A Mini Project Report On

"Dredged sediments as a sustainable material"

Submitted in partial fulfilment of the requirement for the Degree of

Master of Technology in the Department of Civil Engineering

(With specialization in Geotechnical Engineering)

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DECLARATION

I hereby declare that the work presented in the dissertation "**Dredged sediments as a sustainable material**" in partial fulfilment of the requirement for the award of the degree of "MASTER OF TECHNOLOGY" in Civil Engineering (With specialization in Geotechnical Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science & Technology University, is a real record of the work carried out in the said college for six months under the supervision of, Dr. Abinash Mahanta Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

Date Sabana Yasmin

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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CERTIFICATE OF SUPERVISION

This is to certify that the work presented in this report entitled **—** "**Dredged sediments as a sustainable material**" is carried out by Sabana Yasmin, Roll No: PG/C/23/17, a student of M.Tech 3rd semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

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ABSTRACT

The global focus on the conservation of non-renewable resources and the recycling of waste materials is intensifying. In this regard, extensive research efforts are dedicated to identifying methods for the reuse and recycling of various waste materials. Among these, dredged sediments represent a significant resource with the potential to mitigate the depletion of natural resources by serving as secondary raw materials in diverse applications. Dredging is a critical and routine operation for ports and harbors, essential for maintaining sustainable navigation in marine and river environments. However, the ongoing accumulation of contaminated dredged sediments poses risks to the environment, ecology, and marine ecosystems. Effective management of the dredging process and the sediments produced is crucial for the health of marine and river ecosystems. Advancements in technology aimed at recycling dredged sediments into secondary raw materials can help supplement natural resources, provide a practical solution to environmental pollution, address land scarcity for waste disposal, and partially bridge the resource gap. This article explores the current advancements in the recycling and valorization of dredged sediments, highlighting their role in replenishing natural resources and enhancing global sustainability.

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CHAPTER 1 INTRODUCTION

1.1 General

The sediments are very important and beneficial, it enriches the soil with nutrients. The sediments that are deposited on the banks and flood plain of a river are highly mineral rich making it the most fertile farmlands hence reducing the need for fertilizers and pesticides required to grow crops. Boulders, cobbles, pebbles, sand, silt, and clay are the most common types of sediment to be found. Rivers are a valuable natural resource and a crucial part of human life. Rivers mostly act as agents of a rich deposit of sediments that form flood plains and valleys. Sand is an important material that is primarily utilized in construction projects and has a high economic worth. However, sediment in rivers becomes a threat when it is deposited in an unfavourable location. Aggradation and degradation could result from it. Additionally, it results in the meandering, braiding, and broadening of rivers, which puts the embankments and communities along riverbanks at risk through erosion. River sedimentation also raises river bottoms and decreases navigable depth, clogging drainage systems. In these situations, it becomes essential to remove the sediment at specific locations using appropriate methods. Understanding the physical processes of rivers, including sediment transport, bank erosion, and channel mobility, is crucial for developing river restoration and management strategies. The national framework document “National Framework For Sediment Management” Ministry of Jal Shakti Department of Water Resources, River Development & Ganga Rejuvenation outlines the main concerns with sediment management and offers suggestions to stakeholders and policymakers. It becomes very much important to explore the current state of recycling and valorisation opportunities for dredged sediments, contributing to the replenishment of natural resources and enhancing global sustainability.

CHAPTER 2 OBJECTIVE OF THE STUDY

This study aims to investigate the following key components: Sediment Dynamics: Transport, deposition. Composition: Pollutants and nutrient content. Ecological Impact: Effects on biodiversity and habitats. Technological Innovations: Modern dredging methods and sediment reuse technologies. Socioeconomic Aspects: Costs, benefits, and community impact.

By understanding these aspects, sediment management and dredging can be planned and executed in a way that supports both environmental sustainability and economic development.

2.1 Significance of the study

This study holds significance for many reasons sighting maintaining river navigation sediment deposition can obstruct waterways, reducing the depth needed for navigation, flood risk management where excessive sediment deposition can reduce river channel capacity, . Regular monitoring and dredging ensure safe and efficient transport for shipping and boating industries, maintain channel capacity, reducing flood hazards.

Water Quality Improvement: sediments often carry nutrients, organic matter, and pollutants, which can degrade water quality, studying sediment composition helps in mitigating pollution and improving water quality for ecosystems and human use. Unregulated dredging can disrupt ecosystems, alter river morphology, and lead to habitat loss so sustainable dredging practices should be adopted. Studying river sediments ensures dredging is environmentally sustainable and economically viable scientific studies ensure compliance with regulations while balancing economic and ecological needs.

CHAPTER 3 SEDIMENT DYNAMICS

3.1 Sediment transport and composition

Sediment transport is the movement of the organic and inorganic particles by different mediums (water, wind, ice gravity biological agents). The nature of sediment transport is largely dependent on the energy of the transporting medium, which can range from gentle currents in a river to the violent pyro clastic flow from a volcanic eruption.

The size, density, mineral composition, and other characteristics including surface roughness of the sediments are determined by the type of parent rock they are generated from. After the sediment is transported, it is deposited in a wide range of environments, including river channels, lakes, deltas, beaches, and deep marine basins. Transported sediment may include mineral matter, chemicals, pollutants, and organic matter. The total transported sediment load includes all particles moving as bed load, suspended load, and wash load.

Currently, the presence of heavy metals in the sediments and water columns of rivers and lakes, primarily due to anthropogenic activities, is frequently observed, resulting in severe contamination of many of the aquatic ecosystems.

This pollution has progressively become a pressing global issue in aquatic environment, heavy metal is usually distributed as follows: water-soluble species, colloids, suspended forms and sedimentary phases

Heavy metals usually possess significant toxicity to aquatic organisms and then affect human health through food chain and also is not suitable for using as a raw material for construction. Therefore, investigating the transformation and distributions mechanisms of heavy metal in sediment become necessary.

3.2 Classification of coarse medium fine sediments

Wentworth Grade Scale

Standardized definitions of the fractions: Gravel (d$>$ 2 mm), sand (62.5 um$<$d$<$ 2 mm),

silt (4 um $<$d$<$ 62.5 um), clay (d$<$ 4 um)

As per BIS Code IS: 6339 (as been revised in 2013)

Table 1: Classification of sediments

Sediment type	**Particle size**
Coarse sediment	D> 0.25 mm
Medium sediment	D= 0.062 mm to 0.25mm
Fine sediment	D< 0.062

CHAPTER 4 SEDIMENTATION

River Sediments mainly consist of boulders, cobbles, pebbles, sand, silt, and clay. Sand has high economic value and is a valuable material largely used in construction works. Due to huge demand for sand Govt. of India has come up with “Sustainable Sand Mining Management Guidelines – 2016 and a supplemental document "Enforcement and monitoring guidelines for Sand mining-2020"

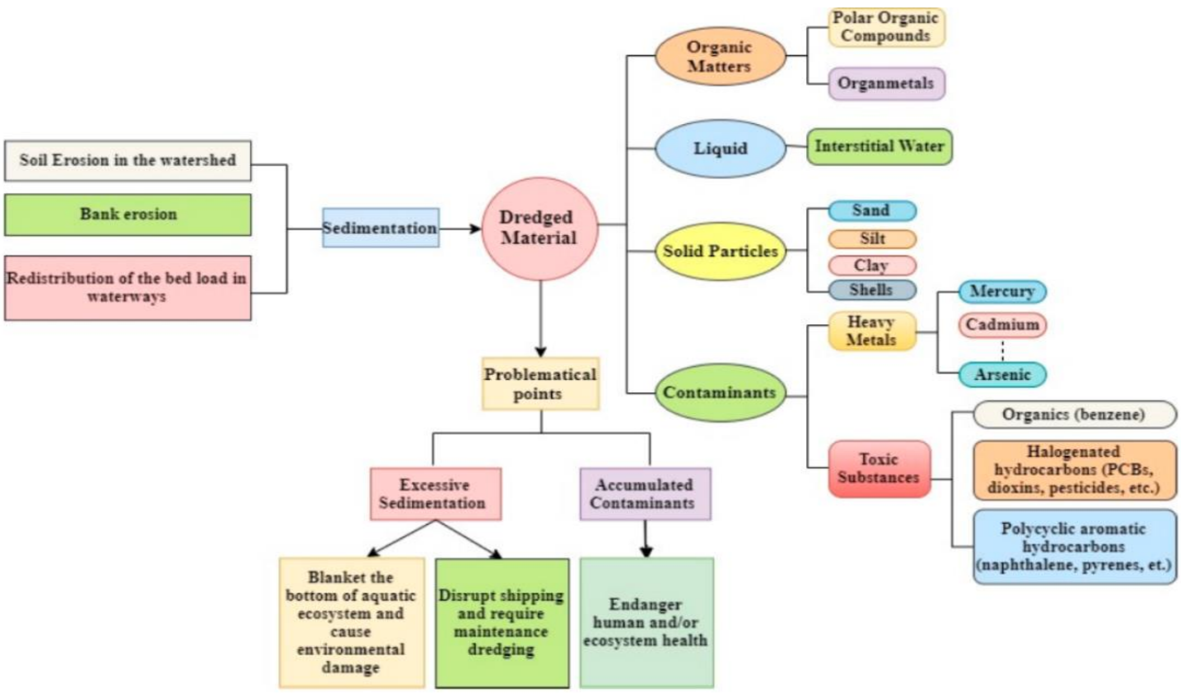

Figure: 1 Dredged material sources, characteristics, and social/ecological

Source: (Solanki et al., 2023)

- Sedimentation in Rivers is due to erosion of riverbanks and upstream areas, various human activities like deforestation, mining, and construction, and increased flow velocity during storms or floods, that results in alteration of riverbed morphology, reduced water quality due to suspended particle, causing navigation challenges for boats and ships
- Sedimentation in Reservoirs is Causes: Sediments transported by inflowing rivers and streams. Soil erosion in upstream watersheds due to agricultural or urban activities. Impacts are reduced reservoir storage capacity over time. Increased risk of flooding.

Impact on dam operations and hydroelectric power generation. Changes in water temperature and quality.

- Sedimentation in watersheds is caused due to surface runoff from agricultural fields, construction sites, and deforested areas, poor land management practices. that impacts the fertility of the soil, loss in upstream areas. Sediment loading in downstream water bodies altering water flow patterns and increasing risk of floods.
- Sedimentation in Lakes is caused because of deposition of sediments carried by inflowing rivers and surface run off. Internal processes like algal blooms and decaying organic matter.
- Reduction in lake depth and volume, leading to "lake aging" or eutrophication. Loss of aquatic habitats. Degradation of water quality, including increased turbidity and nutrient loading

CHAPTER 5 PRINCIPLE OF SEDIMENT MANAGEMENT

5.1 General

The successful management of sedimentation can greatly reduce the loss of reservoir storage capacity, thereby significantly prolonging the lifespan of these water bodies. The benefits associated with effective sedimentation management are extensive.

5.2 Sediment management in reservoirs

1. A well-rounded sediment management strategy, which encompasses measures to lower sediment yield from the watershed, reroute sediments around or through storage facilities, and recover lost reservoir capacity through de-silting, can be effectively employed. For newly established reservoirs, integrated sedimentation management can be incorporated right from the planning stage. In contrast, existing reservoirs may require a holistic approach that combines multiple techniques. It is essential to understand that no single method can ensure complete effectiveness for the long-term sustainability of sediment management.
2. Careful attention must be given to environmental and social safeguards during the planning process. Moreover, a robust institutional framework and sound financing strategies are critical components of a comprehensive sediment management plan.

5.3 Sediment management in lakes and water bodies

1. The significance of lakes and water bodies as habitats and food sources for various fish species, aquatic life, and wildlife cannot be overstated, as they are essential to human existence. These ecosystems are instrumental in regulating river flow, preventing flooding during the rainy season, and ensuring a steady water supply during dry spells. Thus, sediment management in lakes and water bodies is critical for their sustainability.
2. The Ministry of Jal Shakti, Government of India, is actively implementing the "Repair, Renovation & Restoration (RRR) of Water Bodies" initiative, which focuses on the comprehensive enhancement and restoration of water bodies nationwide, in line with the "Guidelines for the scheme on Repair, Renovation and Restoration (RRR) of Water Bodies – 2022."

5.4 Sediment management in rivers

1. Sediment management should become a part of integrated river basin management plan. Regular sediment budgeting for all basins should be done especially which are affected by heavy siltation problem.
2. The removal of sediments from the riverbed can facilitate the channelization of river flow during periods of low water and enhance navigability; however, it is unlikely to have a substantial impact on flood levels. Natural sediment deposition occurs upstream of any barrage, reaching a state of equilibrium after several years.
3. Desiltation upstream of a barrage may be implemented to aid in the channelization of stream flow, but it is crucial to ensure the proper operation of gates to minimize sediment accumulation in the upstream areas of barrages or weirs.
4. Urbanization and infrastructure development, such as the construction of buildings, roads, and embankments, necessitate significant amounts of sediment. The volume of sediment extracted in these instances should be limited to avoid ecological harm to the river or to be utilized beneficially in development projects, whichever is lesser.
5. The exploitable quantity must be determined in advance, and the area should be monitored to prevent excessive extraction practices. It is imperative to approach desiltation and dredging initiatives with great caution, supported by scientific research, including simulations through mathematical and/or physical modelling at appropriate scales, utilizing consistent methodologies relevant to the specific site. However, mathematical and/or physical modelling studies are not required for dredging or desiltation conducted for navigation purposes by the Inland Waterways Authority of India.

CHAPTER 6 SEDIMENT MANAGEMENT OF RIVERS

6.1 General

It is usually recommended to quantify the sediment loading order to identify effectiveness and type of interventions required.

Preventive measures such as erosion control including reforestation, contour farming, watershed management to control sediment input and sediment control such as check dams silt fences to trap sediments and retention pond sand sediment removal techniques including dredging.

6.1.1 Upper Course

In this phase, rivers exhibit steep gradients and possess a significant capacity for sediment transport. The following sediment management strategies may be implemented:

1) **Catchment Area Treatment**

   Effective management of catchment areas and watershed development, in conjunction with sound agricultural practices and measures for riverbank protection and erosion control, is essential to mitigate silt inflow into the river system. This approach should be executed comprehensively. The treatment of catchment areas through a watershed approach is crucial for reducing sedimentation. It is imperative that watershed management programs are appropriately integrated with river basin management initiatives. A reliable and enduring method for sediment control is the implementation of soil conservation practices within the catchment. The strategies to be employed in the catchment may include:

- Afforestation and forest management
- Regarding and management of grasslands
- Agricultural practices such as crop rotation, enhancement of organic matter, mulching, seasonal cover crops, contour cultivation, strip cropping, and terracing.
- Gully control and construction of check dams, including contour bonding and trenching.
- Implementation of suitable land use regulations to safeguard critical areas.
- Various on-farm practices aimed at minimizing soil detachment to decrease silt load may encompass:
- Maintaining grass cover on soil
- Controlling sediment generation through film traps
- Adoption of bio-filter strips, field borders, sediment retention terraces, and ponds.

2) Regrading & Check Dams - The regrading of riverbed slopes and the construction of check dams may be appropriately utilized for managing riverbed degradation based on techno-economic feasibility.
3) Regulated construction activities for roads and residential buildings can also help reduce silt intake in mountainous regions.
4) The occurrence of landslides or landslips, particularly in hilly areas experiencing heavy rainfall, necessitates the implementation of effective slope stability measures.
5) Storage Reservoirs - These reservoirs are designed to store water and incidentally serve as sediment traps.

6.1.2 Middle course

In this stage, the river exits the hills, enters the plains, gets meandered mostly on bed of fine sand, has a wide riverbed and flood plain. Most importantly, the river gets modified through human interventions in terms of huge quantities of water diversion/abstraction and subjected to high degree of pollutant loads from domestic, industrial and agricultural activities. In this stage, following sediments management practices may be adopted: -

- River training works such as bank protection, spurs etc
  River training works are used to control the erosion of riverbanks. Erosion control of riverbank reduces sediments intake in river
- Submerged Vanes
  These methods may be adopted for management focalized aggradations within the river course as per techno-economic feasibility.
- Sand Mining
  In this stage, sand is deposited in the river. If these are mined at this stage and used for construction or other purposes, then a major portion of sediment can be reduced. Sand mining can be done as per the guidelines mentioned above.
- De-siltation/Dredging
  Some locations such as congestion at the mouth of tidal rivers, confluence points and the likes which can be tackled by de-silting after thorough examination. For navigation purpose the river reaches in the waterway path can be dredged, to have minimum required draft for plying vessels. It is necessary to appreciate that de-silting does not always lead to reduction of flood levels as the levels in the river are essentially controlled by the hydraulic conditions persisting at the cross sections forming upstream and downstream boundaries of the reach. The lowering of the bed level within the reach may not have influence on them consequently leading back to drainage problems within the season or within a few years.

6.1.3 Lower course

In this stage, the river experiences considerable changes in the sediment transport and deposition, causes widespread flooding, undergoes frequent changes in the channel path/delta formation.

The following sediments management practices may be adopted: -

- Desiltation/ Dredging
  In this stage, generally delta formation occurs due to heavy siltation, which leads to drainage congestion and the mouth of river gets choked. In these areas, dredging/ de-silting works may be undertaken to maintain flow continuity and ensure sediments transportation to sea.
- River training works wherever possible may be taken up for sediment management

CHAPTER 7 DREDGING

7.1 General

Preventive measures such as erosion control including reforestation, contour farming, watershed management to control sediment input and sediment control such as check dams silt fences to trap sediments and retention ponds and sediment removal techniques including dredging.

Dredging is necessary for the extraction of contaminated sediments, the mining of resources from the sea, and the establishment of marine parks, among other applications. Additionally, dredging may be conducted in rivers or reservoirs for comparable purposes. Dredged material (DM) refers to the substance extracted from the bottoms of waterways. The process of dredging sediments is crucial for ensuring effective navigation and the proper upkeep of harbours, among other facilities (Nguyen et al., 2018).

The sediments that are dredged can be disposed of either on land or in oceanic locations. The management of dredging activities, along with the evaluation and disposal of the dredged materials, is a complex process, as it can negatively affect marine, coastal, or riverine environments and their ecosystems due to alterations in water depth, bottom morphology, or current velocity Additional consequences, including erosion and sedimentation, habitat destruction, and effects on water quality such as heightened turbidity, must also be assessed.

The enforcement of more rigorous environmental standards for the disposal of dredged sediments has significantly limited the options available for both terrestrial and marine disposal, particularly concerning contaminated and toxic sediments. In light of this, the recycling of dredged sediments is increasingly recognized as vital for sustainable dredging management. Proposed applications for this recycling include its use in cement manufacturing, the production of aggregates for concrete, and the creation of concrete for pavement construction. Recycling of dredged sediments has found place for production of ceramic tiles to be used in building industry, for creation of tidal flats, and for beach nourishment

The management of sediments faces significant obstacles due to the high levels of moisture, salt, and organic content present. The selection of an appropriate transportation method, along with the need for large storage facilities—known as confined disposal facilities (CDFs)—where storage, dewatering, desalination, and preconditioning take place, adds to the complexity. Additionally, these sediments are often tainted with heavy metals and polycyclic aromatic hydrocarbons (PAHs) resulting from industrial effluents released into aquatic environments and from the spillage or leakage of petroleum product containers. International conventions (International Maritime Organization 2003; OSPAR 1998) classify such contaminated sediments as unsuitable for offshore disposal, thereby intensifying the challenges associated with their management. Reusing of the sediment requires an in-depth understanding of the characteristics of dredged materials, encompassing their physical, chemical, and mineralogical aspects, as well as geotechnical factors such as shear strength, consolidation, compressibility, and hydraulic conductivity, including any interrelationships among these factors.

Moreover, DS are subjected to diverse natural and artificial environments, ranging from submerged conditions to the unsaturated environments of inland desiccation. This situation underscores the necessity of investigating the impact of these parameters on the geotechnical properties of the sediments to determine their suitability as an artificial resource.

Country / Locations	Period	Description of quantity/volume of dredging sediments (Annually/ periodically)	Sources
India (all ports)	2013–2017	359.6 M m^3	Indian Infrastructure (Dredging), 2019
France, Germany, the Netherlands and United Kingdom		30–50 M m^3 each annually	Harrington et al., 2016
France		174.0 million tonnes	OSPAR, 2017
Netherlands		158.4 million tonnes	OSPAR, 2017
United Kingdom		103.2 million tonnes	OSPAR, 2017
United States		200–500 M m^3	SMED, 2018
United States	2011–2018	2.4 million m^3 annually	Mymrin et al., 2017
Bremen, Germany		600,000 m^3	Kay and Volker, 2002
Brazil		80,313,000 m^3	Brasil, 2009
Atlantic coasts		11.3 million tonnes	CETME, 2012
Mediterranean coasts		2.4 million tonnes	CETME, 2012
Sweden		1.4 M tonnes	CETME, 2012
Belgium	2008–2014	267.2 million tonnes	OSPAR 2017
Germany	2008–2014	228.7 million tonnes	OSPAR 2017
Ports of Paranagru and Antonina in Parana State	2009	3,700,000	IBAMA, 2013; APPA, 2012; 2009
	2011	110,000	IBAMA, 2013; APPA, 2012; 2009
	2013	8,000,000	IBAMA, 2013; APPA, 2012; 2009

Table: 2 Quantity of DS from few countries/locations Source: (Bose and Dhar 2022)

Chemical stabilization of dredged sediments is achieved by combining sediment soil with cement, where the hydration process of the cement leads to the hardening of the soil-cement mixture. Advanced research on dredged soil focuses on optimizing stabilizers and evaluating the hydration effects of additives, with the objective of enhancing soil strength through solidification methods (Azhar et al., 2014).

The accumulation of sediments in aquatic environments poses significant challenges for transportation and shipping activities. The complexities associated with identifying suitable storage locations and disposal techniques render the removal of dredged sediments a considerable issue. In Thailand, approximately one billion cubic meters of soil are dredged annually to facilitate navigation across the nation’s waterways. These sediments are typically disposed of either in the ocean or at designated landfill sites (Kamali et al., 2008).

Depending on the context and intended goals, dredging can be categorized into three prominent types: capital, maintenance, and remediation dredging. Capital dredging is generally a singular operation performed in harbour basins and navigational channels to achieve the necessary depth for ship access. This type of dredging focuses on the extraction of old, uncontaminated sediments and is linked to capital expenditures. (Wahab et al., 2017; Martens et al., 2018)

Environmental dredging, or remediation dredging, serves to adhere to ecological regulations by extracting harmful contaminated sediments. This process ultimately seeks to elevate the quality of water bodies and to restore the health of marine and aquatic ecosystems. (Fan et al., 2019; Liu et al., 2010)

CHAPTER 8 DREDGED SEDIMENT: COMPOSITION, ENVIRONMENTAL IMPACTS AND APPLICATION

8.1 General

An emerging trend focused on the conservation of natural resources, as well as the recycling and reuse of waste, is receiving heightened attention in the context of resource optimization and sustainable development. Comprehensive research studies conducted by various institutes, including Research and Development Centres, have aimed to uncover solutions for the innovation of environmentally sustainable products and materials. At present, sediment materials derived from seas, rivers, channels, and lakes are being recognized as a means to conserve non-renewable resources through the recycling and repurposing of dredged sediments as secondary raw materials in diverse applications, such as backfilling, embankment construction, concrete production, road infrastructure, and many other relevant applications**.** (Miraoui et al., 2012; Lirer et al., 2017; Wang et al., 2018; Baptist et al., 2019).

8.2 Chemical compositions of dredged sediments

The potential uses of DSs for various applications would be possible only after examining the materials' characteristics. Several studies have determined the chemical composition of DSs in the different locations; few of them are presented in the table below:

Table: 3 Composition of Dredged Sediments

Chemical composition (%)	**Slimanou et al., 2019**	**Yoobanpot et al., 2020**	**Slimanou et al., 2020**
SiO_2	46.76	66.20	44.97
Al_2O_3	13.97	19.30	14.17
CaO	17.23	1.01	45.26
MgO	2.63	0.91	2.15
Fe_2O_3	5.3	6.67	4.86
TiO_2			0.69
SO_3	0.39	0.19	
P_2O_5			0.19
Na_2O	1.19	3.98	1.11
MnO			0.03
K_2O	2.23	3.98	2.07

8.3 The disposal and environmental impacts of dredge sediments

Considering the pressing need to lessen negative environmental consequences, the formulation of sustainable approaches for the management of dredged sediments (DSs) has emerged as a critical challenge for scientists, researchers, and those overseeing ports and harbors. This management is essential for the sustainable design and development of dock channels in marine settings. The dredging process poses threats to marine and coastal environments and ecological systems through various means, such as the energy-intensive nature of mechanical dredging, which leads to greenhouse gas emissions, and the noise produced during these operations, which can impair the foraging efficiency of marine mammals**.** (Bianchini et al., 2019; Bolam et al., 2006; Erftemeijer et al.,2012; Manap et al., 2015).

8.4 Use of dredged sediments for various applications

The swift urbanization and development of infrastructure have led to an accelerated increase in waste production, which in turn has rendered the management of waste through appropriate disposal facilities a critical issue. The scarcity of land has resulted in rising costs associated with waste disposal. The uncontrolled disposal of Dredged Sediments (DSs) poses a threat to both environmental and ecological systems. A multitude of research studies has established that recycling and reusing DSs provide significant environmental and economic benefits, playing a vital role in promoting global sustainability. The utilization of DSs through recycling processes is a sustainable method for enhancing natural resource availability, reducing pollution and greenhouse gas emissions, optimizing energy consumption, stimulating economic development, and improving the sustainability of marine ecosystems. Various applications are:

1) Coarse and fine-grained materials
2) Construction and infrastructure development
3) Agriculture, forestry, horticulture, and aquaculture
4) Concrete, aggregates, asphalt, bricks, cement, blocks, tiles and ceramics
5) Highway and railway embankment
6) Geotechnical applications
7) Beach nourishment
8) Coastal Land Management
9) Dams and embankments
10) Biomining projects
11) Land fill Liner, gas vent, leachate drain

CHAPTER 9 DREDGED SEDIMENT CONTAMINATION AND TREATMENT

9.1 General

The predominant contaminants in sediments were heavy metals and organic compounds. The PIANC 2009. PIANC report no 104-2009 “Dredged Material as a Resource: Options and Constraints” reports examined various treatment technologies employed globally, presenting a spectrum of options stating treatment methods include separation, dewatering, thermal immobilization, and bioremediation. The sediment's quality ultimately determines the viability of treatment options. In many instances, the levels of heavy metals and organic contaminants correlate with grain size; generally, finer particles and higher organic matter content indicate a greater potential for contamination.

The in-situ remediation of sediment aims at increasing the stabilization of some metals such as the mobile and the exchangeable fractions, whereas the ex-situ remediation mainly aims at removing those potentially mobile metals, such as the Mn-oxides and the organic matter (OM) fraction. The pH and OM can directly change metals distribution in sediment; however, mainly through changing the pH values, indirectly alters metals distribution.

9.2 The influence of pH and organic matter

The pH level is a significant determinant of heavy metal transfer behaviour in sediment. As sediment pH declines, the competition for ligands such as hydroxide ion carbonate, sulphate, chloride, sulphide, and phosphates between hydrogen ions and dissolved metals becomes increasingly pronounced. This competition results in a decrease in the metals' adsorption capacity and bioavailability, which in turn elevates their mobility. In some cases, a reduction of merely a few pH units can cause the fixation of heavy metals on sediment particles to vary dramatically, ranging from nearly complete retention to almost total release (Gundersen et al., 2003)

The processes of organic matter degradation and acid volatile sulphide oxidation in sediments often lead to a decrease in pH from neutral to acidic, with some cases reaching pH levels as low as 1.2. This alteration in pH can trigger the release of certain metals back into the water, even under conditions where the water remains stable. (Kraus et al.,2006)

Therefore, under similar pH value, the potential mobility of heavy metals in sediment is different significantly. For example, when pH was controlled at 4.0, the potential mobility of metal decrease as follows: Zn > Cd > Ni > As > Cu > Pb (Verhulst et al.,2004)

In natural rivers or lakes, Organic Matter is mainly composed of humic and fulvic substances. The complexation reaction between heavy metals and organic complex ants is usually recognized as the most important reaction pathway, due to this reaction determining, to a large extent, the speciation and bioavailability of metal, and then influencing the mobility of trace metal in natural water environment. However, in severely polluted river, due to the complexity of organic matter, the reaction types between organic complexes and metals are difficult to predict. In most conditions, precipitation, coprecipitation or flocculation usually plays the most important role in heavy metal fixation.

Sedimentary organic compounds, which are frequently abundant in particulate form, play a vital role in the transformation processes of heavy metals. In the sediments of certain rivers and lakes, the proportion of heavy metals that are bound to organic matter usually represents the largest fraction. Additionally, the solubility of organic matter within sediment directly impacts the mobility of heavy metals. Typically, the complexation of metal ions with insoluble organic compounds can markedly decrease their mobility, whereas the formation of soluble metal complexes with dissolved organic matter tends to enhance their mobility. (Hassan at el., 1999)

9.3 The influence of some other factors

Beyond pH, organic matter (OM), additional factors such as temperature, salinity, metal species, and retention time play crucial roles in determining the distribution of heavy metals within sediment. For example, the differing cation exchange capacities of various metals result in distinct mobility patterns, generally ranked as follows: Cs > Zn > Cd > Fe > Ag > Co > Mn. As temperature increases, there is often a gradual decrease in the adsorption of heavy metals onto sediment. Similarly, higher salinity levels in pore water led to a decrease in the overall adsorption of heavy metals, primarily due to competition with other cations. Furthermore, kinetic adsorption-desorption experiments conducted over extended periods reveal that metals that are newly associated with sediment particles tend to be less stable and possess a higher potential for bioavailability compared to those that have been associated for longer durations. (Pennock et al., 1998) (Benyahya et al.,2006)

9.4 Remediation techniques

A two-tiered remediation strategy, like that used in soil remediation, has been adopted for the treatment of heavy metal-contaminated sediment. The first tier focuses on in situ methods to improve the stabilization of metals on sediment particles, such as immobilization, while the second tier involves ex situ techniques for the extraction or separation of metals from the sediment, utilizing methods like washing and flotation. (Sánchez et al.,2005)

9.4.1 In-situ remediation

1. Stabilization and Immobilization: In situ techniques aim to stabilize heavy metals within the sediment, reducing their mobility and bioavailability. Methods such as capping, electro kinetic remediation, and bioremediation are commonly used due to their cost-effectiveness and minimal disturbance to the environment.

2. Biological Methods: Techniques like Phyto stabilization and microorganism immobilization are gaining attention for their low cost and environmental compatibility. These methods utilize plants and microbes to immobilize heavy metals, reducing their mobility

9.4.2 Ex-situ remediation

1. Sediment Washing and Chemical Extraction: These methods involve the physical removal of contaminated sediments and their treatment outside the original location. Techniques such as sediment washing and chemical extraction are effective in removing heavy metals but can be costly and require significant infrastructure

2. Solidification/Stabilization: This involves mixing sediments with binding agents to immobilize heavy metals. While effective, it requires careful monitoring to prevent reversibility and is often used when other methods are not feasible

9.4.3 Emerging technologies

1. Ligand-Coated Nano particles: This novel approach uses engineered nano particles to sequester heavy metals, reducing their bioavailability. It offers a fast and efficient in-situ solution, though it is still in the development phase.

2. Bioleaching: Utilizing microbes to generate acids that solubilize heavy metals, bioleaching is a promising technique for practical application, especially in solid-bed configurations.

9.4.4 Factors influencing remediation choice

1. Site Characteristics: The choice of remediation technique depends on factors such as sediment type, contamination level, and site-specific conditions. In situ methods are generally preferred for slight pollution, while ex situ methods are considered for more severe contamination

2. Cost and Environmental Impact: In situ methods are often more cost-effective and environmentally friendly, whereas ex situ methods, while potentially more thorough, can be expensive and disruptive.

CHAPTER 10 RECYCLING DREDGED SEDIMENTS

Sustainable Development as stated in CEDA (Central Dredging Association) the quality of dredged material is indicative of the environment from which it originates and may be affected by contamination from both local and remote sources. While the presence of contaminants does not preclude its application, it necessitates careful consideration during the selection process. Prior to utilization, it may be essential to treat dredged material to stabilize or eliminate contaminants, which could lead to increased costs and extended handling times

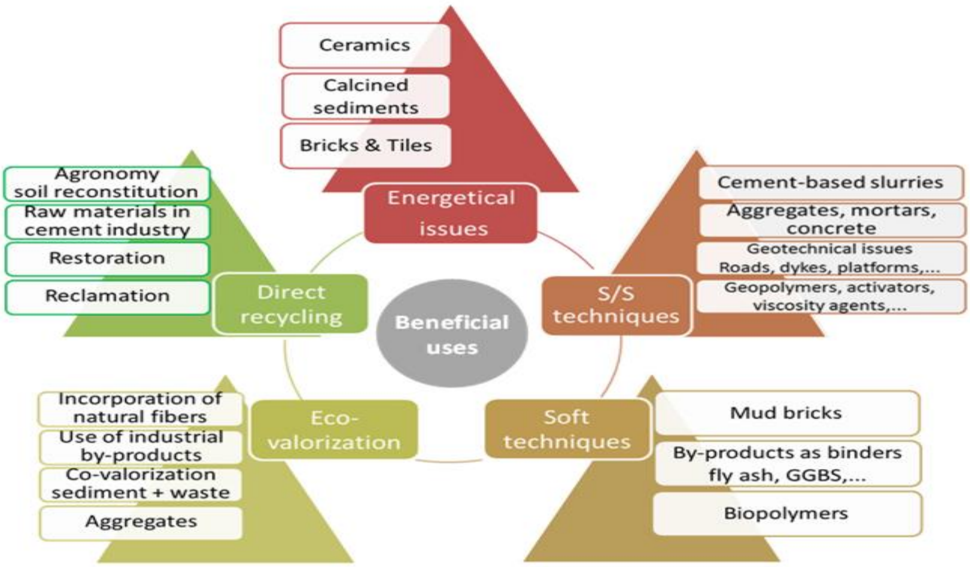

Figure: 2 Potential recycling options for dredged sediments, Source: (Hussan et al.,2022)

10.1 Sediments for pavement construction

The methods of treatment are designed to enhance the inadequate engineering properties of dredged materials, ensuring they meet the requirements for specific applications. The improvement in strength and other attributes is contingent upon the sediments' capacity to interact with the components of pozzolana. Each processing technique varies according to its intended purpose and the chemical reactions involved. Typically, solidification methods employed for challenging sediments aim to reduce their water content. A granular additive, composed of 35% dredging sand from Dunkerque harbour and 65% quarry sand from Boulonnais, combined with twice the quantity of dry fine sediment, can effectively lower the water content. Additionally, this approach can mitigate the impact of organic content on strength development. To reinforce the granular skeleton, lime and cement should be utilized in proportions consistent with AASHTO guidelines (Dubois *et al.*, 2011).

The sediment exhibited around seven percent organic matter, which classifies it as moderately organic. According to the Unified Soil Classification System, it is categorized as OH, making it inappropriate for road construction due to its vulnerability to changes in water content and its compressibility.

The presence of salts, heavy metals, and organic materials in contaminated Dredged materials (DM) can result in the corrosion of reinforcement and chloride attack when reused directly in construction. (Jaesung, *et al.*, 2016) Consequently, it is essential to implement appropriate treatment methods, such as the stabilization of heavy metals and thermal elimination of organic substances, prior to their application in construction or other advantageous uses

An investigation was recently undertaken to assess the mechanical and durability properties of concrete designed for harbour pavement, incorporating dredged marine sand as a partial replacement for standard raw sand Dredged marine sand obtained from the port of Barcelona was used to replace 15% to 50% fine aggregate was able to demonstrate a 14% increase in the strength of the material when they used a 50% replacement of materials**)**. Negligible contaminant content along with excess chloride content was reported. (Limeira *et al.*, 2011)

10.2 Contaminated sediment in cement production

Contaminated sediments sourced from the New York/New Jersey Harbor were utilized as a partial replacement (3-6%) for the raw feedstock in the production of conventional Portland cement. It was anticipated that during the cement manufacturing process, which involves a residence time of 20 to 30 minutes at approximately 1450°C, organic contaminants would undergo degradation while inorganic contaminants would be stabilized, either by being incorporated into cement phases or forming part of the cement kiln dust. This approach, leveraging existing facilities, offered a viable solution for managing significant quantities of dredged material while simultaneously decreasing the demand for raw materials in cement production. This was validated through both bench and pilot-scale experiments. The fine dredged material underwent oven drying at 60°C and was processed to break down clumps into its original particle size. Oversized particles, including shells and larger sand grains, were removed through sieving, preparing the sediments for integration with the feedstock. Notably, the chloride content of the final product remained unaffected by the high chloride levels present in the dredged material, although this aspect continues to be a practical consideration in manufacturing. Key factors influencing the cost of this process include the transportation of sediments to the cement plant, the removal and disposal of debris, sediment dewatering (if necessary), on-site material transfer and storage, modifications to the kiln for the introduction of sediments at the hot end, and additional operating costs associated with kiln cleaning. (Dalton et al., 2004)

10.3 Re-use of sediments as partial replacement of cement in concrete production

A further study was performed to investigate the feasibility of using reservoir sediment as a partial replacement (up to 40%) for cement in concrete production (Junakova and Junak, 2017). The results revealed that the development of concrete strength was delayed due to the incorporation of sediments, with strength reaching 80% at 28 days and 86% at 90 days for a 40% replacement of cement. The conclusion drawn was that diligent monitoring is required when employing reservoir sediment as a binder in concrete formulations.

The combination of iron tailing slag, calcium carbide slag, and cement utilized for backfilling achieved a compressive strength of 2.9 MPa following seven days of curing. The introduction of Portland cement resulted in a decrease in slump, whereas iron tailing slag was found to enhance slump values, which signifies greater workability. Additionally, it was observed that substituting up to 20% of the cement with calcium carbide slag led to an improvement in strength. The concrete slump test is employed to evaluate the consistency of fresh concrete before it hardens, providing insights into the workability and fluidity of the concrete mix. (Chengfu *et al.*,2018)

Phosphoric acid (H_3PO_4) was used to treat heavy metals by converting them into metal phosphate, followed by calcination at 650°C to remove organic content. Phosphatation also reduced water content from 135% to 5%, which reduced the cost of transportation and helped in the valorisation of DM. Further, different concentrations of phosphoric acid gave approximately the same results, (Dia Moussa *et al.*,2014)

This paper investigated the compressibility and shear strength of dredged cohesive sediment, focusing on the impact of composition variations, including sand and organic matter content. The study uses incremental loading oedometer tests and fall cone tests to analyse the mechanical behaviour of the sediment. The results show that the transitional fines content (TFC) plays a crucial role in determining the behaviour of the sediment, with organic matter oxidation significantly affecting compressibility and shear strength. The study also applies power law constitutive equations to describe the sediment's mechanical response to external stresses. (Winterwerp *et al.*,2022)

The advancement of technology aimed at extracting valuable materials from contaminated discarded substances presents a viable alternative to using virgin resources. This approach has the potential to conserve energy, enhance resource efficiency, lower emissions, and support the principles of a circular economy. Selecting the appropriate recycling method for discarded substances is crucial from economic, environmental, and sustainability viewpoints, particularly in the context of a circular economy. As technology continues to evolve, recycling discarded substances may become increasingly lucrative, especially considering dwindling resources and the anticipated rise in the cost of such materials**.** (Noren et al.,2020; Peruzzi et al., 2020).

CHAPTER 11 ZERO WASTE CONCEPTS

The dredging process generates a large volume of DS annually. The DSs can be converted into value-added products with less effort and resources. The circular model of DS can compensate for all resources, energy, and GHG through the circular economy route; a clear policy framework and regulation can increase the rate of utilization of DS. While forming the policy, framework, and rules for enhancing the utilization facilities of DS, the following barriers need to be considered.

1. Lack of initiative between government and private agency for processing DS to a valuable resource/product.
2. Lack of proper policy framework/amendment of existing policies/formation of the new approach to deal with DS.
3. Bridging the gap between industry and government.
4. Government should make policy regarding sustainability context in respect of DS utilization.
5. To make realize that DS is wealth.
6. Policy formation for circular economy instead of the linear economy
7. Lack of adequate and attractive scheme for the entrepreneur who can open the startup for utilization of DS.
8. Policy and government Intervention should be in the context as scheme of incentives, tax exemption, credit facilities, and flexible licensing system towards managing DS.
9. Dedicated data bank hub necessary for accountability of natural resources in the country such as analysis demand and supply in constructions, Infrastructure sector, and other areas
10. Policy correlation within DS utilization, sustainable development, and mitigate of climate change

CHAPTER 12 CONCLUSION

Globally, the conservation of non-renewable resources and the recycling of waste materials are receiving significant attention. In this regard, extensive research efforts are dedicated to identifying methods for the reuse and recycling of various waste materials. Among these, dredged sediments represent a valuable resource with the potential to mitigate the depletion of natural resources by serving as secondary raw materials in diverse applications.

Dredging sediments is a critical and routine operation for ports and harbours, essential for maintaining sustainable navigation systems in marine and river environments. However, the ongoing accumulation of contaminated dredged sediments poses risks to the environment, ecology, and marine ecosystems.

Effectively managing the dredging process and the sediments produced is crucial for the health of marine and river ecosystems. Advancements in technology aimed at recycling dredged sediments into secondary raw materials can help supplement natural resources, provide a practical solution to environmental pollution, address land scarcity for waste disposal, and partially fulfill the demand for resources.

The construction industry is experiencing significant growth, with concrete emerging as a favoured material across various applications, such as pavement, cost-effective building projects, and underground construction. The increasing production of concrete necessitates a greater demand for raw materials, particularly for cement and aggregates. Additionally, habitat restoration and the creation of tidal flats require substantial amounts of sand and fine aggregates prompting to the exploration of sustainable alternatives for concrete raw materials, including the recycling and repurposing of sediments derived from dredging activities.

In recent years, there has been mounting opposition to the ocean dumping of sediments due to environmental concerns. Onshore disposal options are constrained by economic factors, land scarcity, and associated environmental issues. Regulations regarding contaminated or hazardous sediments necessitate that these materials be rendered inert prior to disposal, further increasing costs. Various strategies have been developed to recycle and reuse dredged sediments from coastal areas, reservoirs, lakes, ports, and harbours within the construction sector. Key considerations for these initiatives include economic feasibility, technological practicality, environmental implications, regulatory compliance, and community support.

Sediments have been utilized in the production of concrete for pavements, lightweight aggregates for lightweight concrete, cement masonry units, beach nourishment, land reclamation, and coastal defence projects. The primary contaminants found in sediments include heavy metals and organic compounds, which must be treated appropriately to ensure that the final product meets environmental standards.

It has indicated the potential for utilizing dredged sediments from eutrophic reservoirs as a feedstock for biodiesel production. This possibility requires further exploration, as it could not only alleviate disposal issues but also provide an alternative feedstock for biodiesel, thereby reducing reliance on fossil fuels. Soon, a widespread implementation of recycling and reuse strategies is expected to enhance sustainability efforts. Additionally, a novel approach involves co-composting dredged sediments with green waste, which can then be utilized as a medium for plant growth. Studies have highlighted that the impact assessment of dredged material disposal involves multiple factors that regulatory bodies need to identify, underscoring the necessity for policy guidelines to ensure the assessment system's efficiency.

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