

Review Article

Disposal of Sediments for Sustainability: A Review

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Abstract: In the coastal areas, dredging operations are undertaken for creation, draft enhancement and maintenance of navigable channels for port and harbor activities. Dredging may also be performed in rivers or reservoirs for similar reasons. The dredged sediments may be disposed at on-land or oceanic sites. In the recent years, inexpensive ocean dumping is being eliminated as a disposal alternative, causing a crisis in the management of sediment. In construction industry, production of concrete creates heavy demand on the supply of raw materials for cement and also aggregates for concrete. In many locations, habitat restoration and tidal flat creation also generates demand of fine aggregates. It has been observed that at several sites, supply from quarry is not always an economic and feasible option. Sustainable solution to both the aforementioned problems is re-using the sediments from river and ocean in construction industry or bio-diesel production. Various applications attempted in construction industry include those for production of cement, as fine aggregate in concrete, in construction of pavements, in production of light-weight concrete, among others. This article presents a review of approaches employed to recycle dredged sediments in construction industry and biodiesel production.

Keywords: Recycle, Cement, Concrete, Pavement, Sustainability

1. Introduction

In construction industry, concrete and steel are the main materials which are extensively used. Steel is produced in factory from ores, with limited recycling options. Comparatively, concrete production is more distributed with batching plants coming up around places of developmental activity. Concrete is heterogeneous mixture, requiring coarse and fine aggregate, cement and water as main ingredients, with admixtures and pozzolonas as additional options. Over the years, some locations have faced rising problems of raw materials for cement production and also of aggregates for concrete production due to limitations of supply from quarries. This has generated renewed interest in use of recycled materials for production of cement and concrete. Along with the economics of the process, the scarcity of the raw materials is addressed by these recycling schemes. Furthermore, recycling fosters the environment-friendly and sustainable practices.

In the coastal areas, dredging operations are undertaken for creation, draft enhancement and maintenance of navigable

channels for port and harbor activities. Dredging would be required for removal of contaminated sediments, for mining from sea, and for creation of marine parks, among others. Dredging may also be performed in rivers or reservoirs for similar reasons. The dredged sediments may be disposed at on-land or oceanic sites. Management of dredging operations, as well as assessment and disposal of dredged material is an involved process as it may have an adverse impact on the marine, coastal or fluvial environment and the ecosystems due to changes in water depths, bottom morphology, or current velocity. Other consequences like erosion and sedimentation, the destruction of habitats, and impact on water quality such as increased turbidity also have to be evaluated. Significant issues like accumulation within fishery resources have to be considered for toxic and hazardous sediments. The scheme of sediment management has to be performed under the framework of local regulations pertaining to coastal zone management and land-use. Economic viability of the sediment management scheme and the time frame of evaluation and

implementation are other important considerations. Due to stricter environmental norms governing the disposal of dredged sediments, on-land or oceanic disposal options are getting limited, particularly for the contaminated and toxic sediments. Thus, for sustainable dredging management, recycling of dredged sediments is gaining importance with passing days.

Recycling of dredged sediments has been suggested in cement production, in production of aggregates for use in concrete, in concrete production including that for pavement construction. In addition to cement and concrete production, recycling of dredged sediments has been considered for production of ceramic tiles to be used in building industry, for creation of tidal flats, and for beach nourishment. This paper aims to present a state of the art review of several approaches by which dredged sediments have been proposed to be used in construction industry. After this introduction, the issues regarding disposal of sediments are discussed in section 2. The considerations for re-use of dredged sediments in construction are elaborated in section 3. This is followed by review of literature concerning recycling of non-contaminated sediment in section 4, and that of contaminated sediments in section 5. Section 6 contains discussion regarding the environmental impact assessment of the disposal option chosen and the concluding remarks is presented in section 7, followed by list of references.

2. Issues Regarding Disposal of Sediments

Traditionally, disposal of dredged sediments were performed in deeper ocean, which was convenient and cost-effective option. Later, with growing concerns over the marine environment, ecology and habitat, land disposal options were also adopted in some cases. The different issues relating to the two approaches are discussed below.

2.1. Oceanic Disposal

Dredging, as well as disposal of the dredged sediments, creates disturbances in water which may lead to adverse impact on the marine, coastal or fluvial environment and the ecosystems. The possible reasons behind such changes could be variations in water depths, bottom morphology, or current velocity. Both dredging and disposal of dredged materials may cause erosion in some area and sedimentation on the other, and thus may defeat the purpose. Another factor to be given consideration is the possible destruction of habitats due to either of the activities. There may be undesirable impact on water quality such as increased turbidity and these also need to be evaluated and addressed. If toxic or hazardous sediments are disposed, issues like accumulation within fishery resources have to be considered seriously. The scheme of sediment management has to be performed under the framework of local regulations pertaining to coastal zone management and land-use. Economic viability of the sediment management scheme and the time frame of evaluation and

implementation are other important considerations. Due to stricter environmental norms governing the disposal of dredged sediments, oceanic disposal options are getting limited, particularly for the contaminated and toxic sediments.

2.2. On-land Disposal

In case of disposal on land, first of all, it becomes difficult to identify suitable landfill sites. The local land planning and land use regulations have to be adhered to. Consideration has to be given for the effect of the disposal operation on the local ecosystem. Like in case of marine disposal, in case of contaminated or toxic sediments, regulatory requirement is that they should be made inert before disposal. Additional studies would be required to establish confidence that the disposal would not have any adverse environmental effects. This also would depend on the nature and degree of contamination. The groundwater may get affected over a longer run by the process of leaching of contaminants with infiltration of precipitation. The local vegetation and the possible effects on them due to the disposal have to be evaluated. Due to scarcity of landfill sites near to the dredging locations and the environmental regulations, on-land disposal is also getting difficult. Furthermore, as the contamination of the sediments increases, so does the costs of treatment of the sediments before disposal, rendering the process economically unviable.

3. Considerations for Re-use of Sediments

The geological origin of the marine aggregates is reported to be similar to that of the quarry aggregates. The main difference between them arises from the presence of salts, shells and possible organic matter in the marine aggregates.

3.1. Grain Size Distribution

For use of the dredged sediments as aggregates in building industry, the grain size distribution should be similar to the quarry aggregates which are traditionally used. Furthermore, small sized grains in the sediments signify higher degree of contamination. The flakiness index and elongation index would also have to be checked for suitability.

3.2. Mechanical Properties

The mechanical properties of the sediments should be matching with the requirements for the intended use. For use as aggregates in concrete production, compressive strength would be an important consideration. California bearing ratio (CBR), impact resistance and abrasion resistance would be the considerations if the sediments are to be used in pavement construction. Other properties of interest may be the tensile strength, and Young's modulus, among others.

3.3. Durability Concerns

Depending upon the end use, the concrete or other forms in which sediments are re-used would have to be tested for the durability required for the intended use. A pressing concern in

concrete is that of corrosion of reinforcement, and this may be triggered or enhanced by the presence of chloride, salt, and organic matter in the sediments. This could also lead to increased permeability of concrete, which aggravates the corrosion problem further. For use in areas where sub-zero temperatures are experienced, resistance of the concrete prepared with sediments to freezing and thawing cycles will have to be estimated and concrete should not lose strength when undergoing freeze-thaw cycles. For this purpose, several properties are evaluated, before and after freeze-thaw cycles. Some of the indicative properties are unconfined compressive strength, water content, dry density, CBR index, swelling of samples on immersion, among others.

3.4. Environmental Issues Including Contamination in Sediments

Sediments, when they are re-used, should be inert over the time span of re-use and should be non-dangerous according to the prevalent national/international norms and guidelines. This especially gains significance in case of re-use of hazardous or contaminated waste. Depending upon the degree of contamination and intended use, the sediments may have to be treated before application. This may involve detoxification, immobilization and encapsulation of heavy metals. Various tests are employed to assess the environmental impact of the contaminated and hazardous sediments. Some of them are constant pH leaching test, the Toxicity Characterization Leaching Procedure (TCLP) and the Synthetic Precipitation Leaching Procedure (SPLP), among others.

It is reported that the smaller sized sediments are more contaminated compared to the larger sized ones. In case of sediment contaminated with organic matter, cement hydration may be affected. The presence of acid compounds, like fuming acid, can slow down the rise of pH, thus affecting pozzolanic reactions. It is also reported that during hydration of the cement paste, organo-mineral complex, commonly found in organic soils, release organic matter with increasing pH. The released organic matter reacts with the calcium ions, preventing them from forming hydrates. These would have to be considered for use of sediments as aggregates in concrete.

3.5. Economic Considerations

Another important issue to be evaluated is the economics of the re-use. The cost of other disposal option and the cost of supplying the sediment at the point of use would be compared and weighed against the ecological impact of disposal.

3.6. Thermal Expansion of the Sediment

For production of synthetic lightweight aggregates, thermal expansion properties of the material are very important. When the material is heated to the point of incipient fusion, gases must be formed. As the material calcines, the resulting glass should be of sufficient viscosity to trap the gases thus formed.

4. Recycling of Non-contaminated Sediment

4.1. Sediments for Pavement Construction

In a study in France, the physical and mechanical properties of the marine sediment dredged from Dunkirk Harbour, France, were determined and the design mixes suitable for pavement base material were developed (Dubois *et al.*, 2009) [1]. The sediment contained around seven percent organic matter and was considered as moderately organic. According to the Unified Soil Classification System, the sediment corresponded to the OH classification, and is unsuitable for road construction due to its sensitivity to water content and its compressibility.

The proposed method consisted of dewatering the fine sediments by decantation and improving the granular distribution by adding dredged sand. The initial decantation of fine sediments was done to reduce dissolved salts in the pore water. Addition of dredged sand enhanced the granular distribution and the bearing capacity of the dredged sediments improved. It also reduced the amount of binders needed to meet the performance prescribed for the targeted use in pavement base. In the study, the amount of binders added to the proposed mixes was comparable to the amount used in standard materials.

The environmental impacts of the suggested re-use were evaluated with leaching tests. It was mentioned that the values of chlorides and the soluble fractions obtained classified the proposed lime-mix as non-dangerous material and the sulphate contents conformed to specifications for inert waste. It was reported that the mix could be used as road material according to French regulations.

A recent investigation was conducted for the mechanical and durability properties of concrete for harbor pavement, in which dredged marine sand has been used as partial replacement of the raw sand (Limeira *et al.*, 2011) [2]. The sediment was obtained from the port of Barcelona. The sediment showed an angular shape and lower porosity than crushed limestone sand. Negligible contaminant content along with excess chloride content was reported.

Fresh concrete properties like dry consistency and workability were found to be similar to that of control mix. Slight increase in the density was observed in concrete with sediments. However, other physical and mechanical properties of hardened concrete were similar to the control mix. While flexural resistance requirement was fulfilled, the sediments slightly increased the abrasion resistance of the hardened concrete.

It was reported that use of sediments reduced or maintained the accessible pores, sorptivity and water penetration depth under pressure and these met the standards for use in marine environment. The ultrasonic pulse velocity of hardened concrete was slightly higher than control mix, and this was attributed to the slight enhancement of the paste by use of the sediments in substitution of coarse aggregates, and consequently, less porosity.

From the results of the various tests conducted on the concrete, appropriate behavior of the concrete on short term was obtained compared to the reference mix. Good quality concrete of design strength of 30 MPa was achieved. The study indicated that dredged marine sand may be successfully used as partial replacement of the fine aggregate for concrete production.

A large Research European Interreg IVA Program called “Sustainable Environmental Treatment and Reuse of Marine Sediment” was running in order to better understand the Channel sediment characteristics and to develop and promote sustainable management practices for marine sediments (Maherzi and Abdelghani, 2014) [3]. Physical and geotechnical characterization of different sediments sampled from different French ports were carried out which revealed that the sediments had a great initial water content and classification was fine and plastic materials with low to high organic matter content. Accounting for the inherent variability in the properties of the sediments, their reuse as pavement sub-grade layer was explored.

4.2. Sediments for Light Weight Aggregate

On the basis of specific gravity or bulk density, aggregates may be classified as lightweight, normal-weight and heavy-weight. Heavy-weight aggregates, as produced from haematite ores, are used in heavy density concrete, which find application in radiation shielding. Lightweight aggregates, as generated from pumice, scoria, tuff and other volcanic origin rocks, are applied in production of lightweight aggregate concrete which would have structural application. Additionally, they may be used in concrete masonry, geotechnical fills, horticulture and soil improvement, concrete wall board, roof tile, among others. Lightweight aggregates may also be of synthetic origin. A study was performed on production of synthetic lightweight aggregates from sediments dredged from the Shihmen Reservoir in Taiwan (Tang *et al.*, 2011) [4]. According to the Unified Soil Classification System, the sediment was inorganic clay of low to medium plasticity and was found to be non-hazardous by toxicity characteristic leaching procedure.

After dredging of the fine reservoir sediment, it was hauled, air-dried, and crushed. This was followed by sieving, graining, and sintering into lightweight aggregate, which was found suitable for structural and non-structural concrete applications. Properties of the manufactured lightweight aggregates were tested and compared with commercially available ones. Additionally, the engineering properties of the concrete prepared with fine and coarse aggregates, and cement, and concrete masonry units made from the fine and coarse aggregates, cement and blast furnace slag were tested and examined.

The concrete was found to have good workability with slump of 130 to 230 mm and density was around 17 kN/m³. The 28 day compressive strength varied between 20 and 35 MPa, which was acceptable by the standards. The bulk density of the concrete masonry units was less than 19 kN/m³ and compressive strength ranged between 8 to 15 MPa, which

were also complying with the standards. Water absorption of these units was found to be significantly lower (0.05 to 0.13 g/cm³ as against standard of maximum 0.45 g/m³), thus implying good durability too. It was concluded that the fine reservoir sediment could be utilized in production of lightweight aggregate.

Dredged sediments were utilized to produce non-sintered lightweight aggregates by a novel technique (Peng *et al.*, 2017) [5]. The different properties such as physical properties, mechanical strengths, water resistance, harsh environment resistance, and microstructure were investigated for evaluation of the aggregates produced. The conclusion was that while using dredged sediment as raw material for producing non-sintered light weight aggregates in concrete pouring, a stable shell layer was extremely essential to protect them from crushing or being hydrated.

4.3. Re-use of Sediments as Partial Replacement of Cement in Concrete Production

Another study was conducted for utilization of reservoir sediment as partial replacement (up to 40%) of cement in production of concrete (Junakova and Junak, 2017) [6]. The development of strength of concrete was delayed due to use of sediments, reaching 80% at 28 days and 86% at 90 days for 40% replacement of cement. It was concluded that careful monitoring would be required while using reservoir sediment as binder in concrete.

4.4. Sediments for Brick Production

Using 50% to 60% of mass of sediments dredged from sea, bricks of composite material were produced in a study for Brazilian seaports (Mymrin *et al.*, 2017) [7]. The composite blocks met the stipulated Brazilian norms for the conventional bricks. Thus technically, economically and environmentally attractive option of disposal of marine sediments as well as production of building blocks could be performed.

4.5. Other Options for Re-use of Sediments

The dredged sediments may be used in beach replenishment, land reclamation, and coastal defenses. An experiment was conducted to test such strategy for Westerschelde estuary (Van der Wal *et al.*, 2011) [8]. Clean sand dredged from the navigation channel was deposited seawards of an eroding tidal flat to modify the morphology and hydrodynamics. After five years of intensive monitoring, it was found that the tidal and sub-tidal area was improving and moving towards the sea. Sand in the impact zone was found to become finer after disposal. Despite morphological success and absence of negative ecological impacts, unfortunately, new habitats were not created. Possible causes might be dynamic environment of the chosen site, the associated poor macro-faunal community with low biomass, among others.

Solidified sea bottom sediments, when dredged, normally gives off horrible smell. A study was conducted with solidified sea bottom sediments for the construction of an artificial tidal flat in Ago Bay, Japan (Dabwan *et al.*, 2017) [9]. In-situ

solidification system for the treatment of sea bottom sediments, the “Hi-Biah-System” was developed and the dredged sediments were thus first treated. The various factors monitored included the environmental conditions, acid volatile sulphide, loss on ignition, water content, chemical oxygen demand, total organic carbon, total nitrogen, chlorophyll A and particle size. These were monitored in the constructed tidal flat, along with the benthos individuals and the clams and were found to be similar to the natural tidal flats. Further, the use of solidified sea bottom sediments as soil parent material in the germination/growth of seagrass was successfully explored. It was concluded that the treated solidified sediments obtained using aforementioned system, added with soil conditioner and hardener seems to

be effective for the germination of seagrass. A mixture of solidified sediments and the sand by weight ration was fixed at 70:30.

5. Recycling of Contaminated Sediments

5.1. Hazardous Sediments for Building Materials

A study demonstrated the vitrification and production of ceramic materials from sediment excavated from the Venice lagoon (Bernstein *et al.*, 2002) [10]. The sediment was classified as toxic waste due to the presence of several heavy metal ions (mainly, Zn and Pb) and also organic pollutants, making disposal expensive. During the vitrification process, the organic portion is destroyed while the inorganic one is immobilized in chemically bonded to the highly durable glass network. The advantages of this disposal method are process flexibility in which several topologies of waste may be treated, volume reduction, and process cost, which can be less than landfill disposal. Over and above, the scheme is ecologically attractive, thus making vitrification a popular choice for hazardous waste disposal.

With systematic use of glass cullet correction (~20%) in the large scale sediment treatment, chemical durability and stability could be achieved. The sintered glass ceramic exhibited bending strength of around 150 MPa, Vickers micro-hardness of 7.5 GPa with densification time of 3 hours. The mechanical properties of the final glass ceramic were in the range of traditional construction material and thus, could be used in building industry. The final cost of the entire process was reported as competitive with respect of other inertization process and also sediment landfill disposal cost.

5.2. Contaminated Sediment in Cement Production

Contaminated sediments from New York / New Jersey Harbour were used as partial (3 – 6%) replacement of the raw feedstock in conventional Portland cement manufacture (Dalton *et al.*, 2004) [11]. It was expected that during the cement manufacturing process, with a resident time of 20-30 minutes in high temperature of around 1450°C, the organic contaminants would get degraded and the inorganic ones would be stabilized – either locked into cement phases or be in cement kiln dust. Using existing facilities, the method

promised management of considerable amount of dredged material while reducing the cement manufacturer’s demand on raw materials. This was demonstrated with bench and pilot scale plants.

The fine dredged material was oven dried at 60°C and was broken down from clumps to its original particle size. Sieving removed the oversized particles including shells and large sand particles. Then, the sediments were ready for mixing with the feedstock. The chloride content of the final product was not affected by the high chloride content of the dredged material, although it remains a practical manufacturing consideration.

The crucial factors governing the cost of the process are transportation of the sediment to the cement plant, debris removal and disposal, sediment dewatering (if needed), material transfer and storage on site, kiln modifications for introduction of sediments at the hot end of the kiln, and incremental operating costs for kiln cleaning.

5.3. Contaminated Sediments as Aggregates

A recent study evaluated the environmental impact of contaminated sediments when used as aggregates in hot mix asphalt for road construction (Pinto *et al.*, 2011) [12]. The petroleum contaminated sediment from Indiana Harbor Canal (IHC) was identified as toxic and highly contaminated. The contaminants ranged from heavy metals (Hg, Cd, Cr, Pb), to organic compounds like polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC), polychlorinated biphenyls (PCB). Several VOCs and PAHs may have carcinogenic and mutagenic effects and are priority pollutants in U.S. Environmental Protection Agency (EPA). Disposal in landfills of such pollutants pose problems.

Hot Mix Asphalt (HMA) had been used as common form of pavement construction in the U.S. The processes of incineration, oxidation, volatilization, dilution and solidification, which occur when contaminated soil is used in HMA as constituent, are beneficial in trapping the contaminants and preventing their migration to the environment. The control mix was with 0% sediment and the best mix was with 10% sediment. The constant pH leaching test, the Toxicity Characterization Leaching Procedure (TCLP) and the Synthetic Precipitation Leaching Procedure (SPLP) were applied to assess the environmental impact.

Both TCLP and SPLP indicated that the release of metals, PAHs, and VOCs present in the sediments to the environment were not significant either under a co-disposal scenario with municipal solid waste, or under rainfall influence. It was concluded that the dewatered sediment from the IHC could be used for partial replacement of aggregates in HMA for construction of pavements and the process would be potentially considered environmentally safe. Furthermore, it was suggested that further studies for optimization of the HMA composition, sediment dewatering, and manufacturing process may be conducted and HMA may be one effective disposal alternate for petroleum contaminated sediments.

Binary cement (magnesium oxide cement and ordinary Portland cement) with carbon dioxide curing presented a

novel and green stabilization/solidification technology for recycling contaminated sediment as valuable and eco-friendly construction materials (Wang *et al.*, 2017) [13]. Adopting this binary cement approach, the compatibility of heavy metals and cement was improved upon by providing sufficient magnesium hydrates for metal sequestration. Magnesium cement reduced the compressive strength of the blocks which was then improved by carbon dioxide curing wherein the soluble magnesium hydrates were converted to stable carbonates and the strength enhancement was 2.8 times.

5.4. Contaminated Sediments for Creation and Restoration of Habitats

A large percentage (~75%) of contaminated sediments from New York / New Jersey harbor was found to be unsuitable for open ocean disposal. However, they were not considered as hazardous waste and their use for habitat creation and restoration was explored (Yozzo *et al.*, 2004) [14]. Several categories of habitat creation / restoration were discussed, which included creation of artificial reefs and shoals, oyster reef restoration, bathymetric re-contouring, creation / restoration of intertidal marshes and mudflats, filling dead-end basins and canals, creation of bird / wildlife islands, remediation / creation of upland habitats (landfill / brownfield restoration). These were suggested as the most environmentally sound and technically feasible options for sediment placements of ports and harbors.

The various regulatory guidelines and their authorities were elaborated, which included Clean Water Act, regulations of individual states, like State Environmental Quality Review, Significant Coastal Fish and Wildlife Habitats, Remedial Action Work-plan, among others. Demonstration projects, including post-construction environmental monitoring were felt to be necessary before full-scale implementation of such schemes. Final selection of suitable scheme would be based on the cost, placement capacity, regional stakeholder support, and outcome of the demonstration projects.

5.5. Sediments for Biodiesel Production

The sediments from eutrophic reservoir were evaluated with respect to the cetane number, iodine number, and heat of combustion for use in biodiesel production (Kuchkina *et al.*, 2008) [15]. The sediments contained large amounts of algal lipids and pollutants and nutrients. The use of the sediments reduced the cost price of the biodiesel, as the sediments were by-products originated from the lake restoration actions and were free cost raw materials. The parameters were found to be compliant to the standards. This bio-fuel was found to be potentially useful for engines. Such sediments might be further studied for large scale production of biodiesel and preferred over other feedstock on basis of the economy. This would be a win-win situation for both the dredging agency and the biodiesel production company as the former would have their disposal problem solved and the latter would get free raw material. Further, the use of biodiesel would automatically reduce the dependency on the fossil fuel. Thus this would lead

to a truly sustainable environment-friendly solution.

5.6. Sediments as Plant Growth Medium

An experiment was conducted to test reclaimed sediment as plant growing medium by co-composting with green waste (Mattei *et al.*, 2017) [16]. The treated sediment did not show any important eco-toxicity or increased microbial diversity and allowed an excellent plants growth. It was concluded that co-composting was an excellent sustainable option to reuse dredged sediments as growing substrate.

6. Impact Assessment for the Disposal Operations

The efficiency and the rationality of the environmental impact assessment applied to coastal sediment dredging and the oceanic disposal was reviewed (Lee *et al.*, 2010) [17]. The impact considerations and the goals depend on the coastal activities involved and the characteristics of the marine environment involved. Dredging areas and dredged sediment disposal areas were grouped by the authors in terms of their project characteristics and goals, which facilitated appropriate assessment fields of emphasis to be selected. The emphasis items would include marine physics, chemistry, pelagic and benthic ecosystems, and fish eggs and juveniles, fish and fishery resources. A survey of the interested parties, a review of the oceanic disposal of dredged sediments, and a checklist of the core assessment items were presented along with suggestions for improvement of the assessment system. They proposed that specific guidelines were needed to be established for marine environmental assessment system to ensure the validity and efficiency of the system.

The disposal operations of the sediments may be at regular interval or irregular interval. Studies need to be conducted for evaluation of the impacts of these disposal activities of heterogeneous materials for both regular and irregular intervals. The significance of impacts and recovery processes associated with capital dredging involving infrequent deposition of heterogeneous materials over restricted time periods had been studied (Ware *et al.*, 2011) [18]. It was reported that such operations resulted in occurrence of persistent changes to seafloor substrata within the license area and this subsequently affected the composition of associated faunal communities present. Though the two sites studied were geographically distinct, similar species are identified as being particularly sensitive to capital disposal activities in both areas. Informed decisions regarding disposal site location such as, using information regarding sediment characteristics, local hydrodynamics, and dispersive capacity, have been proven to minimize long-term impacts on the seafloor and associated faunal communities resulting from disposal of maintenance dredging. In the case of capital dredging disposal, it was opined that the dispersive capacity of the licensed site may be less of a consideration than the potential consequences of shoaling. The similarity between sediment characteristics of the receiving environment and the disposal material would

help to restore the faunal community in minimum time subsequent to the disposal operation.

7. Conclusions

Large scale developmental activities have resulted in expanding construction industry. Concrete is popular choice of material in many applications, including that of pavement, low-cost construction, under-ground construction, among others. The concrete production creates an ever increasing demand on raw materials for cement production and also aggregates for concrete. Habitat restoration and creation of tidal flats require large quantities of sand or other fine aggregate. Meeting such demands by mining in quarries is, in many cases, difficult and uneconomic. This encourages exploration of sustainable options for raw materials for concrete like recycling and re-use of sediments obtained from dredging operations.

In the recent years, there had been increasing pressures against ocean dumping of sediments due to environmental concerns. On-land disposal options were limited because of the economics involved, scarcity of land and resulting environmental issues. For contaminated or hazardous sediments, the regulations imply that they be made inert before disposal, thus making disposal costlier. On the other hand, there had been shortage of quarries for aggregates and soil for backfill and landfill. As a coupled solution option, there have been varied approaches for recycle and reuse of dredged sediments from coastal regions, reservoirs, lakes, ports and harbors in construction industry. The major considerations for such activities are economic viability, technological feasibility, environmental impact, regulatory requirements and local support.

Sediments have been reportedly used for production of concrete for pavements, production of lightweight aggregates for lightweight concrete and cement masonry units, beach nourishment, land reclamation, and coastal defense works. The predominant contaminants in sediments were heavy metals and organic compounds. These had to be appropriately treated such that the resulting product could be environmentally acceptable. Some attempts were by vitrification and production of ceramic, production of cement in kiln, production of hot mix asphalt, among others. Contaminated but non-hazardous sediments could be one option for creation or restoration of habitats, tidal flats, bathymetric recontouring, and filling dead-end basins. Thus, coastal, river or reservoir sediments have found wide application in production of cement, aggregate, concrete, masonry units, ceramic and tiles, hot mix asphalt, landfill material. Some research has already been reported in literature and they have been discussed in the paper. These options may be systematically evaluated for best possible sustainable solution to the problems of disposal of dredged sediment and that of shortage of quarry aggregates and raw materials for construction.

There have been some studies which indicated the potential use of dredged sediments from eutrophic reservoirs as

feedstock in production of biodiesel. This option needs to be further explored as it would not only address the disposal issue but also aid in alternate feedstock for bio-diesel production. Additionally, the exploitation of the fossil fuels would be reduced. In coming years, large scale adoption of such methods of recycle and reuse is envisaged for achieving sustainability. Another novel approach was to co-compost the sediments with green waste and later use them as plant growth medium. As brought out in studies by some researchers, the impact assessment for the disposal of dredged materials would involve many factors, which need to be enumerated by the regulating agencies and policy guidelines need to be established for ensuring the efficiency and validity of the assessment system.

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