flow reduction, improved flood control
2	Downs, P., Dusterhoff, S., Sears, W	Yes	Linked to population growth, presumably construction	Historical data	Incision
3	Brunier, G., Anthony, E., Goichot, M., Provansal, M., Dussouillez, P	No	Construction	Digital channel datasets from 1998-2008	Irregular incision, mean thalweg depth increase of 1.4 m and 1.34m for main stem and Basaac respectively. Creation of many deep pools, with some widening rather than deepening. Increase in bottom slope. Leads to increased shear stresses, potentially triggering regressive erosion
4	Macaire, J-J., Gay-Overjero, I., Bacchi, M., Cocirta, C., Patryl, L., Rodrigues, S.	Dams, vegetation changes	NA	Mineralogy	Aggregate mining has contributed to long term changes in the composition of sands in the Loire River due to floodplain incision
5	de Leeuw, J., Shankman, D., Wu, G., Frederik de Boer, W., Burnham, J., He, Q., Yesou, H., Xiao, J.	Not specified	Construction	NA	Increased turbidity, widening of channel, deepening of channel. Potential for lower water levels, increased flow speeds, and increased irrigation
6	Kondolf, G., Piégay, H., Landon, N	Yes, river manipulations, intensive farming	Construction	Historical maps, aerial photos, modern photos, and	Fragmentation of riparian forest for minging and storage areas but increase in forest cover in catchment. Flood magnitudes and sediment

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
		andagriculture		fieldwork results	supply likely to decrease as a result. Mining caused incision in 20th century.
7	Daityari, S., Yawar Ali Khan, M	NA	Construction	NA	NA
8	Ratnayake, N., Silva, K., Kumara, I	NA	Construction	Upstream salinity values	Mining increases salt water intrusion up river
9	Kondolf, G	Yes, dams	Construction	Review	Incision, channel instability (may lead to increased sediment loads), bed coarsening, removal of coarse, woody material that is userd as cover by fish, channel widening and shallowing leading to higher temperatures. Flood plain pit mining destroys riparian habitats. Pits often intersect with ground water, hence may contaminate it. Floodplain mines may become in-stream during floods
10	Kowalska, A., Sobczyk, W	No	Construction	Review	Not described
11	Cheng, C-C., Hsu, H-M.,Lin, Y-H	NA	Construction	NA	Not described
12	Kurylyk, B., MacQuarrie, K., Linnansaari, T., Cunjak, R., Curry, R.	NA	Mining used to create thermal refugia to mitigate impacts of warming on cold water fish	NA	Not described
13	Kondolf, G		Construction	NA	NA
14	Podimata, M., Yannopoulos, P	No	Construction	Various game theory outcomes	Reduced sediment rate, changed river flows, altered channel morphology, bank erosion, channel degradation, fish habitat degradation,

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
					loss of riparian flora and fauna. Prevents aggradation in areas critical to flooding, reduces sedimentation
15	Brown, K., Daniel, W	Yes, urbanisation	Not specified	Different sites in river	Channel widening, braided flow, bank destabilisation
16	Wyzga, B., Amirowicz, A.,Radecki-Pawlik, A., Zawiejska, J	Yes, channel modification, increase in catchment forest cover	Not specified	Different sites in river	Incision, leading to increased flow capacities, decreased valley floor inundation. Increased flood hazard to downstream reaches. Bed coarsening
17	Kumar, N., Kumar, A	No	Not specified	IVI of different species	Removal of vegetation, disturbance of ground, altered soil profiles, hydrology, topography, nutrient status
18	Isik, S., Dogan, E., Kalin, L., Sasal, M., Agiralioglu, N	Dams	Construction	Conditions pre-1975	Significant incision above 12km from the river mouth
19	Ma, X., Lu, X., van Noordwijk, M., Li, J., Xu, J.	Yes, vegetation restoration, dams	Construction	Historical data	Bank erosion - uncertain how much is related to sand mining
20	Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., Jiang, J.	No	Construction	Historical data	Large increases in outflow channel width and depth, leading to lower lake levels
21	Aazami, J., Sari, A., Abdoli, A., Sohrabi, H., Van den Brink, P.	Yes, pulping and papermaking, agriculture, fish ponds	Construction	MMI of different river sections	Increased turbidity, low pH, high electrical conductivity, low DO, high sulfate, iron, toxic heavy metals, high BOD
22	Mingist, M., Gebremedhin, S		Construction	Evidence from surveys	Decreased sediment load, increased river depth and width, increased flow rates, decreased gravel bed cover, pool creation, loss of vegetation, changes in river colour, decreased

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
					river perenniality, decreased water volume
23	Ronquim, C., Cordeiro, G., de Amorim, M., de C. Tesxeira, A., Leivas, J., Galdino, S	Yes, chemical pollution from industry, sewage, bank engineeringwater consumption, dams, deforestation	Construction	Area used for certain activities	Increased no./area of lakes associated with sand mining, loss of rice growing land, fines/financial losses for the farmers who actually own the lands.
24	Venson, G., Marenzi, R., Almeida, T., Deschamps-Schmidt, A.,Testolin, R., Rörig, L., Radetski, C	No	Construction	4 sites that had experienced sand mining were compared with a reference site	
25	González, E., Masip, A., Tabacchi, E	Yes, different forestry management practices, dams	Not specified	Different sites	Reduction in sediment supply, loss of channel migration, channel be incision, disconnection of floodplain from river and groundwater
26	González, E., Masip, A., Tabacchi, E., Poulin, M.	Yes, different restoration practices, different channel management techniques	Not specified	Composition and health of revegetated areas	
27	Wyzga, B., Zawiejska, J., Radecki-Pawlik, A., Hajdukiewicz, H	NA	NA	NA	NA
28	Finkl, C., Khalil, S., Andrews, J., Keehn, S., Benedet, L.	Not important	Not specified	Not important	Not important
29	Campana, D., Marchese, E., Theule, J., Comiti, F	Yes, dams, channel modifications	Construction	River course over time	Channal narrowing, incision, floodplain disconnection, bank degradation associated with mining on narrow river

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
30	Freedman, J., Carline, R., Stauffer, J	Yes, dams	Not specified	Ecological metrics (eg. species diversity), stable isotope analysis variation between sites	Removal or spawning habitat, decreased food availability, increase in fine sediment layers
31	Nakayama, T., Shankman, D				Mining likely to increase flood risk
32	Bayram, A., Önsoy, H., Kankal, M., Kömürcü, M	Yes, municipal waste water, dams	Not specified	Different sites in river	Increased turbidity and SSC. May also impact groundwater
33	Liébault, F., Lallias-Tacon, S., Cassel, M., Talaska, N	Yes, reforestation, torrent control	Not specified	Different sites and rivers experiencing different anthropogenic pressures	Incision, loss of braiding
34	Litwin, R., Smoot, J., Pavich, M., Oberg, E., Steury, B., Helwig, B., Markewich, H., Santucci, V., Sanders, G	Yes, periodic flooding	Construction, creation of navigable channel	Comparisons to historical maps and photos	Significant erosion, that has continued after mining was stopped. Nobody knows why
35	Dang, M., Umeda, S., Yuhi, M	Yes, dams	Construction	Temporal variation in a number of categories	Significant degradation, followed by aggradation after mining was halted. Decrease in riverbed sediment volume
36	Bayram, A., Önsoy, H	Yes, municipal waste water, dams	Construction	Different sites in river	6m decrease in groundwater, Suspended Sediment Concentration, Mn, Cr, Fe have all increased as a result of sand minnig.

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
37	Picco, L., Mao, L., Rigon, E., Moretto, J., Ravazzolo, D., Delai, F., Lenzi, M.	Yes, channel modifications	Not specified	Aerial photos	Decrease in active channel, increase in stable islands associated with mining
38	Moretto, J., Rigon, E., Mao, L., Picco, L., Delai, F., Lenzi, M.	Yes, dams, flow diversions	Construction	Different sites, different times	Incision, channel narrowing, change from braided to wandering river. Cessation of mining has led to decrease in erosion and narrowing processes
39	Latapie, A., Camenen, B., Rodrigues, S., Paquier, A., Bouchard, J., Moatar, F	Yes, channel modifications, dams, bridges	Construction	Different sites, different times	Incision during mining, aggradation following cessation of mining
40	Chapuis, M., Dufour, S., Provansal, M., Couvert, B., Linares, M	Yes, dams, channel modifications	Not specified	Bed forms and bedload movement following flood events	Combination of gravel mining and damming produced incision and changed river to single channel
41	Huang, M-W., Liao, J-J., Pan, Y-W., Cheng, M-H	Yes, bridges, weirs	Construction	Sites over time	Massive incision (~30m), changed channel type, narrowed channel width,
42	Provansal, M., Dufour, S., Sabatier, F., Anthony, E., Raccasi, G., Robresco, S	Yes. Dams, reforestation, land use changes, torrent control works	Not specified	Comparison of river reaches over time	Incision, narrowing reductin in sediment, but not all due to aggregate mining
43	Sadeghi, S., Kheirfam, H		Not specified	Different sites and times	Both bed load (BL) and sediment load (SL) increased during sand mining. BL increased far more than SL leading to increases in the BL:SL ratio
44	Gumiero, B., Rinaldi,	Yes, weirs, bank	Construction	Different sites	Incision up to 10m, narrowing, changing

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
	M., Belletti, B., Lenzi, D., Puppi, G	protections, channelisation, levees			channel patterns
45	Nasrabadi, T., Ruegner, H., Sirdari, Z., Schwientek, M., Grathwohl, P		Not specified	Different sites	Metal concentrations were homogeneous near sand mining operations, likely due to constant Total Suspended Sediment levels produced my sand mining
46	Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L., Lenzi, M	Yes, dams, torrent control works, deforestatino, reforestation	Construction	Different sites	In the most disturbed river (Brenta), there was little variation in vegetation units
47	Ortega-Becerril, J., Garzón, G., Béjar-Pizarro, M., Martínez-Díaz, J	Yes, groundwater overexploitation	Construction	Different sites and times	Incision, channel narrowing, bank undermining
48	Picco, L., Comiti, F., Mao, L., Tonon, A., Lenzi, M.	Yes, dams, deforestation, erosion and torrent control works	Construction	Different sites and times	Incision, spread of riparian forests, channel narrowing
49	Skalski, T., Kędzior, R., Wyżga, B., Radecki-Pawlik, A., Plesiński, K., Zawiejska, J	Yes, channel modifications	Not specified	Different sites	Channel changed to single thread, up to 3.5m of incision
50	Farahani, H., Bayazidi, S	No	Construction in nearby towns	Survey response	
51	Calle, M., Alho, P., Benito, G	No	Not specified	Different sites and times	2-3m incision, channel narrowing
52	Asaeda, T., Sanjaya, K	Yes, afforestation	Not specified	Different sites	Afforestation and sand mining limit gravel deposition
53	Sanchis-Ibor, C.,	No	Not specified	Sites over time	Incision, channel narrowing. Has led to gravel

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
	Segura-Beltrán, F., Almonacid-Caballer, J				patches being confined to the lower reaches of the river, limiting its ability to recover.
54	Béjar, M., Gibbins, C., Vericat, D., Batalla, R	No	Channel maintenance	Times while mining was and wasn't occurring	Suspended Sediment Concentration increased by an order of magnitude during mining
55	Kiss, T., Balogh, M., Fiala, K., Sipos, G	Yes, channel modifications	Not specified	Different segments of river - different flubial bars	Incision, increase in cross-sectional channel area, changes to fluvial levee frequency and morphology
56	Smith, T., Meyer, E	Yes, dams	Not specified	Different sites	Incision, increase in silt
57	Paukert, C., Schloesser, J., Fishcer, J., Eitzmann, J., Pitts, K., Thornbrugh, D	Yes, dams, urbanization	Not specified	Control and dredge sites at different times	Deeper, slower current velocities, channel widening, bank erosion, riverbed degradation
58	Harvey, B., Lisle, T		Gold mining	NA	Channel migration, changes in bed particle size, changes in hydraulic forces, increase scour, incision, increased turbidity, deposition of fine bedload, more embedded substrate
59	Milner, A., Piorkowski, R	No	Gold mining	Sites with different mining histories and control sites	
60	Brown, A., Lyttle, M., Brown, K	No	Not specified	Different sites	Increase in bank-full widths, longer pools, exposed bedrock, increased turbidity
61	Rempel, L., Church, M	No	Not specified	Undisturbed reference sites using BACI design	Created area with loose surface of gravel and sand

No.	Author	Other stressors?	Use of sand	Comparator	Physical response
62	Meador, M., Layher, A	Yes, variety	Mostly construction	NA	Channel degradation, incision, changes in width, thalweg relocation, sedimentation, increased turbidity
63	Kanehl, P., Lyons, J				

No.	Author	Biological response	Other impacts	Political response
1	Kondolf, G	Loss of spawning habitat for fish, changes in fish and inverterbrate populations, destruction of riparian habitat		Mentions some bans and management strategies
2	Downs, P., Dusterhoff, S., Sears, W	Not discussed		Not discussed
3	Brunier, G., Anthony, E., Goichot, M., Provansal, M., Dussouillez, P	Not discussed		Sand mining is a politicaly sensitive topic
4	Macaire, J-J., Gay-Overjero, I., Bacchi, M., Cocirta, C., Patryl, L., Rodrigues, S.	NA	NA	NA
5	de Leeuw, J., Shankman, D., Wu, G., Frederik de Boer, W., Burnham, J., He, Q., Yesou, H., Xiao, J.	May reduce the productivity of *Vallisneria spiralis*, the food of the endangered Siberian crane. Noise could affect *Neophocaena phocaenoides*. No impacts reported as of yet.		Mining of Poyang lake began as a result of a ban on mining in the Yangtze. Mining temporarily postponed in 2008 over environmental concerns.
6	Kondolf, G., Piégay, H., Landon, N	Decrease of water tables associated with incision may prevent new forest developing.		Commercial mining outlawed in 1992
7	Daityari, S., Yawar Ali Khan, M	NA	NA	NA
8	Ratnayake, N., Silva, K., Kumara, I	NA	Salt water intrusion increases chloride content of sediment	Regulations exist, but aren't followed. Regulations detailed in the Mines and Minerals act No. 33 of Sri Lanka
9	Kondolf, G			
10	Kowalska, A., Sobczyk, W	Not described		
11	Cheng, C-C., Hsu, H-M.,Lin, Y-H	Not described		

No.	Author	Biological response	Other impacts	Political response
12	Kurylyk, B., MacQuarrie, K., Linnansaari, T., Cunjak, R., Curry, R.	Increase in thermal refugia for cold blooded fish		
13	Kondolf, G	NA	NA	Regulation is piecemeal and poorly enforced
14	Podimata, M., Yannopoulos, P	Not discussed		State should raise penalty for illegal mining by 75%.
15	Brown, K., Daniel, W	Increased stranding rate of mussels. Decreased abundance near mining sites.		
16	Wyzga, B., Amirowicz, A.,Radecki-Pawlik, A., Zawiejska, J	Decreased diversity and abundance of fish species in mining affected areas		
17	Kumar, N., Kumar, A	Changed rates of carbon and nitrogen cycling, ecosystem productivity, altered microbial community structure and soil functional processes	N	
18	Isik, S., Dogan, E., Kalin, L., Sasal, M., Agiralioglu, N			
19	Ma, X., Lu, X., van Noordwijk, M., Li, J., Xu, J.			
20	Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., Jiang, J.			Suggestion to prohibit sand mining
21	Aazami, J., Sari, A., Abdoli, A., Sohrabi, H., Van den Brink, P.	Sand mining reduced macroinverterbrate tolerance, abundance, diversity and community composition		
22	Mingist, M., Gebremedhin, S	Reduced vegetation leads to less protection for eggs and juveniles, decreased oxygen harms eggs (*labeobarbus*, fish)		Mining was conducted under licenses from the government, but these are arbitrarily given and not enforced. More

No.	Author	Biological response	Other impacts	Political response
				regulation is proposed.
23	Ronquim, C., Cordeiro, G., de Amorim, M., de C. Tesxeira, A., Leivas, J., Galdino, S			
24	Venson, G., Marenzi, R., Almeida, T., Deschamps-Schmidt, A.,Testolin, R., Rörig, L., Radetski, C			
25	González, E., Masip, A., Tabacchi, E	Changed health and species composition of the residual natural forest. Poplar plantations more dependent on irrigationl.		
26	González, E., Masip, A., Tabacchi, E., Poulin, M.	Channel widening through gravel extraction produced vegetation most similar to reference sites. Floodplain mining led to forests quite different from those naturally oberved		
27	Wyzga, B., Zawiejska, J., Radecki-Pawlik, A., Hajdukiewicz, H	NA	NA	NA
28	Finkl, C., Khalil, S., Andrews, J., Keehn, S., Benedet, L.	Not important		
29	Campana, D., Marchese, E., Theule, J., Comiti, F			
30	Freedman, J., Carline, R., Stauffer, J	Decline in species richness and abundance. Macroinverterbrate assemblages were significantly different (lower abundance, biomass, community evenness). Particular decline in substratum chooser and brood hiding species		

No.	Author	Biological response	Other impacts	Political response
31	Nakayama, T., Shankman, D			
32	Bayram, A., Önsoy, H., Kankal, M., Kömürcü, M			
33	Liébault, F., Lallias-Tacon, S., Cassel, M., Talaska, N			
34	Litwin, R., Smoot, J., Pavich, M., Oberg, E., Steury, B., Helwig, B., Markewich, H., Santucci, V., Sanders, G			
35	Dang, M., Umeda, S., Yuhi, M			
36	Bayram, A., Önsoy, H			
37	Picco, L., Mao, L., Rigon, E., Moretto, J., Ravazzolo, D., Delai, F., Lenzi, M.	Increase in vegetation height associated with more stable islands		
38	Moretto, J., Rigon, E., Mao, L., Picco, L., Delai, F., Lenzi, M.			
39	Latapie, A., Camenen, B., Rodrigues, S., Paquier, A., Bouchard, J., Moatar, F			
40	Chapuis, M., Dufour, S., Provansal, M., Couvert, B., Linares, M			
41	Huang, M-W., Liao, J-J., Pan, Y-W., Cheng, M-H			
42	Provansal, M., Dufour, S., Sabatier, F., Anthony, E., Raccasi, G., Robresco, S			
43	Sadeghi, S., Kheirfam, H			
44	Gumiero, B., Rinaldi, M., Belletti, B., Lenzi, D., Puppi, G	Unexpected relations between vegetation types and river landforms can occur in		

No.	Author	Biological response	Other impacts	Political response
		heavily human-impacted conditions. Riparian vegetation diversity can be high in impacted rivers		
45	Nasrabadi, T., Ruegner, H., Sirdari, Z., Schwientek, M., Grathwohl, P			
46	Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L., Lenzi, M			
47	Ortega-Becerril, J., Garzón, G., Béjar-Pizarro, M., Martínez-Díaz, J			
48	Picco, L., Comiti, F., Mao, L., Tonon, A., Lenzi, M.	Following cessation of mining, there was a brief recovery phase before the river appears to be in equilibrium but in a more degraded state. This suggests cessation of mining is not enough to restore a river's morphological patterns/degradation		
49	Skalski, T., Kędzior, R., Wyżga, B., Radecki-Pawlik, A., Plesiński, K., Zawiejska, J	Incision reduced ground beetle diversity on lowest benches, high diversity on highest bench that is basically free from flooding. Sites with incision had less diversity than other sites. Incision tends to isolate areas of exposed riverine sediments, negatively affecting specialist species in these areas which are replaced by widely distributed species		
50	Farahani, H., Bayazidi, S	destruction of fauna and flora, erosion, water pollution and decreased flow rates reported by respondants.	Economic benefits concentrated in owner, transporter and land owner, but overall positive social impacts benefits for	

No.	Author	Biological response	Other impacts	Political response
			villages.	
51	Calle, M., Alho, P., Benito, G			
52	Asaeda, T., Sanjaya, K	The limiting of gravel deposition enables afforestation		
53	Sanchis-Ibor, C., Segura-Beltrán, F., Almonacid-Caballer, J			
54	Béjar, M., Gibbins, C., Vericat, D., Batalla, R	Drift increased with sediment, though not all species responded in the same manner		
55	Kiss, T., Balogh, M., Fiala, K., Sipos, G			
56	Smith, T., Meyer, E	Decrease in mussel abundance and diversity in mined pools		
57	Paukert, C., Schloesser, J., Fishcer, J., Eitzmann, J., Pitts, K., Thornbrugh, D	Change in fish assemblage composition, increase in lentic and exotic fish abundance, decline in native benthic fishes		
58	Harvey, B., Lisle, T	Entrainment of organisms, reduction in abundance of inverterbrates, reduction in spawning gravels, change in fish habitats (associated with change in habitat depth/volume), change in roughness elements, potential changes in fish behaviour, high Suspended Sediment Concentrations can damage/kill biota, reduce feeding efficiency, reduced risk of predation,		
59	Milner, A., Piorkowski, R	Big differences in abundance (lower), taxon dominance (higher), total biomass (lower)		

No.	Author	Biological response	Other impacts	Political response
60	Brown, A., Lyttle, M., Brown, K	Small invertebrates more abundant in control areas, biomass of large invertebrates decreased in disturbed areas, fish density lower in disturbed areas		
61	Rempel, L., Church, M	Effects on fish community could not be confirmed, differences in macroinvertebrate community compostion reverted after a flood		
62	Meador, M., Layher, A	Equivocal evidence of effect on fish densities/composition, varying effects of sedimentation		
63	Kanehl, P., Lyons, J	Disturbed areas did worse		

IMPACTS OF SAND MINING

70

Countries reportedly experience illegal extraction of river and coastal sand

80%

Of cement is made up of sand

450

Critically endangered Yangtze finless porpoises live in Poyang Lake, world's largest sand mine

32-50 BILLION

Tonnes of sand and gravel are extracted globally each year

100% RECYCLED

WWF IMPACTS OF SAND MINING ON ECOSYSTEM STRUCTURE, PROCESS & BIODIVERSITY IN RIVERS

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