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SCOPING ACTIVITIES

**CG5: sand and gravel mining –
new insights on an emerging environmental problem**

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Introduction

1 Sand and gravel represent the highest volume of raw material consumed on earth after water and air (UNEP, 2014). Silica sand is the new gold, important to our daily life but an underestimated resource because it is very often cheap, freely accessible, and for the most part only the extraction costs need to be covered. This "high volume - low value" paradox in sand and gravel mining undermines the colossal quantities being used and our increasing dependence on them despite the significant adverse impacts their extraction has on the environment. Hence, a large discrepancy exists between the magnitude of the problem, public perception and its lack of visibility on the science and political agenda.

2 Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. It can also refer to a textural class of soil or soil type. The composition of sand varies depending on the local rock sources and conditions. The most common constituent in inland continental and non-tropical coastal settings is silica (Silicon dioxide or SiO_2) usually in the form of quartz. Quartz because of its chemical inertness and considerable hardness is the most common mineral resistant to weathering. The second most common type of sand is calcium carbonate or aragonite formed by various forms of life like bacteria, coral, and shellfish as deep ocean water moves into warm shallow banks where reefs have dominated the ecosystem for millions of years like in the Caribbean.

3 Quartz sand that is recently weathered from granite or gneiss quartz crystals is angular and called grus or sharp sand in the building trade. Sand particles range in diameter from 0.0625 mm (or1/16 mm) to 2 mm. An individual particle in this range size is termed a sand grain. Sand grains are between gravel (with particles ranging from 2 mm up to 64 mm) and silt (with particles smaller than 0.625 mm down to 0.004 mm). This size specification between sand and gravel has remained constant for more than a century. Rachel Carson in the 40s once wrote that "in every grain of sand there is a history of the Earth".

Sand and gravel resource

4 Globally, between 47 and 59 billion tonnes of material is mined every year, of which sand and gravel (also called aggregates) account for both the largest share (from 68-85%) and the fastest extraction increase (Krausmann et al., 2009; Steinberger et al., 2010; UNEP, 2014). Generally, there is a dearth of information and reliable data on aggregate mining. This

makes environmental assessment very difficult and has contributed to the lack of awareness on this issue. However, from an indication of the world demand for aggregates and taking all estimates of use in a wide range of sectors into consideration, the world consumption exceeds 40 billion tonnes a year (Krausmann et al., 2009; USGS, 2012, 2013; EDE, 2013). This is about twice the yearly amount of sediment transport by all the rivers of the world (Milliman and Syvitski, 1992).

5 Sand and gravel are usually extracted from dunes, quarries and river beds. However, decline in inland resources has focussed mining in marine and coastal areas requiring a significant dredging industry. The growth of population and of cities have meant huge construction activities leading to huge demand for these special kinds of sand, and natural sources are running low (Fig. 1a, b, &c). In 2013, the French director, Denis Delestrac made a documentary called “Sand wars” about the impact of the lack of construction sand, the champion consumption of sand. “Sand seems like an infinite resource, but it isn’t” (Dzieza, 2016).

6 There are thousands of miles of dunes in the Sahara and Gobi deserts. Most desert sand grains are too smooth as the wind erosion process forms round grains that do not bind well (Zhang et al., 2006) and are not used for concrete and land reclamation. On the contrary, tremendous amounts of ocean sand gets used for land reclamation and construction (Fig. 2). The sea floor is covered only by a thin layer of sand which forms the habitat of organisms. Invariably, there must be consideration of both sand extraction in relation to available sediment resources and environmental impacts.

Fig. 1a: Artisanal sand and gravel mining on the coastline in Accra, Ghana (UNIDO, 2011)

Fig 1b: Sand Mining near Panguila, Angola (UNIDO, 2011)

Fig. 1c: Commercial sand mining on the Lagos lagoon in Lagos, Nigeria, (note the dredgers in the foreground) courtesy Bunmi Nubi (NIOMR)

Fig. 2: Industrial sand extraction - typical construction-aggregate trailer suction hopper dredger supplying sand for beach nourishment

7 A cursory assessment of the use and demand for sand and gravel in a wide range of sectors reveals a consumption for infrastructure activities (land filling/reclamation, asphalt pavements, concrete highways/roads, buildings, houses, bridges, dams, etc.); shoreline developments (beach resorts, nourishment/replenishment, coastal defences and protection measures – seawalls, groins, revetments, wave breakers etc.) and artificial islands projects (Singapore city state expansion, Dubai Burjkhalifa tower, World Island projects, South China Sea islands, etc.); and industry (glass production, electronics (microchips), aeronautics (light weight alloys), wine, plastics, paints, tires, toothpaste and cosmetics among several other applications. Sand shortages, rising costs, illegal trade and conflicts over diminishing sand are widely reported (Radford, 2005; Global Witness, 2010; USGS, 2012; 2013; EDE, 2013; UNEP, 2014; UN Comtrade, 2014; Dzieza, 2016).

8 The total aggregate extraction in Germany and the USA are derived from hundreds of sites dispersed throughout these countries. While the extraction from the three largest operations in the USA together accounted for a total of 16 m m^3 in 2000 (Bolen, 2000) the unprecedented rate of extraction in Poyang lake in China is more than an order of magnitude higher than the combined operations (De Leeuw et al., 2010). Although Chinese per capital sand consumption (based on an estimated sand production of 2.6 billion $m^3\ y^{-1}$ (Cheng, 2006) of ca. 2 $m^3\ y^{-1}$ per capita is below that of the USA and the European Union, it is projected to increase to 3-4 $m^3\ y^{-1}$ when its per capita GDP surpasses US$15,000.00 in 2030 (Maddison, 2007). In terms of an 11 % population increase, this suggests that over the next decade, Chinese demand will increase by 55 to 110 percent.

9 The demand for sand and gravel will continue to grow rapidly around the world particularly in newly developing countries especially where rapid economic boom allows strong growth in the construction industry (eg. India, China, UAE, etc) and in developed countries for upgrading dilapidated infrastructure (eg. USA, etc.). However, resource depletion

and environmental concern restrict the possibilities of sand mining in China and in the densely populated North-western Europe (De Leeuw et al., 2010).

10 Sand extraction in the North Sea has developed in response to this and in 2006 more than half of the sand and gravel extraction in the Netherlands originated from marine resources (UEPG, 2008). Invariably, there is a significant pressure on marine aggregates and their use presently greatly exceeds natural renewal rates. The large quantity of material extracted and the method of extraction unequivocally have deleterious and hidden consequences on the environment (Mensah, 2002; Wu et al., 2007; Lu et al., 2007; and Padmalal et al., 2008). The pressure and the extent of its impacts have raised issues on its emergence as a global environmental change in the light of current and future demand.

11 A well-known classic example of demand for land reclamation for more space for infrastructure development is the city State of Singapore. The city increased its land area by more than 20 percent in the last 40 years mostly by using aggregates to reclaim land from the sea (Fig. 3). Singapore imported more than 517 million tonnes of sand in the last 20 years from Indonesia, Malaysia, Thailand and Cambodia and is by far the largest importer of sand world-wide (UN Comtrade, 2014; Aquaknow, 2014; UNEP, 2014). It is the world's highest per capita consumer of sand at 5.4 tonnes per inhabitant.

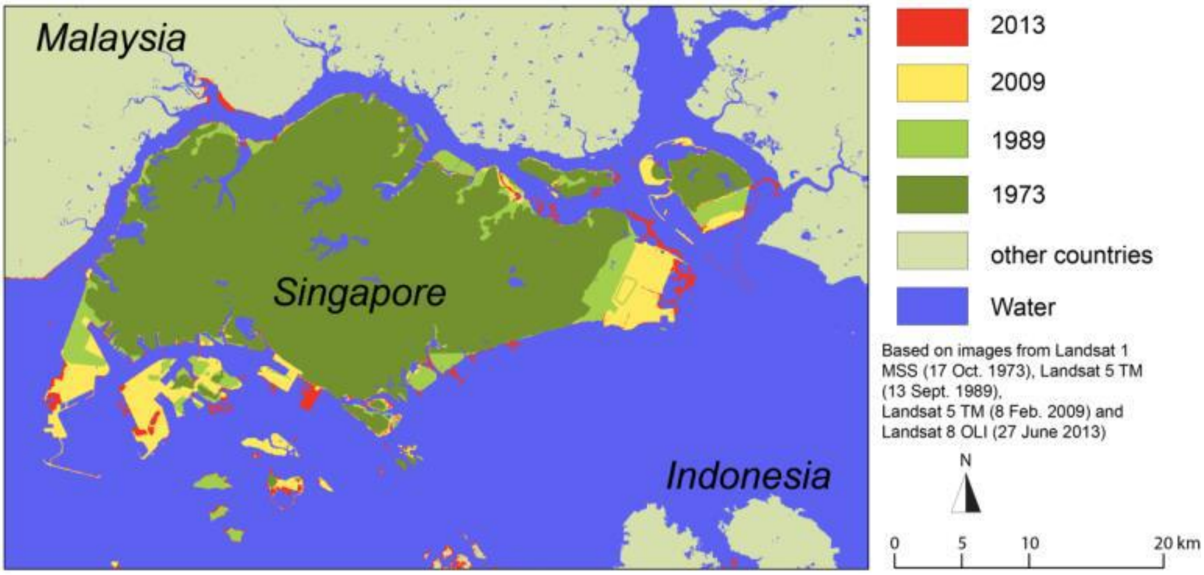

Figure 3: A map of Singapore shows its area increasing from 1973 to 2013. Remote sensing analysis: UNEP/GRID-Geneva.

12 In recent times, as a response to halting a rapid rate of erosion (25-30 metres per year) of Victoria beach in Lagos, Nigeria, approximately 90 million cubic metres of sand from marine shelf waters was dredged to reclaim about 1000 hectares of land for the development of a modern city for Lagos. The Eko Atlantic city project (Fig. 4), protected by the 'Great Wall of Lagos' along the shoreline of Victoria Island, is as an example of infrastructure built from aggregates mining from the near-shore environment. There have been several debates as to the impacts the project will have on the immediate environment. Conclusions on likely impacts of the project on adjacent coastal areas and likely snowball effect along the shoreline of the Eastern Gulf of Guinea are at best conjectural and not based on solid scientific evidence from the study or existing literature.

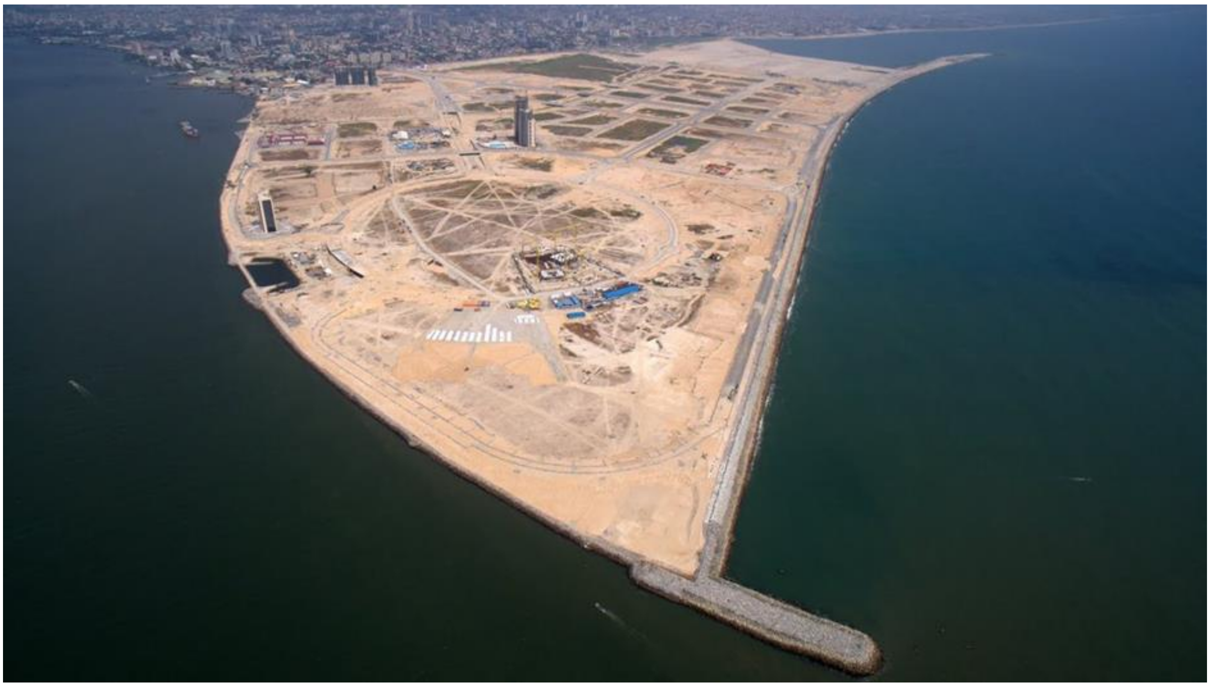
Fig. 4: Eko Atlantic City Project (EACP) in Lagos, Nigeria.

Environmental impacts

13 Interest in the environmental impacts of sand and gravel extraction dates back some 50 years and became more significant in the 1960s (Millner et al., 1977; de Groot, 1979b). The environmental impacts of dredging have been well documented, with general reviews of the topic provided by de Groot (1979a, 1979b, 1986), ICES (1992, 2001), Newell et al. (1998, 2013), and van Rijn et al. (2005). However, a significant body of literature on the impacts of dredging on marine ecosystem now abound. Sand and gravel mining represent serious threats to habitats especially at uncontrolled and rapid rates of exploitation.

14 These include impacts on the physical landscape, biodiversity, water turbidity, water table levels, and on climate through the emissions of carbon dioxide from transportation (UNEP, 2014). There are also socio-economic (Fig. 4 - Eko Atlantic city project in Lagos), cultural and political consequences arising from conflicts (eg. Singapore, Malaysia, and Indonesia, Cambodia) and the disappearance of low-lying sand islands (Maldives, Indonesia, etc.) and coastal counties in the United States with retreating beaches. (UNEP, 2014; Guerin, 2003).

Physical alteration of the topography

15 Marine sand mining is often very destructive. Physical alteration on marine seabed include furrows due to dredging which may take different recovery time depending on regeneration rate of the area; this may range from a time scale of few months to several decades depending upon the extracted material, the geometry of the excavation, the water depth, and the hydrodynamic regime of the system. In very energetic shallow sandy areas, such as those found in estuaries, recovery may take place after just one (or a few) tidal cycle. On the contrary, in deep and low-energy areas of fine sand (e.g., the German Baltic Sea), recovery could take decades, even for small depressions. Dredged pits have been found to remain as seabed features for decades.

Impacts on biodiversity

16 Extraction of marine sand and gravel has its primary impact at the seabed thus the effects of this activity are targeted at bottom substrata and benthic fauna (Desprez, 2000; van Dalfsen et al., 2000). Studies have shown that dredging causes an initial reduction in the abundance, species diversity, and biomass of the benthic community (Newell et al., 2002, 2013). The scale of impacts on benthic fauna is influenced by the type of dredger employed as well as the nature of the receiving environment. Other impacts on benthic communities concern the nature and stability of the sediment, through the exposition of underlying strata, and the tidal current strength, through the alteration of the local topography. Dredging and extraction of aggregates from the benthic (sea bottom) zone destroys organisms, habitats and ecosystems and deeply affects the composition of biodiversity, usually leading to a net decline in faunal biomass and abundance (Desprez et al., 2010) or a shift in species composition. Long-term recovery can occur only where original sediment composition is being restored (Boyd et al., 2005).

Impact on hydrodynamics

17 Sand and gravel extraction have a potential to modify or cause changes in local waves and current patterns. Localised changes in wave heights and current patterns due to dredging results to concurrent change in erosional and depositional patterns and even in shoreline modifications. Beach erosion may occur, because of offshore dredging, due to a reduction in the sediment supply to the coast. This effect is induced either by the direct extraction of material which would normally supply the coast, or by trapping these sediments within the dredged depressions. In addition, if the alterations of the sea bottom topography affect the wave refraction patterns, erosion may result from modification of the wave directions at the coastline.

Impact of turbidity on water column

18 Surface turbid plumes are generated by screening process, overflow of material from hopper during dredging and from mechanical disturbance of the bed sediment, by head of pipe. Large increases in suspended solid concentrations tend to be short-lived and localized, close to the operating dredger. However, turbid plumes with low suspended sediment concentrations can affect much larger areas of the seabed, over extended time periods (several days instead of several hours), especially when dredging is occurring simultaneously in adjacent extraction areas. Changes in water turbidity is frequently accompanied by changes in pH.

Coastal and inland erosion

19 Several hotspots of shoreline erosion have been identified along the African coastline (UNIDO, 2011) from Conakry (Guinea) to Luanda (Angola). While shoreline dynamics are largely natural processes (hydrographic conditions like reinforcement of onshore waves due to wave refraction from adjacent headlands) human activities such as sand and gravel mining and damming of inland rivers contribute to accelerated coastal erosion. Aggregate mining on the continent is largely unregulated and results in several embayment along the shoreline due to localized coastal recession with changes in near shore bathymetric contours and wave refraction pattern.

20 Near-shore dredging of aggregates, sand mining in rivers and coastal dune systems can lead to long-term erosion (Kondolf, 1997; Thornton et al., 2006; De Leeuw, 2013). Elsewhere, the need to maintain retreating/shrinking beaches has been to build and re-build artificial beaches by infusions of sand loss to erosion. This is a cycle in which coastal cities are trapped in the USA (Miami, Myrtle, Virginia, North Carolina outer banks, New York's long

Island, New Jersey's Cape May, etc.) among several others. With sea levels rising, demand for beach sand is only going to grow. About 57 percent of the coast in the lower 48 states is already eroding according to the USGS (Dzieza, 2016). "Every single coastal erosion problem we have right now is only going to get worse, not better". Young says, "It's only going to erode faster, not slower, require more sand, not less." He foresees a future of rising costs and conflict over diminishing sand.

Economic impact and need for science-based policy

21 Aggregates are a free resource and sand and gravel trading is a lucrative business worldwide. Sand prices have risen in recent years. The sharp practices in the trade can also be expected to rise. Unfortunately, sand extraction comes at the expense of other economic sectors and livelihoods such as tourism, fishing, agriculture, insurance, housing and infrastructure. There is a lack of proper scientific methodology for river sand mining which has led to indiscriminate sand mining which attracts various practitioners including smugglers and influential mafias in different countries (UNEP, 2014).

22 A major concern is lack of adequate information and data in many countries (Velegrakis et al., 2010) except the EU, UK, and USA. This limits regulation of extraction in many developing countries. In some cases, access to data is difficult and available data are not standardized. In addition, except for the leading role of the UK and EU (Cooper, N. J., and Brew, D. S. (2013), there is limited collaboration/co-ordination between the marine scientific research establishments and the marine aggregates industry. There is also a lack of monitoring systems, strict regulatory policies and environmental impact assessments to limit indiscriminate mining.

23 Strategic environmental assessment has been advocated to overcome this short coming (De Leeuw, 2010) while in the UK the development of Marine Aggregate Regional Assessments (MAREAS) is a major step in understanding the cumulative and in combination effects of dredging within regional seabed areas. Funding is provided through the Marine Aggregate Levy Sustainability Fund (MALSF) for high quality science and targeted research and development, including specific information gaps, better understanding of the pressures and impacts from marine aggregate extraction, or testing of new survey technologies and assessment methodologies.

What are the implications for science?

1. Sand is running out. Both the large quantity of material consumed and the rapid rates of extraction may not be sustainable on the long-term. "Their use greatly exceeds the renewal rates". It may not be there anymore!

2. There is a lack of proper scientific methodology for river and marine sand mining. A linkage of science and the industry by wider collaboration and co-ordination between marine scientific research and marine aggregate industry should allow for exchange of ideas for evolving methodologies and improving technologies for extraction.

3. There is a need for science and policy to assess information gaps, provision, access and standardization of data in the industry.

4. The largest consumption of sand and gravel is in the construction industry. Are there alternatives/substitutes/options to reduce the consumption of sand and

lower dependency in the industry? For example, optimizing the use of existing buildings in built environment.

5. Could science and technology evolve novel sustainable use of the resource? E.g. recycling (of buildings, quarry dust, concrete rubble, glass, incinerator ash, etc.) and desert sand mixed with other materials.

6. Could incentives be provided to the construction industry to reduce the use of sand and gravel by substitutes; and having taxes on sand and gravel to provide regulatory costs to support sustainable use of available sand and gravel resources.

7. Although mining of sand and gravel is already or becoming an issue in many countries, there is no mention of seabed mining or coastal erosion in the SDG indicators!

References

Aquaknow, (2014): Sand mining- the ‘high volume – low value’ paradox Aquaknow. <http://www.aquaknow.net/en/news/sand-mining-high-volume-low-Value-paradox/ (accessed 03.02.14).

Bolen, W. P., (2000): Sand and gravel construction. US Geological Survey Minerals Yearbook 2000.http://minerals.usgs.gov/minerals/pubs/commodity/sand_&_gravel_construction/590400.pdf.

Boyd, S. E., Limpenny, D. S., Rees, H. L., Cooper, K. M., (2005): et al., (2005): The effects of marine sand and gravel extraction on the macro benthos at a commercial dredging site (results 6 years post-dredging). ICES Journal of Marine Science 62, 145-162.

Cheng, J. (2006): Opportunity and countermeasure of sea sand resource development in Chinese shallow sea. China Ocean News (in Chinese).

de Groot, S. J. (1979a): An assessment of the potential environmental impact of large-scale sand dredging for the building of artificial islands in the North Sea. Ocean Management, 5: 211–232.

de Groot, S. J. (1979b): The potential environmental impact of marine gravel extraction in the North Sea. Ocean Management, 5: 233 – 249.

de Groot, S. J. (1986): Marine sand and gravel extraction on the North Atlantic and its potential environmental impact, with emphasis on the North Sea. Ocean Management, 10: 21 – 36.

De Leeuw, J., Shankman, D., Wu, G., de Boer, W. F., Burnham, J., He, Q., Yesou, H., Xiao, J., (2010): Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China. Reg. Environ Change 10, 95-102. DOI 10.1007/s10113-009-0096-6.

Delestrac, D. (2013): Le Sable: enquête sur une disparition, film documentary broadcast on Arte channel, May 28, 2013.

Desprez, M. (2000): Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel. Short and long-term post-dredging restoration. ICES Journal of Marine Science, 57: 1428 – 1438.

Desprez, M., Pearce, B., Le Bot, S., (2010): The biological impact of overflowing sands around a marine aggregate extraction site: Dieppe (eastern English Channel). ICES Journal of Marine Science 67(2), 270-277.

Dzieza, J., (2016): Sand's End – THE VERGE –Miami Beach has run out of sand. Now what? http://www.theverge.com/2016/11/17/13660014/miami-beach-sand-erosion-nourichment-climate-change

EDE, (2013): Environment Data Explorer, Total road network, Source: International Road Federation, World Road Statistics, GRID- Geneva, United Nations Environment Programme. http://ede.grid.unep.ch/ (accessed 03.02.14).

Eko Atlantic Project-Opinion papers EIA. Retrieved from: http://www.ekoatlantic.com/ (accessed 09.04.17).

Global Witness, (2010): Shifting sand – How Singapore's demand for Cambodian sand threatens ecosystems and undermines good governance. Global Witness, London. Pp.48
Guerin, B., (2003): The shifting sands of time - and Singapore, Asia Times online, 31 July 2003 http://www.atimes.com/atimes/Southeast_Asia/EG31Ae01.html (accessed 04.02.14).

ICES, (1992): Report of the ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries. ICES Cooperative Research Report No. 182. 178 pp.

ICES, (2001): Effects of Extraction of Marine Sediments on the Marine Ecosystem. Ed. by the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem. ICES Cooperative Research Report No. 247. 80 pp.

Kondolf, G.M., (1997): Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21(4), 553-551.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K-H., Haber, H., Fischer-Kowalski, M., (2009): Growth in global materials use, GDP and population during the 20th century. Ecological Economics 68, 2696-2705.

Lu, X. X., Zhang S. R., Xie, S. P., Ma, P. K., (2007): Rapid channel incision of the lower Pearl River (China) since the 1990s. Hydrological Earth System Science Discussions 4, pp 2205-2227

Maddison, A., (2007): Historical statistics for the world economy: 1-2003 AD. Groningen Growth and Development Centre, University of Groningen. http://www.ggdc,net/maddison/Historical_Statistics/horizontal-file_03-2007.xls. Viewed on May 6th 2008

Mensah, J. V., (2002): Causes and effects of coastal sand mining in Ghana. Singap J Trop Geogr 18:69-88

Millner, R. S., Dickson, R. R., and Rolfe, M. S. (1977): Physical and biological studies of a dredging ground off the east coast of England. ICES Document CM 1977/E: 48. 11 pp.

Milliman, D., Syvitski, M., (1992): Geomorphic/Tectonic Control of Sediment Discharge to the Ocean: The Importance of Small Mountainous Rivers. J. Geol. 100 (5), 525-544.

Newell, R. C., Seiderer, L. J., and Hitchcock, D. R. (1998): The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the seabed. Oceanography and Marine Biology, 36: 127 – 178.

Newell, R. C., Seiderer, L. J., Simpson, N. M., and Robinson, J. E. (2002): Impact of marine aggregate dredging and overboard screening on benthic biological resources in the central North Sea: Production Licence Area 408. Coal Pit. Marine Ecological Surveys Limited. Technical Report No.ER1/4/02 to the British Marine Aggregate Producers Association (BMAPA).72 pp.

Cooper, N. J., and Brew, D. S. (2013): Chapter 5 – Impacts on the Physical Environment p68-87, In: Newell, R. C., and Woodcock, T. A. (Eds.) 2013, Aggregate Dredging and the Marine Environment, An overview of recent and current industry practice. The Crown Estate, 165pp. ISBN: 978-1-906410-41-4

Padmalal, D., Maya, K., Sreebha, S., Streejaa, R., (2008): Environmental effects of river and sand mining: a case from the river catchments of Vembanad Lake, Southwest coast of India. Environ Geol. 54, 879-889. DOI 10. 1007/s00254-007-0870-z.

Radford, T., (2005): It's the way you tell them, Environment & Poverty Times, 3, Special Edition for the World Conference on Disaster Reduction January 18-22. 2005, Kobe, Japan, UNEP/GRID-Arendal.

Steinberger, J. K., Krausmann, F., Eisenmenger, N., (2010): Global patterns of materials use: a socioeconomic and geophysical analysis, Ecological Economics, 69, 1148-1158.

Thornton, E. B., Sallenger, A., Conforto Sesto, J., Egley, L., McGee, T., Parsons, R., (2006): Sand mining impacts on long-term dune erosion in southern Monterey Bay. Marine Geology 229, 45-58.

UEPG, (2008): The European Aggregates Industry – Annual Statistics 2006. In: Statistics 2006. European Aggregates Association, Brussels. http://www.uepg.eu/uploads/documents/141-98-statistics 2006en.xls. Viewed 6 May 2008

UN Comtrade, (2014): Import of Natural sand except sand for mineral extraction as reported. United Nations Commodity Trade Statistics Database. http://comtrade.un.org (accessed 04 02.14).

UNIDO (2011): Report on the Inventory of Hotspots and course notes on Physical Alteration and Destruction of Habitats in the sixteen participating countries of the Guinea Current Large Marine Ecosystem (GP/RAF/04/004/11-B2) 159pp

UNEP, (2014): Sand, rarer than one thinks. 15 p. UNEP Global Environmental Alert Service (GEAS). www.unep.org/geas

USGS, (2012): The 2010 Minerals Yearbook – Cement. U. S. Geological Survey, Reston.

USGS, (2013): Sand and Gravel (construction) statistics. In : Kelly, T. D., Matos, G. R., (Eds.), Historical statistics for mineral and material commodities in the United States. U. S. Geological Survey Data Series 140, Reston.

van Dalfsen, J. A., Essink, K., Toxvig Madsen, H., Birklund, J., Romero, J., and Manzanera, M. (2000): Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. ICES Journal of Marine Science, 57: 1439 – 1445.

van Rijn, L. C., Soulsby, R. L., Hoekstra, P., and Davies, A. G. (Eds). (2005): SANDPIT: Sand Transport and Morphology of Offshore Sand Mining Pits. Process Knowledge and Guidelines for Coastal Management. End document May 2005, EC Framework V Project No. EVK3 - 2001- 00056. Aqua Publications, the Netherlands. 716 pp.

Velegrakis, A. F., Ballay, A., Poulos, S., Radzevicius, R., Bellec, V., Manso, F., (2010): European marine aggregates resources: Origins, usage, prospecting and dredging techniques, Journal of Coastal Research 51, 1-14. DOI: 10. 2112/S151-002.1.

Wu, G., de Leeuw, J., Skidmore, A. K., Prins, H. H. T., Liu, Y., (2007): Concurrent monitoring of vessels and water turbidity enhances the strength of evidence in remotely sensed dredging impact assessment. Water Research 41:3271-3280

Zhang G., Song, J., Yang, J., Liu, and X., (2006)) Performance of mortar and concrete made with a fine aggregate of desert sand, Building and Environment. 41, 1478–1481.

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