Environmental management for dredging sediments

The requirement of developing nations

Norpadzlihatun Manap [a, b, *] and Nikolaos Voulvoulis [b]

[a] Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Beg Berkunci 101, Parit Raja, Batu Pahat Johor 86400, Malaysia [b] Centre for Environmental Policy, Imperial College London, 1515, 15 Prince's Gardens, South Kensington Campus, London SW7 2AZ, United Kingdom

ABSTRACT

Scientific research has characterized the effects of dredging, an underwater excavation process for navigational purposes or material extraction, and has shown its association with a number of chemical, physical and biological impacts. Due to this, much environmental management has been applied in the dredging industry in order to manage its detrimental effects. However, developing nations may have different approaches towards their dredging environmental management to compare to their companions with higher economic strength. Moreover, scientific evidence to make an informed decision is often lacking, hence affecting the number of research executed at these nations, limiting their efforts to preserve the environment. This paper reviews the dredging environmental impacts and its two important factors, dredging technology and sediment characteristic, that determine the magnitude of impacts through literature review, and discusses the need for a more integrated dredging environmental management to be developed for developing nations

Keywords

Integrated environmental management; Dredging; Multi-criteria decision analysis; Decision-making method; Developing nations

1. Introduction

Decrease of invertebrate species due to sediment change, increase of oxygen demand due to re-suspension of sediments that also affects lighting intensity, and increase of turbidity levels caused by plumes, can be triggered by dragging, scooping and dumping acts while dredging (Balchand and Rasheed, 2000, Crowe et al., 2010; de Leeuw, 2010). Besides the environmental impacts, conflicting issues including cost, public perception, rules and regulations, socio-economic and managerial aspects of dredging have received excessive consideration over the last few years. This comes from the fact that dredging has increased in demand due to numerous projects, from the decrease of the seabed of River Scheldt and the expansion of Panama Canal to the development of projects in India for the construction of ports due to increased waterborne transportation (George, 2011; Krizner, 2010; Schexnayder, 2010; Thacker, 2007). Dialogues over the sustainability of dredging practices have risen together with its popularity, highlighting the need for research in assessing its sustainability based on its conflicting issues including from environmental, socio-economic and managerial aspects. However, this kind of research has fallen short.

Furthermore, different types of decision makers including idealists, politicians or environmentalists can greatly influence decision-making processes of dredging industry, and often, contradictory views are expressed during negotiations and investigations (Alvarez-Guerra et al., 2010). In other industries, many development projects have benefitted from strategic environmental management that offers holistic analysis by integrating different environmental management tools in order to achieve a balanced and sustainable decision (Abriak et al., 2006, Agius and Porebski, 2008, Wang and Feng, 2007). Multi-criteria decision analysis (MCDA) has been widely used to rank alternatives based on the assessment of different criteria (Alvarez Guerra et al., 2009; Balasubramaniam, 2005). This tool has previously been applied together with comparative risk assessment, adaptive management, life cycle analysis and risk assessment analysis (European Environment Agency, 2003, Langmead et al., 2009, Maxim et al., 2009, Ness et al., 2010).

Potentially disproportionate costs caused by considering one aspect alone, such as using sediment quality analysis only to characterize contamination level in a dredging area, in dredging decision-making have created waves of worry among dredging stakeholders (Burton, 2002). Thus, development of a sustainable decision-making method for dredging, taking into account the issues discussed above, is a necessity.

This paper assesses dredging environmental impacts and its two important factors(dredging technology and sediment characteristic) that determine the magnitude of impacts through literature review, and discusses the need for a more integrated dredging environmental management to be developed for developing nations.

2. Dredging technologies

Excavation, transport and disposal of sediments are the three main stages of dredging activities (Fig. 1). These are successively repeated until a target quantity of sediments is dredged (Thorn, 1975), with each stage requiring different technologies. Historically, and as the dredging industry has developed, technologies have improved, and today different types of dredgers are available to be utilized for different applications.

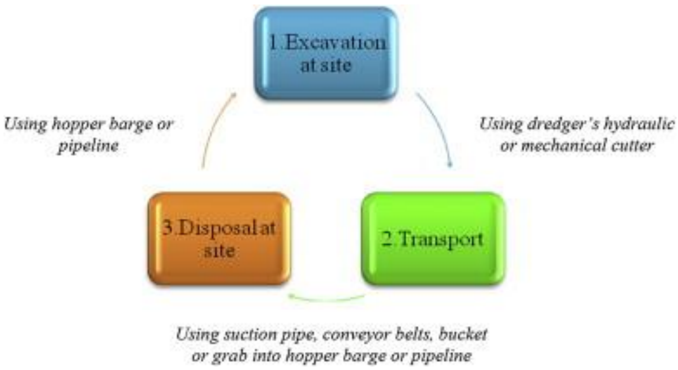

Fig. 1. Stages of dredging (Highley et al., 2007, Verbeek, 1984).

Dredging starts with the excavation of sediments at a site with a hydraulic and/or mechanical cutter (Antipov et al., 2006, Du and Li, 2010, Honmagumi and Chiyoda Kenki, 1995, Klein, 1998). Different types of dredgers are required for different sediments and depths, but similar extraction methods may be required for both capital and maintenance dredging, whether through suction or grab (Den Herder, 2010, Fujimoto and Tadasu, 1998). Trailer dredgers are commonly used at sea, and deepen by dragging their cutter along the seabed, extracting loose sediments until the hopper is full and ready for disposal (Gubbay, 2005, Messieh et al., 1991). Conversely, anchor dredgers are generally confined to small areas such as lakes and port basins, and move by anchor and/or hydraulic spud: a part of dredger that penetrated into the sea or river beds to retain stability while dredging (Mostafa, 2012, Quimby, 1914, Reba, 1975). Pit excavators and bar skimmers, on the other hand, are commonly used to extract sediments from river beds (Ge et al., 1999, Highley et al., 2007, Padmalal, 2008). Backhoe dredgers, trailing suction hopper dredgers and cutter suction dredgers are among the other types of dredgers frequently used to date (Guo, 2011, Ikeda and Nomoto, 1999, Lefever and Van Wellen, 2011, Lin et al., 2010, Liu, 2005, Tack, 2010, Tashiro, 2009).

Dredged sediments are then transferred into hopper barges or pipelines using suction pipes, conveyor belts, bucket or grab (Duran Neira, 2011, Nippon, 1996, Schnell, 1984). The hopper barges or pipelines then transport the dredged sediments to the intended disposal site. Dredging often still takes place during transport when the practice of excess dredging is applied, which involves the continuation of dredging after the hopper is full, with the surplus volume discharged over the hopper weirs (Highley et al., 2007, Thorn, 1975, Van Nieuwenhuijzen and Van Den Broeck, 2011).

Finally, the dredged sediments are disposed at a selected site. Several methods are available for this, including agitation dumping, side casting, dumping in rehandling basins, sump rehandling operations, or direct pumping ashore. Open water disposal is the most economical and widely used method, with hopper barges as the usual means of transport (Katsiri et al., 2009, Kizyaev et al., 2011, Krishnappan, 1975, Saxena et al., 1975). During open disposal, the dredged sediments are barged to the designated dumping site and disposed through its bottom gate (Krishnappan, 1975, Thorn, 1975). Another technique is the use of pipelines to pump the dredged sediments onto land. This process includes loading sediments into the hopper, transporting them through pipelines; and then pumping them ashore (Welte, 1975).

During open disposal, either silt curtains or booms may be used to contain suspended sediments in order to prevent diffusion and help sedimentation (Elander and Hammar, 1998). A boom is a heavy structure comprising a plastic cover, connectors, skirt, tension member and ballast weight which is hooked to an air or solid float (Dreyer, 2006). A submerged or floating silt curtain consists of a tension member, ballast weight, anchor and curtain (Dreyer, 2006, Guo et al., 2009, Ishizaki and Rikitake, 2010, Otoyo, 2003, Sawaragi, 1995, Trang and Keat, 2010, Ueno, 2010). However, there is concern regarding their use due to the risk of contaminationleakages (Morton, 2001, Su, 2002, Thibodeaux and Duckworth, 2001).

Open disposal is generally not permitted when handling highly contaminated sediments (Krizek et al., 1975). Contaminated dredged sediments often require remediation, for example through mechanical mixing and aeration (Kim, 2004, Toyo Kensetsu et al., 1994). Other remediation techniques include sequential extractiontechniques, pretreatment, physical separation processes, containment, washing, thermal extraction, bioremediation, electro kinetics, solidification/stabilization, vitrification, and chemical oxidation (Morinaga Kumi et al., 1997, Mulligan et al., 2001, Pensaert et al., 2008). Many of these techniques are often costly; however precise dredging can lower the dredging cost by determination of dredging depth based on the pollution level prior dredging. This method can also provide a favourable environment for the benthos (Zhang et al., 2014).

3. The influence of sediments characteristics

Sediment characteristics refer to the role of sediments as a contaminant source. Sediments act as a sink in that they adsorb and retain contaminants that have settled on the bottom of rivers and marine waters, coming from both point and diffuse sources (Burton, 2002, Riley and Chester, 1971, Rothwell et al., 2010, Salomons and Brils, 2004, US Geological Survey, 2004). Point sources, defined as identifiable sources, include waste dumps, direct effluent from industry and household effluent (Office of Naval Research, 2008, Salomons and Brils, 2004, Zühlke, 1994). Conversely, examples of diffuse sources, defined as undetermined sources, include weathering, atmospheric deposition, erosion, sewer system sediments and mining traces (Parkhill, 2002, Salomons and Brils, 2004).

Sediments also retain nutrients, including N and P (Moss et al., 1996). The natural source of these nutrients is from the microbial processes of microorganisms, homogeneous reactions and equilibrium reactions (Stolzenbach and Adams, 1998). However, the level of nutrients can increase as a result of human activities, such as through the release of fertilizer-borne nutrients used in agriculture (Lair, 2009, Salomons and Brils, 2004). Along with nutrients, sediments also retain and transport metals including Zn, Hg, Cd, As, Pb, Cu and Ni. Among the sources of these metals are weathered sedimentary rocks and underwater volcanic actions. The use of chemicals in various industries, including pharmaceutical, textiles and agriculture also results in the release of volatile and soluble organic compounds into the environment, which at the same time shows that human activities can artificially increase metal and organic concentrations (Garrett, 2000, Holt, 2000).

Sediments can therefore also release contaminants into the environment, as contaminants bound on sediment particle surfaces and interior matrices can be released when sediments are disturbed (Burton, 2002, Fluck et al., 2010, Garrett, 2000, Salomons and Brils, 2004). Transportation of contaminants by sediments is dependent on several factors, primarily particle size (Jain and Ram, 1997). Sediment particles are classified into different sizes, namely fine particle size up to 2 μm (clay), particle size up to 16 μm (silt), particle size between 63 μm and 64 mm (sand and gravel), and particle size more than 64 mm (rock) (Nittrouer et al., 2007, Tsinker, 2004, Verbeek, 1984). Furthermore, contaminants in sediments may be transported in different forms, whether in dry gaseous state, dry particulate or wet deposition(Lair, 2009). Ocean and wetland systems, tides, currents and waves can be attributed to sediment transportation (Nielsen, 2009, Office of Naval Research, 2008).

Sediment Quality Guidelines (SQGs) have been used to screen potentially contaminated sediments before dredging, even though this is not a regulatory requirement (Burton, 2002, Wenning, 2005). Currently in the US, Ireland, the UK, Belgium and Canada, SQGs are used to determine the sediments' level of contamination at a dredging site, although still not because of regulatory requirements (Pan, 2009, Praveena, 2008, Suedel et al., 2008, The National Oceanic and Atmospheric Administration (NOAA), 2006). SQGs are utilized to evaluate the quality of dredged sediments in order to help protect both the environment and humans from contamination exposure (Burton, 2002). This means that if the sediments exceed the guideline values, it becomes necessary to consider an alternative technological means to handle them (O'Connor, 1998).

Along with SQGs, Water Guideline Values (WGVs) are used to monitor the chemical parameters of the water column affected by dredging operations. WGVs can be determined from two perspectives: water quality in aquatic water systems; and quality of water intended for potable use (MacGillivray and Kayes, 1994). They are usually derived from either studies on humans or animal toxicity, but the latter is more widely used.

4. Dredging environmental impacts

The easiest way to understand the environmental impacts of dredging is through a traditional source–pathway–target assessment of risks. With the sources covered under sediments characteristics earlier, and with pathways of contaminants mainly associated with transport of sediments and therefore dependent on dredging technologies, a conceptual model illustrating source, pathway and target linkages is presented in Fig. 2. This figure also indicated examples of impacts that could be due to the activities of dredging namely physical impacts (PI), chemical impacts (CI) and biological impacts (BI).

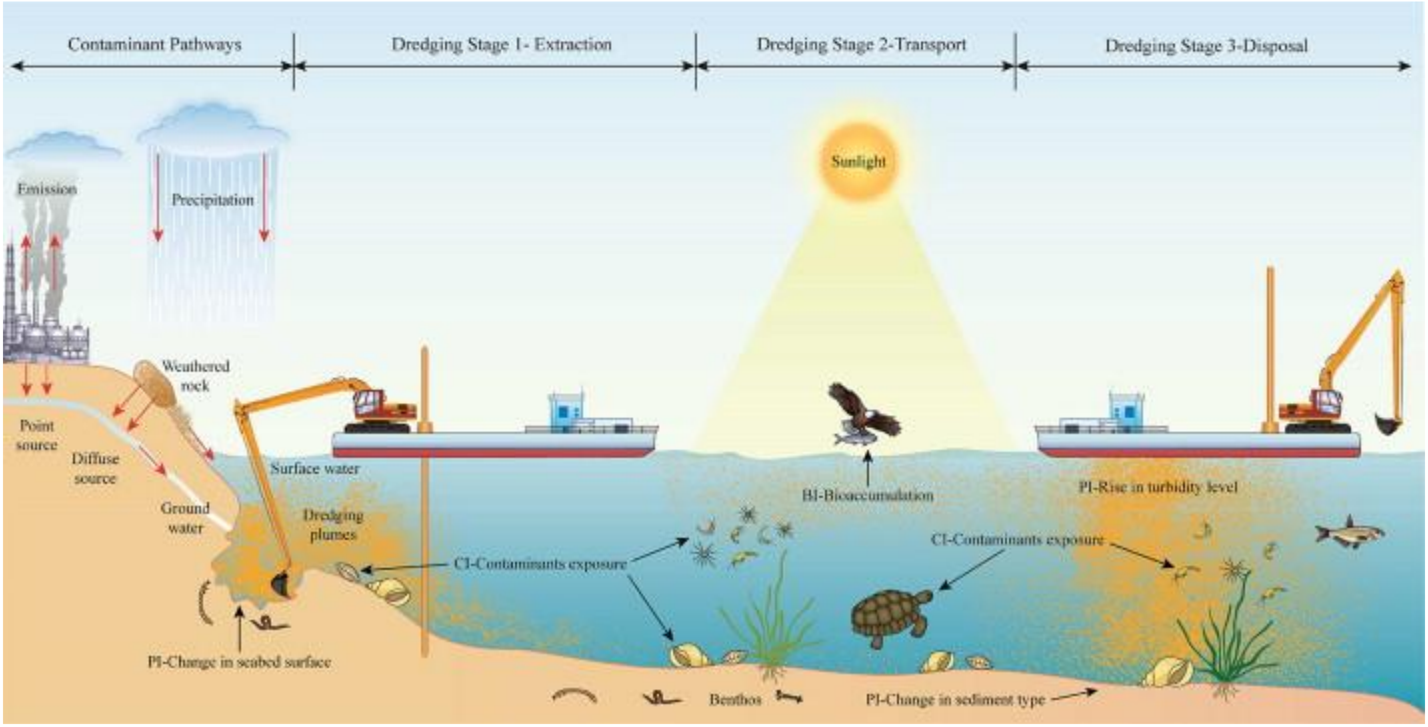

Fig. 2. Conceptual model for assessing dredging impacts.

Understanding the nature and extent of sediment contamination requires investigating the sources of pollution. Industrial effluents and sedimentary rocks represent point and diffuse sources for contaminated sediments, respectively. From such sources, contaminants can dissipate into groundwater, be released through precipitation, or be transported by sediments into surface water, and finally adsorbed and retained in sediments on sea or river beds (De Nobili et al., 2002, Jain and Ram, 1997, Moss et al., 1996). Similarly, contaminant pathways into the environment are through media including sediments, air, groundwater, surface and marine water. Through contaminant precipitation, absorption or direct influent from point and diffuse sources into the media, contaminants are retained or transported directly into surface and marine water (Jain and Ram, 1997, Moss et al., 1996). This can be followed by bioaccumulation in food web communities triggered by the disturbance of sediments, including from dredging activities (De Nobili et al., 2002, Moss et al., 1996).

Fig. 2 illustrates that environmental impacts of dredging can take place during extraction, followed by transport and disposal of dredged sediments. Sediment extraction causes a variety of impacts, including dispersal of contaminants from sediments into the water, change in seabed surface, formation of dredging plumesand exposure of benthos and fishes to contamination. The dredged sediments are then transported to designated disposal sites. The impacts of these two stages can include bioaccumulation, contamination exposure, change of sediment type and rise in turbidity level.

Contaminant pathways including dredging technologies and sediments have been highlighted in Fig. 2. Examples of the risk of different technology and its level of contamination associated with these pathways are summarized in Table 1. It was found that a low environmental risk according to biological parameters is normally associated with low contamination. Additionally, mechanical dredgers (including mechanical shovel and clamshell) posed a lower environmental risk than hydraulicdredgers (cutter suction dredger). Nevertheless, the environmental risk according to chemical parameters remained high at both site categories, regardless of the technology used.

Table 1. The risk of different technology and level of contamination.

Dredging technology and level of contamination at dredged site	**Environmental risk**	**Reference**
Cutter suction dredger with cutter crown and sweep head (low)	38% Biological, 54% chemical[a]	Groote et al. (1998)
Mechanical shovel (low)	29% Chemical	Piou (2009)
Clamshell (low)	0% Biological	Su (2002)
Dragline and excavators (high)	55% Biological, 67% chemical	Ponti et al. (2009)
Mechanical shovel and bunds (high)	86% Biological	Ellery and McCarthy (1998)
Backhoe equipped with sieve bucket, excavator, auger dredger, silt curtains and oil boom (high)	80% Biological	Thibodeaux and Duckworth (2001)

a

The percentage represents the likelihood of the environmental parameter to degrade. It is calculated based on the number of times negative impact occurred in each research compared to 'positive' and 'no effect' impacts.

The impacts of dredging vary according to chemical, biological and physical parameters of the aquatic environment. Further descriptions of dredging impacts and parameters that have been monitored can be found in Table 2. Whether these parameters increased or decreased as a result of dredging has been indicated with a mark (X) and numbered to show its reference.

Table 2. Impacts of dredging.

	During dredging		After dredging		During disposal		After disposal	
Parameter	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**
Chemical impacts								
Organic compound in sediments and water			X (1, 2, 3, 22, 18)	X (5, 11)	X (21, 22)			
Inorganic compound in sediments and water	X (10)		X (10)					
Oxygen demand			X (4)					
Biological impacts								
Benthic fauna			X (1, 2, 7, 13, 18)	X (8, 19, 20)		X (23, 24)	X (27)	X (25, 26)
Benthic flora			X (6)	X (14)				
Fishes				X (15)				
Physical impacts								
Turbidity			X (12, 4)					
Transparency				X (13)				
Bed roughness			X (16)					
Erosion of the coastal area			X (17)					
Recovery rate after 2 years							X (26)	
Sand percentage							X (27)	

X (number of reference): 1 = (Ponti et al., 2009), 2 = (Toes, 2008), 3 = (Mackie, 2007), 4 = (Messieh et al., 1991), 5 = (Piou, 2009), 6 = (Munawar, 1989), 7 = (Constantino, 2009), 8 = (Balchand and Rasheed, 2000), 9 = (Douvere and Ehler, 2009), 10 = (Thibodeaux and Duckworth, 2001), 11 = (Shigaki et al., 2008), 12 = (Su, 2002), 13 = (Bonvicini Pagliai et al., 1985), 14 = (Ellery and McCarthy, 1998), 15 = (Thibodeaux and Duckworth, 2001), 16 = (Ellery and McCarthy, 1998), 17 = (Sergeev, 2009), 18 = (Rasheed and Balchand, 2001), 19 = (Padmalal, 2008), 20 = (Kenny and Rees, 1996), 21 = (Ljung, 2010), 22 = (Cappuyns, 2006), 23 = (Ware et al., 2010), 24 = (Crowe et al., 2010), 25 = (Cruz-Motta and Collins, 2004), 26 = (Powilleit et al., 2006), 27 = (Wilber et al., 2007).

5. Causes to environmental impacts of dredging

A number of possible causes for dredging impacts, as illustrated in the conceptual model, are presented in Table 3. The table shows that impacts of dredging are highly dependent on the levels of contamination of dredged sites and technologies used. Furthermore, the increase in chemical parameters that occurs during dredging and disposal shows that the disturbance of sediments exposes the ecosystem to contaminants. Increases in the levels of organic and inorganic compounds heighten the risk of contaminant exposure that can negatively affect flora and fauna. The change in physical parameters further reinforces this point. While it has been noted that some positive changes can occur during the various stages of dredging, this review treats those more as anecdotal and suggests that the impacts are largely detrimental to the environment.

Table 3. The environmental impacts and possible causes.

Environmental impact	Possible cause	Remarks
Increase of chemical content in sediments and the water after dredging (Munawar, 1989)	Dispersal of contaminants into the water due to excavation Contaminants previously dispersed deposited back into sediments after dredging Excavation exposes new layer of sediments with higher value of contaminants	Silt curtain may not fully contain dispersal due to leakage (Thibodeaux and Duckworth, 2001)
Increase of oxygen demand (Messieh et al., 1991)	Increase of aquatic fauna Chemical pollutants maximize the need for oxygen to decompose	NA
Increase in number of polychaeta (Ponti et al., 2009)	Excavation exposes sources of food	Exposure of food sources attracts other polychaeta species, creates competition and congests the dredged site resulting in decrease of weaker species (Ponti et al., 2009)
Decrease in number of polychaeta (Ponti et al., 2009)	Excavation removes polychaeta from their habitat	Recovery rate is between 1 and 2 years (Kenny and Rees, 1996, Powilleit et al., 2006)
Decrease of light penetration (Douvere and Ehler, 2009, Munawar, 1989)	Dredging stages cause high level of turbidity	High level of turbidity is temporal (Herbich and Brahme, 1991, Messieh et al., 1991)
Increment of chemical body burden in crab (Su, 2002)	Dispersal of chemicals leads to bioaccumulation	NA
Habitat change (Padmalal, 2008)	Excavation changes sediment type and forces polychaeta species to change their habitat	NA

6. Other dredging problems

Current legislative actions aiming to preserve the environment from dredgingharmful effects, and their related problems, are listed in Table 4. Another important issue relating to dredging is its high cost. The cost of dredging varies according to the technology and equipment used, estimated volume, type of dredged material, distance from excavation to disposal site, time and distance of mobilization and demobilization, and disposal method. The high cost has always been the main problem for port operators, who are responsible for dredging and maintaining deep channels, but also need to spend funds to expand or build new terminals in order to cater for growing trade activities (Anderson and Barkdoll, 2010, Williams, 2008). Although operational costs are perceived as the biggest issue by a number of dredging stakeholders, few papers have discussed or analysed the cost of dredging. For example, Lee (2011) attempted to create a framework for dredging cost, analysing the construction operation process, type of river section, and the combination of equipment employed for river dredging. This analysis was based on historical data of river dredging projects conducted in South Korea (Lee et al., 2011).

Table 4. Dredging related rules and regulations in nations and their problems.

Criteria	The US	The UK	France	Malaysia
Dredging related rules and regulations	- Water Resources Development Act (WRDA), 1986 - Harbour Maintenance Act of 1986 - Water Resources Development Act of 1996 - Clean Water Act (Gibb, 1997)	- Water Framework Directive - Marine and Coastal Access Act 2009 (Transitional Provisions) Order 2012 - Food and Environmental Protection Act 1985 - London Convention 1972 and - OSPAR Convention for licensing of dredged material disposal - Harbour Act - Coast Protection Act 1949 - Merchant Shipping Act - Environmental Impact Assessment Directive - Habitats Directive - Birds Directive - The Town and Country Planning Act 1971 Control of Pollution Act (Part 2) 1984 Coast Protection Act 1949 (Bray et al., 1979, Eisma, 2006)	- Prevention and repression of marine pollution by immersion (Law n°76 599 of July, 7, 1976) - Require licence of immersion and public investigation (Decree n°82 842 of September, 29, 1982) - Environmental protection and integration of environmental problem in all public or private activities likely to have environmental impacts (Law n°76 629 of July, 10, 1976) -Procedures of authorization and declaration (Law n°92 3 of January, 1992 Decree n°93 742 of mars, 29, 1993 and Decree n°93 742 of mars, 29, 1993) - GEODE thresholds (Decree of June, 14, 2000) (Abriak	- EIA 1987 Order, 11(c) Mining (Government of Malaysia, 5th November 1987) - Occupational Safety and Health Act 1994 - Factories and Machineries Act 1967 - Wildlife Act 1972 - Fisheries Act 1985 - Guidelines on Erosion Control for Development Projects in the Coastal Zone - Environmental Impact Assessment Guidance Document for Sand Mining/Dredging Activities (Department of Irrigation and Drainage Malaysia, 1997, Department of Environment Malaysia, 2007)

Criteria	The US	The UK	France	Malaysia
			et al., 2006) EIA (OSPAR Commission, 2009)	
Dredging problems	Economic and environmental problems: - Trends in the shipping industry toward larger vessels requiring deeper draughts - The result of years of dismissing environmental problems as irrelevant - High cost of sediment remediation (Gibb, 1997) Managerial problem: - Confliction between stakeholders from federal, state and local political leadership during dredging	Environmental problem: - Loss of natural habitat - The deteriorating water quality - Polluted dredged material - Beneficial use of dredged material (Vellinga, 2002) - Conflicts on defining what constitutes waste to describe dredged sediments (Mink et al., 2006) Managerial problem: - Potential friction between EU Directives and international conventions - Other Directives on environmental protection, including Habitats and Birds Directives and Waste Framework Directive, lead to delays or cancellation of projects and to increase costs (Mink et al., 2006)	Environmental problem: - Harbour sites are located in sheltered zones where tides, streams, swell, and wind cause the trapping of sediments that becomes an obstacle for the access of ships to the harbour infrastructures Social problem: - Dredging involves many stakeholders including the community and each stakeholder has a view and some interests can diverge - The late involvement of environmental protection is responsible for blockings, loss of money and loss of time - No public inquiry procedure while applications are being considered (Gac et al., 2011)	Social and economic problem: - Public participation (Emang, 2006) - Economic vs the Environment (Briffett et al., 2004) Managerial and environmental problem: - Conflict of power distribution (State vs Federal) that cause delays (Staerdahl et al., 2004) - No mandatory action for monitoring (Briffett et al., 2004) - No incentives for mitigation measures (Briffett et al., 2004) - Difficult to enforce EIA 1987 Order (Emang, 2006) - Lack of cumulative impact analysis (Briffett et al., 2004) - Illegal sand dredging - Environment aspect was not included during pre-planning stage (Briffett et al., 2004) Lack of baseline data/evidence based documents (Briffett et al., 2004)

Despite the fact that developing countries were estimated to become the largest dredging markets in the world over the next few years, stiff competition from foreign dredging contractors heightens the need to lower costs for local dredging contractors (George, 2011, Thacker, 2007). This, together with poor facilities and limited dredging and environmental expertise, increases the risk of environmental negligence in developing countries. In addition to the issues faced in developed countries, dredging operators in developing countries, for example Malaysia, face an even greater challenge of limited funds (Barrow, 2005, Bartelmus, 1986). Although the maritime industry in Malaysia has been treated as a priority by its government (Ministry of Finance Malaysia, 2010, Mohamad, 2010, Tun Abdul Razak, 2010), this nation is facing a challenge in effectively monitoring the impacts of dredging. The sensitivity of its environment, which is deteriorating, makes it more critical to investigate the impacts of dredging at a national level (Spalding, 2001).

7. Dredging environmental management

Environmental management tools that have previously been applied in the dredging industry are outlined in Table 5. These include tools for auditing and monitoring, data collection, and strategic monitoring and planning (Barrow, 2005, Bartelmus, 1986). Examples of tools used for auditing and monitoring include Environmental Impact Assessment (EIA), Life Cycle Analysis (LCA) and risk assessment analysis (Guinée and Heijungs, 2000, Horne, 2009, Kiker, 2007, Linkov and Seager, 2011, Morrisey, 1993, Staerdahl et al., 2004). Another set of environmental management tools focus on data collection, with one example being the use of Geographical Information System (GIS).

Table 5. Environmental management tools and their application in dredging industry.

Environmental management tools		**Applications in dredging industry**	**Strengths and/or weaknesses**
Auditing and monitoring	Environmental Impact Assessment (EIA)	Used globally (i.e. in Malaysia that stipulating dredging in the Environmental Impact Assessment Order of 1987) [1]	Reducing the unexpected impacts and providing an advance warning of environmental problems (Barrow, 2005). However, it can involve minimal public participation (i.e. in Malaysia) and can be excessively time consuming and costly (Barrow, 2005, Morrisey, 1993, Staerdahl et al., 2004)
	Life Cycle Analysis (LCA)	To support the choice of different sediment management options by compiling and evaluating the environmental consequences of each choice [2]	It can be a very data-intensive analysis that is complex, time consuming and costly (White, 1993)
	Risk assessment analysis	Examples: dredging risk assessment model applications (DRAMA), risk-based environmental windows, comparative risk assessment, water quality, sediment quality, and ecological risk assessment [3]	Its weakness associated with its dual nature of accounting for both probability and severity (Pan, 2009)
Data collection	Geographical Information System (GIS)	Examples: GIS-based dredging model system and geostatistical GIS model to identify cadmium and zinc contamination areas in sediments [4]	Substituting conventional maps and card indexes to display information
Strategic monitoring and planning	Integrated environmental management (IEM)	Examples: comparative risk assessment and MCDA, coupling of comparative risk assessment, MCDA, and adaptive management, coupling of MCDA, LCA and risk assessment analysis, harmonized framework for ecological risk assessment of sediments,	A combination of many environmental tools providing a holistic analysis

Environmental management tools	Applications in dredging industry	Strengths and/or weaknesses
	evaluation of the Norwegian management system for contaminated sediments, Driving force–Pressure–State–Impact–Response (DPSIR) in Malaysia's dredging industry, and decision analysis approach to dredged material management [5]	

Reference: [1] = (Briffett et al., 2004, Government of Malaysia, 5th November 1987), [2] = (International Organization for Standardization, 1997, Vestola, 2009), [3] = (Agius and Porebski, 2008, Alvarez Guerra et al., 2007, Deliman et al., 2002, Liu et al., 2006, Suedel et al., 2008, Zeman et al., 2006), [4] = (Howlett et al., 2000, Vianna, 2004), [5] = (European Environment Agency, 2003, Langmead et al., 2009, Maxim et al., 2009, Ness et al., 2010).

A combination of strategic monitoring, planning and the above is gaining support as an integrated environmental management approach that aims to achieve sustainable development and maximize benefits for society, the economy, and ecosystems by integrating and balancing the issues of resource exploitation, social and economic activities, and environmental preservation (Wang, 2006). A number of applications of this tool have been developed, usually coupled with multi-criteria decision analysis (MCDA), which aims to create structured and defendable decisions (Kiker, 2007).

8. Potential of integrated environmental management framework for dredging industry

In general, a significant body of research has reviewed the environmental impacts of dredging, and many environmental management tools have been identified attempting to control its adverse effects.
Nevertheless, these tools are subjected to their individual weaknesses that could limit their effectiveness.

It has been noted that environmental management tools and practices which enable the integration of the conflicting issues during dredging decision-making should be put into practice in order to make a sustainable decision and prevent its adverse impacts. Furthermore, the sources, pathways and impacts of dredging should be taken into consideration when identifying measures for reducing dredging impacts (Eisma, 2006, Oste and Hin, 2010, Raaymakers, 1994, Vellinga, 2002).
The concept of integrated environmental management has an all-encompassing definition; Wang (2006) has defined this concept as: “a process that aims to achieve sustainable development and maximize benefits for human society and ecosystems by balancing resource exploitation, socio-economic activities, and environmental protection through co-operation and coordination of administrative entities and stakeholders” (Wang, 2006). Hence, integrated environmental management could provide a structured framework to accommodate different views of stakeholders, and identifies the most suited scale of actions towards addressing multi-criteria and conflicting issues, as faced by many countries (Antunes and Santos, 1999). Successful applications of this concept have been seen in the Integrated Coastal Managementand the Integrated Coastal Zone Management, which is among the tools of the Integrated Environmental Management (IEM) (Antunes and Santos, 1999, Pacheco et al., 2007).
However, the focus of previous research has generally been on developed countries, with fewer attempts made addressing how these tools can be applied in developing countries. Developed and developing countries have very different primary concerns. In developing countries, the desire for economic growth and development often takes

precedence over environmental issues and concerns, while developed countries often have the economic strength to put greater emphasis on environmental concerns (Vellinga, 2002).

Understanding the conceptual model, as illustrated in Fig. 2, is a first step to help develop this framework. Source–pathway–receptor linkages, as described in the conceptual model, offer different opportunities for reducing, avoiding or mitigating environmental impacts. These measures can be applied by controlling the levels of contaminants from point and diffuse sources, managing the pathways by using appropriate, environmentally friendly technologies and remediating sedimentsbefore disposal, or by avoiding environmentally sensitive habitats and protecting sensitive environmental targets.

It is critical to employ a tool for environmental management that relates these choices to the wider issues of dredging. The use of integrated environmental management has gained support within the dredging industry (Abriak et al., 2006, Agius and Porebski, 2008, Wang and Feng, 2007). Coupling qualitative measurements with sediments data collection for the characterization of dredged sites could further lessen the dependency on scientific measurements, including sediments characterization, in the dredging decision-making process, thus making it more holistic, integrated and sustainable.

One of the most notable attempts on this was the methodology for dredging developed at the Port of Dunkirk, France (Abriak et al., 2006, Junqua et al., 2006). Its steps include characterizing dredged sites according to the types of sediments and sources of pollution, developing waste improvement options, and determining the most relevant management scenario. Through the active participation of dredging professionals, researchers and local communities, this methodology follows an integrated environmental management approach, making use of risk assessmentand Multi-Criteria Decision Analysis (MCDA) (Kiker, 2007). However, a variation to the Port of Dunkirk methodology, as in Fig. 3, that characterizes dredged sites according to sediments, and which requires costly data collection, might be more appropriate for developing nations. Moreover, focussing on scientific data alone will overshadow other important dredging considerations.

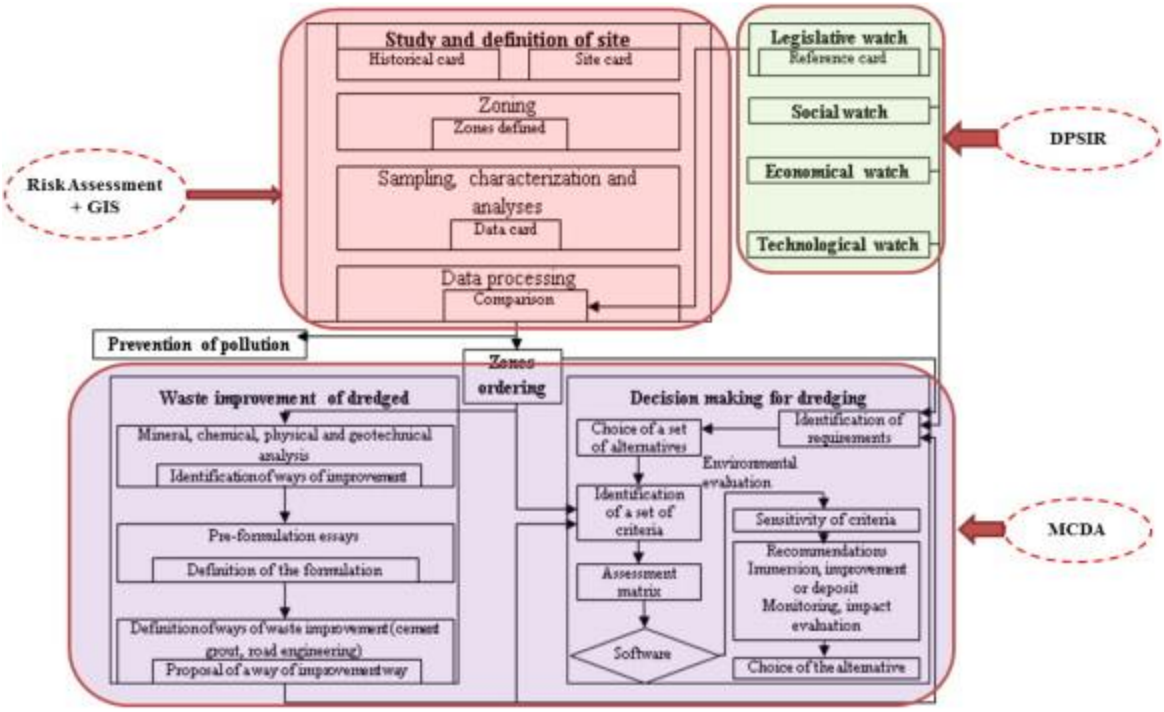

Fig. 3. Methodology for dredging at Port of Dunkirk, France (Abriak et al., 2006).

Developing countries have an opportunity and a duty to review and learn from practices in order to sustain growth without causing significant damage to their environment. Despite the fact that developing countries were estimated to become the largest dredging markets in the world over the next few years, stiff competition from foreign dredging contractors heightens the need to lower costs for local dredging contractors (George, 2011, Thacker, 2007). This, together with poor facilities and limited dredging and environmental expertise, increases the risk of environmental negligence in developing countries. In addition to the problems faced in developed countries, dredging operators in developing countries, for example Malaysia, face an even greater challenge of limited funds (Barrow, 2005; Bartelmus, 1986). Although the maritime industry in Malaysia has been treated as a priority by its government (Ministry of Finance Malaysia, 2010, Tun Abdul Razak, 2010, Mohamad, 2010), this nation is facing a challenge in effectively monitoring the impacts of dredging. The sensitivity of its environment, which is deteriorating, makes it more critical to investigate the impacts of dredging (Spalding, 2001).

A significant body of research has reviewed the environmental impacts of dredging, and many environmental management tools have been identified attempting to control its adverse effects. Nevertheless, the focus of research has generally been on developed countries, with fewer attempts made addressing how these tools can be applied in developing countries. Therefore, further research balancing the problems of dredging particularly for emerging economies such as Malaysia is a necessity. A variation to the Port of Dunkirk methodology (Fig. 3) which requires costly data collection and hard to implement (Choueri et al., 2010), might be more appropriate for developing nations.

Developed and developing countries have very different primary concerns. In developing countries, the desire for economic growth and development often takes precedence over environmental problems and concerns, while developed countries often have the economic strength to put greater emphasis on environmental concerns. Despite this, the development of any nation, regardless of economic status, should be balanced with the need to preserve the environment.

Malaysia is used here as an example of a developing country. It is among the most richly diverse regions for coral reefs, of which 91% are at risk due to anthropogenic activities, such as dredging (Spalding, 2001). In addition, Malaysia houses a number of tropical islands which are the habitat of abundant and exotic wildlife. It was also noted that the number of fisherman in Malaysia increased 3% in 2010 from the previous year, showing a growing dependence on the fishing industry (Department of Fisheries Malaysia, 2010; Omar, 2011). Furthermore, Malaysia is currently undergoing major economic development as part of a government plan to become a fully developed country by 2020. To that end, much effort has been made to increase the economic wellbeing and quality of life of its people (Mohamad, 2010). This has included the government's provision of USD 250 million over the years 2006–2009 to build and extend ports, and to ensure the safety of ship navigation for the fishing industry (Ministry of Finance Malaysia, 2010). Dredging is a major component of this, and it has been noted in previous research that Malaysia is facing difficulties in effectively monitoring the impacts of dredging (Manap et al., 2012), making even greater the need for this country to develop an effective environment managementtool for dredging to avoid further environmental deterioration. However, a recent risk-based decision-making framework for the selection of sediment dredging option has been developed using Malaysia's case studies, which could be beneficial to dredging industry of this country (Manap and Voulvoulis, 2014a, Manap and Voulvoulis, 2014b).

9. Discussion

Conventional environmental management tools and analyses have been shown to only focus on certain aspects such as economic or scientific evidence, which is not well balanced and frequently sidesteps other important environmental, socio-economic, management, or technical concerns. Therefore, tools and analyses, which integrate and balance multiple criteria during sediment management decision-making, are a necessity. Developing and developed countries may have different approaches to managing issues of dredging and sediment management. Developed countries have the ability to emphasize the environmental issues due to their high purchasing power; however developing countries that strive for economic strength may not have the luxury of doing so.

In fact, the lower the average income of a country, the lower the pressure to value the environment becomes. Therefore, a country may select an approach to environmental management depending on its economic strength. The approach can be reactive, receptive, constructive or proactive (Vellinga, 2002). Nevertheless, countries with abundant natural resources such as Malaysia should not take for granted their biodiversity, as this treasure has been depreciated over the years (Spalding, 2001).

For countries that are striving to enhance the quality of life of their people (such as Malaysia and its 2020 Vision), the rapid development towards a strong economy may worsen the already reduced environmental status.

It should be noted by countries such as Malaysia that the pioneering countries of the industrial revolution, the UK and the US, are still paying their debts to the environment by remediating contaminated lands, due to their historical rapid development (Stolzenbach and Adams, 1998). Therefore, it is critical for countries such as Malaysia which still fall into the developing category to change their perspective now from reactive towards proactive, with respect to managing the impacts of dredging.

It is undisputed that the Environmental Impact Assessment (EIA) system in developing countries is weak and without neglecting the economic aspect, therefore a risk-based approach for integrated environmental management framework offering a holistic and integrated strategy that can improve the preservation of environment of these countries is a necessity (Ahammed and Harvey, 2004, Alshuwaikat et al., 2007, Jain, 1999, Jou and Liaw, 2006, Kolhoff et al., 2009, Rajaram and Das, 2008, Tang et al., 2005, Tortajada, 2000).

10. Conclusion

This paper indicates the need for an integrated approach to dredgingenvironmental management that incorporates environmental implications and the disturbance of ecosystem equilibrium, which as demonstrated vary according to sediment properties and the technology used, in addition to the economic considerations which otherwise dominate the process, to be specifically develop for dredging at developing countries. The additional concerns of legislative challenges, negative public perception and cost must also be taken into account, thus creating the need for a more integrated approach to dredging management.

Acknowledgements

Acknowledgements are given to Universiti Tun Hussein Onn Malaysia, the Ministry of Education Malaysia and Malaysian Maritime and Dredging Corporation Sdn. Bhd. for the support given during the writing of this paper.

References

Abriak, N., Junqua, G., Dubois, V., Gregoire, P., Mac Farlane, F., 2006. Methodology of management of dredging operations I. Conceptual developments. Environ. Technol. 27, 411e429.

Agius, S., Porebski, L., 2008. Towards the assessment and management of contaminated dredged materials. Integr. Environ. Assess. Manag. 4, 255e260. Ahammed, R., Harvey, N., 2004. Evaluation of environment impact assessment procedures and practice in Bangladesh. Impact Assess. Proj. Apprais. 22, 63.

Alshuwaikat, H.M., Rahman, S.M., Aina, Y.A., 2007. The rationale for SEA to over come the inadequacy of environmental assessment in Bangladesh. J. Environ. Dev. 16, 227.

Alvarez Guerra, M., Viguri, J., Casado Martinez, M.C., DelValls, T.A., Casado-Martnez, M.C., 2007. Sediment quality assessment and dredged material management in Spain: part I, application of sediment quality guidelines in the Bay of Santander. Integr. Environ. Assess. Manag. 3, 529e538.

Alvarez Guerra, M., Viguri, J., Voulvoulis, N., 2009. A multicriteria-based methodology for site prioritisation in sediment management, Environ. Int. 35, 920e930. http://dx.doi.org/10.1016/j.envint.2009.03.012.

Alvarez-Guerra, M., Canis, L., Voulvoulis, N., Viguri, J.R., Linkov, I., 2010. Prioritization of sediment management alternatives using stochastic multicriteria acceptability analysis. Sci. Total Environ 408, 4354e4367.

http://dx.doi.org/ 10.1016/j.scitotenv.2010.07.016.
Anderson, M.J., Barkdoll, B.D., 2010. Incorporation of air emissions in dredging method selection. J. Waterw. Port Coast. Ocean Eng. 136, 191e199.
Antipov, V.V., Antipov Yu, V., Brakker, I.I., Brenner, V.A., Naumov Yu, N., Pushkarev, A.E., Pushkarev, V.A., Podkolzin, A.A., Zhabin, A.B., 2006. Channel dredging method, involves cutting ground with working blades of mechanical cutting tools installed on rotary cutting head, which performs horizontal intermittent movement in both directions transversely to axis of rotation. RU122595.
Antunes, P., Santos, R., 1999. Integrated environmental management of the oceans. Ecol. Econ. 31, 215e226. Balchand, A.N., Rasheed, K., 2000. Assessment of short term environmental impacts on dredging in a tropical estuary. Terra Aqua 16e26.
Balasubramaniam, A., Voulvoulis, N., 2005. The Appropriateness of Multicriteria Analysis in Environmental Decision-Making Problems. Environ. Technol. 26, 951e962. http://dx.doi.org/10.1080/09593332608618484.
Barrow, C.J., 2005. Environmental Management and Development. Routledge, New
York. Bartelmus, P., 1986. Environment and Development. Allen and Unwin Inc., Boston. Bonvicini Pagliai, A.M., Cognetti Varriale, A.M., Crema, R., Curini Galletti, M., Vandini
Zunarelli, R., 1985. Environmental impact of extensive dredging in a coastal marine area. Mar. Pollut. Bull. 16, 483e488. Bray, R.N., Bates, A.D., Land, J.M., 1979. Dredging a Handbook for Engineers. John Wiley and Sons, North, Central and South America.
Briffett, C., Obbard, J., Mackee, J., 2004. Environmental assessment in Malaysia: a means to an end or a new beginning? Impact Assess. Proj. Apprais. 22, 221e233.
Burton Jr., G. Allen, 2002. Sediment quality criteria in use around the world. Limnology 3, 65e76. Cappuyns, V., 2006. Assessment of heavy metal mobility in dredged sediments: porewater analysis, single and sequential extractions. Soil Sediment Contam. 15,
169.
Choueri, R.B., Cesar, A., Abessa, D.M.S., Torres, R.J., Riba, I., Morais, R.D., Mozeto, A.A., DelValls, T.A., 2010. Harmonised framework for ecological risk assessment of sediments from ports and estuarine zones of North and South Atlantic. Ecotoxicology 19, 678e696. http://dx.doi.org/10.1007/s10646-009-0442-y.
Constantino, R., 2009. Clam dredging effects and subsequent recovery of benthic communities at different depth ranges. Mar. Environ. Res. 67, 89e99.
Crowe, S.E., Gayes, P.T., Viso, R.F., Bergquist, D.C., Jutte, P.C., Van Dolah, R.F., 2010. Impact of the Charleston Ocean Dredged Material Disposal Site on nearby hard bottom reef habitats. Mar. Pollut. Bull. 60, 679e691.
Cruz-Motta, J.J., Collins, J., 2004. Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage. Mar. Pollut. Bull. 48, 270e280.
de Leeuw, J., 2010. Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China. Regional environmental change natural and social aspects 10, 95e102.
De Nobili, M., Francaviglia, R., Sequi, P., 2002. Retention and mobility of chemicals in soil. In: Violante, A., Huang, P.M., Bollag, J.-M., Gianfreda, L. (Eds.), Developments in Soil Science. Elsevier, pp. 171e196.
Deliman, P.N., Ruiz, C.E., Schroeder, P.R., 2002. Dredging Risk Assessment Modelling Applications (DRAMA) for evaluation of dredging impacts. In: Proceedings of the Third Specialty Conference on Dredging and Dredged Material Disposal.
Den Herder, A., 2010. Suction dredger for transporting sand and shingle from bottom of the sea has belt located in centerline of the suction dredger when used and is designed such that distribution belt can swivel at both sides of the suction dredger backwards. EP168527:0-8.
Department of Fisheries Malaysia, 2010. Annual Fisheries Statistic, pp. 1e45.
Department of Environment Malaysia, 2007. Environmental Impact Assessment (EIA) Guidance Document for Sand Mining/Dredging Activities.
Department of Irrigation and Drainage Malaysia, 1997. Guidelines on Erosion Control for Development Projects in the Coastal Zone DID 1/97.
Douvere, F., Ehler, C.N., 2009. New perspectives on sea use management: initial findings from European experience with marine spatial planning. J. Environ. Manage. 90, 77e88.
Dreyer, H.B., 2006. Submersible boom for use in aquatic environment, has buoyancy unit to raise and lower horizontal support unit between two positions, and boom curtain suspended from horizontal support unit.

US096033:0-15.
Du, Yuhai, Li, Hongwei, 2010. Mechanical Technology for Dyke Reinforcement by Sediment Discharge in the Lower Reaches of the Yellow River. Yellow River Conservancy Press, Chengdong Lu, Zhengzhou, Henan 450004, Peoples R China.
Duran Neira, C., 2011. Closed-circuit water system for suction dredgers, drives water accumulated in compartment through spout pipe towards dredging head of suction pipe for recirculating aspirated water. ES030040:0-13.
Eisma, D., 2006. In: Eisma, D. (Ed.), Dredging in Coastal Waters.
Elander, P., Hammar, T., 1998. The remediation of Lake Jarnsjon: project implementation. Ambio 27, 393e398.
Ellery, W., McCarthy, T., 1998. Environmental change over two decades since dredging and excavation of the lower Boro River, Okavango Delta, Botswana.
J. Biogeogr. 25, 361. Emang, J.J.J., 2006. Public Participation in EIA Process in Sarawak:
Any Room for Improvement?. European Environment Agency, 2003.
Environmental Indicators: Typology and Use
in Reporting.
Fluck, R., Chevre, N., Campiche, S., 2010. Sediment Quality Assessment
.
Fujimoto, T., Tadasu, O., 1998. The Development of Underwater Dredging System for Rocky Sea Bottom at Narrow Channel, p. 340.
Gac, S.L., Chiffoleau, A., Claudel, H., Lozach, L., 2011. Status of French and English Port Dredging Regulations, pp. 1e54.
Garrett, R.G., 2000. Natural sources of metals to the environment. Hum. Ecol. Risk Assess. 6, 945.
Ge, Y., Sun, J., He, R., 1999. Spiral reamer type dredger. CN110894.
George, C., 2011. Obstacles an opportunities. Dredg. Port Constr. Jan. 2012, 26e29.
Gibb, B., 1997. Dredging, environmental issues and port experience in the United States. Marit. Policy Manag. 24, 313e318.
Government of Malaysia, 5th November 1987. Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987.
Groote, J.D., Dumon, G., Vangheluwe, M., Jansen, C., 1998. Environmental monitoring of dredging operations in the Belgian nearshore zone. Terra Aqua 70, 21e25.
Gubbay, S., 2005. A Review of Marine Aggregate Extraction in England and Wales,

1970e2005. Guine

ee, J.B., Heijungs, R., 2000. Life cycle assessment. In: Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc..
Guo, J., 2011. Pipeline dredger for dredging downriver, has piston provided in pipe body and connected with handle, and aerating sealing rubber ring connected with lower end of pipe body, where aerating sealing rubber ring is provided with aerator. CN20287342:0-6.
Guo, S., He, J., Su, Z., Wang, L., Zhang, Q., Zhu, X., 2009. Silt-blocking curtain wall for grab dredger construction, has floating body connected to floating frame i.e. steel pipe fence frame, and curtain i.e. woven cloth, located below floating body. CN20142239:0-8.
Herbich, J.B., Brahme, S.B., 1991. Literature Review and Technical Evaluation of Sediment Resuspension during Dredging.
Highley, D.E., Hetherington, L.E., Brown, T.J., Harrison, D.J., Jenkins, G.O., 2007. The Strategic Importance of the Marine Aggregate Industry to the UK.
Holt, M.S., 2000. Sources of chemical contaminants and routes into the freshwater environment. Food Chem. Toxicol. 38 (Suppl. 1), S21eS27.
Honmagumi, K.K., Chiyoda Kenki, K.K., 1995. Mud processing e by dredging using a closed hydraulic grab bucket, removing large solids, agitating with a high pressure pump and solidifying. JP192176:0-9.
Horne, R., 2009. Life Cycle Assessment: Principles, Practice and Prospects.
Howlett, E., Galagan, C., Clausner, J., Johnson, B., 2000. DREDGEMAP: a GIS-based Dredging Model System, pp. 1929e1932.
Ikeda, S., Nomoto, G., 1999. Self-driving type dredger for sea bed. JP053416.

International Organization for Standardization, 1997. International Standard ISO 14040 e Environmental Management e Life Cycle Assessment e Principle and Frameworks. IS0 14040:1997(E), pp. 1e12.
Ishizaki, M., Rikitake, M., 2010. Pollution prevention curtain used in dredging constructions, has one way valve into which water is made to flow in from exterior, which is provided in inside of cover of curtain installed in hung-down state. JP102110:0-7.
Jain, A.B., 1999. An overview of the environmental regulatory aspects in India and in developed countries. Chem. Bus. India 13, 107.
Jain, C.K., Ram, D., 1997. Adsorption of metal ions on bed sediments (Adsorption d'ions meediments de fond). Hydrol. Sci. J. 42, 713.

etalliques sur les seJou, J., Liaw, S., 2006. A study on establishment of EIA system in the Taiwan region.
J. Environ. Assess. Policy Manag. 8, 479.
Junqua, G., Abriak, N., Gregoire, P., Dubois, V., Mac Farlane, F., 2006. Methodology of management of dredging operations II. Applications. Environ. Technol. 27, 431e446.
Katsiri, A., Pantazidou, M., Damikouka, I., Kontogiorgi, C., Tringali, A., 2009. Disposal options for dredged marine sediments based on physicochemical and toxicological characterization. Glob. NEST J. 11, 449e456.
Kenny, A.J., Rees, H.L., 1996. The effects of marine gravel extraction on the macro-benthos: results 2 years post-dredging. Mar. Pollut. Bull. 32, 615e622.
Kiker, G.A., 2007. Integrating Comparative Risk Assessment and Multicriteria Decision Analysis, pp. 37e51.
Kim, N.C., 2004. Sediment treatment method for purifying lake and reservoir water and system. KR013864:0-1.
Kizyaev, B.M., Golubev, N.K., Bass, V.N., 2011. Method to clean canals and waterways from sediments includes working and washing of sediments with a hydraulic dredger into a dump arranged in a near-bed zone and fenced with banking dams along the whole perimeter. RU145021:0-1.
Klein, J., 1998. Sediment dredging and macrophyte harvest as lake restoration techniques. Land Water 42.3, 10e12.
Kolhoff, A.J., Runhaar, H.A.C., Driessen, P.P.J., 2009. The contribution of capacities and context to EIA system performance and effectiveness in developing countries: towards a better understanding. Impact Assess. Proj. Apprais. 27, 271e282.
Krishnappan, B.G., 1975. Dispersion of dredged spoil when dumped as a slug in deep water. In: First International Symposium on Dredging Technology. D213eD2-32.
Krizner, K., 2010. Manufacturers make their move. World Trade, WT100 23, 16. http://www.worldtradewt100.com/articles/manufacturers-make-their-move.
Krizek, R.J., Giger, M.W., Jin, J.S., 1975. Dewatering of dredged materials by evaporation. In: First International Symposium on Dredging Technology. F3-29eF3
38.
Lair, G., 2009. How do long-term development and periodical changes of river-floodplain systems affect the fate of contaminants? Results from European rivers. Environ. Pollut. 157, 3336.
Langmead, O., McQuatters Gollop, A., Mee, L., Friedrich, J., Gilbert, A., Gomoiu, M., 2009. Recovery or decline of the northwestern Black Sea: a societal choice revealed by socio-ecological modelling. Ecol. Modell. 220, 2927.
Lee, J., Lee, S., Woo, S., Shin, D., 2011. Framework of the approximate cost estimating model for river dredging construction. KSCE J. Civ. Eng. 15, 33e42. http:// dx.doi.org/10.1007/s12205-011-1061-8.
Lefever, J., Van Wellen, E., 2011. Cutter suction dredger for dredging ground under water, has vessel loosening ground fragments, which are sucked away by suction conduit, and vessel comprising sounder to measure depth of under water ground after ground is dredged.
Lin, J., Liu, X., Su, Y., Wang, S., Zhao, L., 2010. Quickly desalting dredger fill by preparing desulfurization gypsum containing calcium sulfate dihydrate, maintaining dredger fill at specified water content, and mixing dredger fill and desulfurization gypsum. CN10169368:0-5.
Linkov, I., Seager, T.P., 2011. Coupling multi-criteria decision analysis, life-cycle assessment, and risk assessment for emerging threats. Environ. Sci. Technol. http://dx.doi.org/10.1021/es100959q.
Liu, H., 2005. Environmental protection dredging machine for water area. CN114841.
Liu, A.J., Kong, F.X., Wang, D., 2006. Water quality risk assessment for sediment dredging operations, Wulihu in Taihu Lake. Huan Jing Ke Xue 1946e1952.
Ljung, K., 2010. Canal estate development in an acid sulfate soil e implications for human metal exposure. Landsc.

Urban Plan. 97, 123e131.
MacGillivray, A., Kayes, R., 1994. Environmental Measures: Indicators for the UK Environment.
Mackie, J.A., 2007. Declining metal levels at Foundry Cove (Hudson River, New York): response to localized dredging of contaminated sediments. Environ. Pollut. 149, 141e148.
Manap, N., Voulvoulis, N., Zulkifli, N., 2012. The applications of Driving force, pressure, state, impact and response in Malaysia's dredging industry. Int. J. Food, Agric. Environ. 10, 1031e1038.
Manap, N., Voulvoulis, N., 2014a. Risk-based decision-making framework for the selection of sediment dredging option. Science of the Total Environment 496, 607e623. http://dx.doi.org/10.1016/j.scitotenv.2014.07.009.
Manap, N., Voulvoulis, N., 2014b. Environmental Screening Method for Dredging in Contaminated River. Applied Mechanics and Materials 567, 50e55. www. scientific.net/AMM.567.50.
Maxim, L., Spangenberg, J., O'Connor, M., 2009. An analysis of risks for biodiversity under the DPSIR framework. Ecol. Econ. 69, 12.
Messieh, S.N., Rowell, T.W., Peer, D.L., Cranford, P.J., 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Cont. Shelf Res. 11, 1237e1263.
Ministry of Finance Malaysia, 2010. In: Anggaran Perbelanjaan Persekutuan 2011, vol. 1, p. 684.
Mink, F., Dirks, M., Raalte, G.V., Vlieger, H.D., Russell, M., 2006. Impact of European union environmental law on dredging. Terra Aqua 104, 3.
Mohamad, M., 2010. The Way Forward e Vision. Available from: http://www.pmo. gov.my/?menu¼page&page¼1904.
Morinaga Kumi, K.K., Trade Service, K.K., DCR System, K.K., 1997. Method for disposal of sludge collected by dredger from sea bed e involves mixing calcined lime with sludge for absorption of moisture during stirring.
Morrisey, D.J., 1993. Environmental impact assessmentda review of its aims and recent developments. Mar. Pollut. Bull. 26, 540e545.
Morton, B., 2001. Dredging through the remains. Mar. Pollut. Bull. 42, 333 e334.
Moss, B., Madgwick, J., Phillips, G., 1996. A Guide to the Restoration of Nutrient-enriched Shallow Lakes. W W Hawes, United Kingdom.
Mostafa, Y.E.S., 2012. Environmental impacts of dredging and land reclamation at Abu Qir Bay, Egypt. Ain Shams Eng. J. 3, 1e15.
Mulligan, C.N., Yong, R.N., Gibbs, B.F., 2001. An evaluation of technologies for the heavy metal remediation of dredged sediments. J. Hazard. Mater. 85, 145e163.
Munawar, M., 1989. In situ bioassessment of dredging and disposal activities in a contaminated ecosystem: Toronto Harbour. Hydrobiologia 188e189, 601e618.
Ness, B., Anderberg, S., Olsson, L., 2010. Structuring problems in sustainability science: the multi-level DPSIR framework. Geoforum 41, 479.
Nielsen, P., 2009. Coastal and Estuarine Processes. World Scientific, Singapore.
Nippon, C.C.L., 1996. Dredging method of sand, earth and colloidal sediments from dams, lakes e has first conveyor partly laid on ground and partly on water with float bodies connecting second conveyor through transfer device for dredge transportation.
Nittrouer, C.A., Austin Jr., J.A., Field, M.E., Kravitz, J.H., Syvitski, James P.M., Wiberg, P.L., 2007. Writing a Rosetta stone: insights into continental margin sedimentary processes and strata. In: Special Publication Number 37 of International Association of Sedimentologists, pp. 1e38.
O'Connor, T.P., 1998. Comparative criteria: land application of sewage sludge and ocean disposal of dredged material. Mar. Pollut. Bull. 36, 181e184.
Office of Naval Research, 2008. Science and technology focus. In: Office of Naval Research. http://www.onr.navy.mil/Focus/ocean/motion/default.htm (accessed 13.10.10).
Omar, S.Z., 2011. Information and communication technology for fisheries industry development in Malaysia. Afr. J. Agric. Res. 6, 4166.
OSPAR Commission, 2009. Assessment of the environmental impact of dredging for navigational purposes. Biodivers. Ser. 1e18.
Oste, L., Hin, J., 2010. How to Assess Sediment without Sediment Environmental Quality Standards?.
Otoyo, K.K., 2003. Sediment dredging method e.g. sludge deposited on seabed of lakes, involves dredging sediment

deposited on sea-bed or inner side of cylindrical air curtain which is formed by ejecting air bubbles.
Pacheco, A., Carrasco, A.R., Vila-Concejo, A., Ferreira, O., Dias, J.A., 2007. A coastal management program for channels located in backbarrier systems. Ocean Coast. Manag. 50, 119e143.
Padmalal, D., 2008. Environmental effects of river sand mining: a case from the river catchments of Vembanad lake, Southwest coast of India. Environ. Geol. 54, 879e889.
Pan, J., 2009. Environmental Risk Assessment of Inorganic Chemicals in the Mining Environments (Dissertation or Thesis).
Parkhill, K., 2002. Effect of inorganic sediment on whole-stream productivity. Hydrobiologia 472, 5e17.
Pensaert, S., Dor, T., Van den Bossche, P., Hendrik, N., Vandycke, S., 2008. The Svartsjo Project: Environmental Dredging and Dewatering of Pulp-and-paper Sludges. Helmholtz Centre Environmental Research-UFZ, Permoserstrasse 15, Leipzig D-04318, Germany.
Piou, S., 2009. Changes in the geochemistry and ecotoxicity of a Zn and Cd contaminated dredged sediment over time after land disposal. Environ. Res. 109, 712e720.
Ponti, M., Pasteris, A., Guerra, R., Abbiati, M., 2009. Impacts of maintenance channel dredging in a northern Adriatic coastal lagoon. II: effects on macrobenthic assemblages in channels and ponds. Estuar. Coast Shelf Sci. 85, 143e150.
Powilleit, M., Kleine, J., Leuchs, H., 2006. Impacts of experimental dredged material disposal on a shallow, sublittoral macrofauna community in Mecklenburg Bay (western Baltic Sea). Mar. Pollut. Bull. 52, 386e396.
Praveena, S.M., 2008. Application of sediment quality guidelines in the assessment of mangrove surface sediment in Mengkabong lagoon, Sabah, Malaysia. Iran. J. Environ. Health Sci. Eng. 5.
Quimby, W.J., 1914. Digging and dredging machinery. United States Patent Office 564704.
Raaymakers, S., 1994. Dredging in sensitive environments down under. Mar. Pollut. Bull. 28, 275e276.
Rajaram, T., Das, A., 2008. A methodology for integrated assessment of rural linkages in a developing nation. Impact Assess. Proj. Apprais. 26, 99.
Rasheed, K., Balchand, A.N., 2001. Environmental studies on impacts of dredging. Int. J. Environ. Stud. 58, 703.

Reba, B.V., 1975. Anchoring for floating dredger with cables, winches and anchors e has bow and stern cables guided over hydraulic cylinder-operated pulleys. NL016200.
Riley, J.P., Chester, R., 1971. Introduction to Marine Chemistry. Academic Press Inc. (London) Ltd., London.
Rothwell, J.J., Dise, N.B., Taylor, K.G., Allott, T.E.H., Scholefield, P., Davies, H., Neal, C., 2010. A spatial and seasonal assessment of river water chemistry across North West England. Sci. Total Environ. 408, 841e855.
Salomons, W., Brils, J., 2004. Contaminated Sediments in European River Basins. European Sediment Research Network, p. 71.
Sawaragi, T., 1995. Marine structures for ocean space utilization. In: Sawaragi, T. (Ed.), Developments in Geotechnical Engineering. Elsevier, pp. 315e358 (Chapter 6).
Saxena, P.C., Vaidyaraman, P.P., Brahme, S.B., 1975. Spoil disposal practices in India. In: First International Symposium on Dredging Technology. D447eD4-58.
Schexnayder, C.J., 2010. Panama Canal Project Revs Up With New Award. ENR 265, 1.
Schnell, L.L., 1984. Water dredging hydraulic or pneumatic excavator bucket wheel e has pressure feed pipe opening into protruding ring socket joined to casing linked with conveyor pipe. DE3220797:0-15.
Sergeev, A., 2009. The impact of two newly built port terminals in the Eastern Gulf of Finland on sedimentation processes and coastal zone dynamics. Est. J. Eng. 15, 212e226.
Shigaki, F., Kleinman, P.J.A., Schmidt, J., Sharpley, A., Allen, A., 2008. Impact of dredging on phosphorus transport in agricultural drainage ditches of the Atlantic coastal plain. J. Am. Water Resour. Assoc. 44, 1500.
Spalding, M., 2001. World Atlas of Coral Reefs.
Staerdahl, J., Schroll, H., Zakaria, Z., Abdullah, M., Dewar, N., Panich, N., 2004. Environmental impact assessment in Malaysia, South Africa, Thailand and Denmark: background, layout, context, public participation and environmental scope. J. Transdiscip. Environ. Stud. 3.
Stolzenbach, K.D., Adams, E.E., 1998. Contaminated Sediments in Boston Harbor. Marine Center for Coastal Processes, MIT Sea Grant College Program, Massachusetts.
Su, S., 2002. Potential long-term ecological impacts caused by disturbance of contaminated sediments: a case study. Environ. Manage. 29, 234e249.
Suedel, B.C., Kim, J., Clarke, D.G., Linkov, I., 2008. A risk-informed decision framework for setting environmental windows for dredging projects. Sci. Total Environ. 403, 1e11.
Tack, B., 2010. Cutter head for use with cutter suction dredger for dredging ground under water, has rotation-symmetrical revolving body rotatable around rotation axis that runs perpendicularly to longitudinal direction of ladder. NL2004442:0-23.
Tang, S., Tang, C., Carlos, W.L., 2005. Public participation and environmental impact assessment in mainland China and Taiwan: political foundations of environmental management. J. Dev. Stud. 41, 1.
Tashiro, F., 2009. Dredging system for excavating the bottom of water area, has grab bucket, suspended from jib of crane via holding rope and closing rope, which is provided with acceleration sensor and angular speed sensor. JP096772:0-15.
Thacker, S., 2007. Dredging projects. Int. Financ. Law Rev. 26, 59.
The National Oceanic and Atmospheric Administration (NOAA), 2006. London Convention and Protocol: Guidance for the Development of Action Lists and Action Levels for Dredged Material. In 2012.
Thibodeaux, L.J., Duckworth, K.T., 2001. The effectiveness of environmental dredging: a study of three sites. Remediat. J. 11, 5e33.
Thorn, M.F.C., 1975. Loading and consolidation of dredged silt in a trailer suction hopper dredger. In: First International Symposium on Dredging Technology. B11eB1-14.
Toes, A., 2008. Effects of deposition of heavy-metal-polluted harbor mud on microbial diversity and metal resistance in sandy marine sediments. Arch. Environ. Contam. Toxicol. 55,

372e385.
Tortajada, C., 2000. Environmental impact assessment of water projects in Mexico. Int. J. Water Resour. Dev. 16, 73.
Toyo Kensetsu, K.K., Daiichi Kogyo Seiyaku Co Ltd., Ekuseno Yamamizu, K.K., 1994. Spray device to remove smell during dredging operations e comprising pump, long nozzle, essential plant oil and diluent liquid.
Trang, V., Keat, T., 2010. A Review of the Current State-of-the-arts on the Application of Silt Screens as Sediment Control Equipment in Open Water, pp. 60e66.
Tsinker, P.G., 2004. Port Engineering: Planning, Construction, Maintenance, and Security.
Tun Abdul Razak, M.N., 2010. The 2011 Budget Speech, pp. 1e38.
Ueno, Y.J.P., 2010. Pollution prevention apparatus used in dredging boat, has pollution prevention curtain attached to float frame so as to surround float frame, to prevent outflow of polluted water by suspending down the curtain into bottom surface of water. JP128468:0-6.
US Geological Survey, 2004. Chesapeake Bay river input monitoring program. In: US Geological Survey. http://va.water.usgs.gov/chesbay/RIMP/waterchem.html (accessed 17.10.10).
Van Nieuwenhuijzen, E., Van Den Broeck, M., 2011. Method for loading dredging vessel e.g. trailing suction hopper dredger with dredged material, involves adjusting height position of overflow above settled layer subject to value of control parameter measured during filling of hold. BE000253:0-20.
Vellinga, P., 2002. Dredging in a changing environment. Terra Aqua 3e15.
Verbeek, P.R.H., 1984. Soil Analysis and Dredging, pp. 11e21.
Vestola, E.A., 2009. LCA in contaminated sediment remediation. In: VTT Symposium, pp. 87e94.
Vianna, L.F. de N., 2004. A geostatistical GIS model to identify cadmium and zinc contamination risk areas in sediments of Sepetiba Bay, Rio De Janeiro e Brazil.
J. Coast. Res. 39, 1488e1493. Special Issue.
Wang, Q., 2006. Toward integrated environmental management for challenges in water environmental protection of Lake Taihu basin in China. Environ. Manage. 37, 579e588.
Wang, X.Y., Feng, J., 2007. Assessment of the effectiveness of environmental dredging in South Lake, China. Environ. Manage. 40, 314e322.
Ware, S., Bolam, S.G., Rees, H.L., 2010. Impact and recovery associated with the deposition of capital dredgings at UK disposal sites: lessons for future licensing and monitoring. Mar. Pollut. Bull. 60, 79e90.
Welte, A., 1975. New processes of unloading trailing suction hopper dredgers. In: First International Symposium on Dredging Technology. H1-1eH1-20.
Wenning, R.J., 2005. Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments.
White, A., 1993. Life cycle assessment. Environ. Sci. Technol. 27, 1016.
Wilber, D.H., Clarke, D.G., Rees, S.I., 2007. Responses of benthic macroinvertebrates to thin-layer disposal of dredged material in Mississippi Sound, USA. Mar. Pollut. Bull. 54, 42e52.
Williams, C., 2008. Saint John hopes new research study will help manage dredging. Can. Sail. 14.
Zeman, A., Patterson, T., Calabrese, E.J., Kostecki, P.T., Dragun, J., 2006. Characterization of Contaminated Sediments for Remediation Projects in Hamilton Harbour e Risk Assessment and Remedial Approaches towards Restoration and Management of Contaminated Rivers, pp. 401e421.
Zhang, R., Zeng, F., Liu, W., Zeng, R.J., Jiang, H., 2014. Precise and economical dredging model of sediments and its field application: case study of a river heavily polluted by organic matter, nitrogen, and phosphorus. Environ. Manage. 53, 1119e1131.
Zühlke, R., 1994. Response of macrofauna to drifting tidal sediments. Helgol. Mar. Res. 48, 277e289.