Forging the Future: Pioneering Approaches in Business, Management and Economics Engineering to Overcome Emerging Global Challenges - 2024

https://doi.org/10.24867/FUTURE-BME-2024-116 Original scientific paper

EXPLORING THE POTENTIAL OF SEDIMENT BENEFICIAL USE: ECONOMIC VIABILITY AND ENVIRONMENTAL SUSTAINABILITY

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Abstract

Over the past few decades, sediment has gained recognition as a challenging resource, attributed to its potentially harmful effects and the substantial volumes found within aquatic environments. Although, traditionally viewed as a waste product of dredging operations, sediment holds immense potential for beneficial use across multiple sectors, offering economic benefits while addressing environmental concerns. The utilization of sediment as a construction material constituent offers a sustainable alternative to virgin resources, reducing extraction pressures and lowering production costs. However, the economic feasibility of sediment beneficial use hinges on several critical factors. The quality of sediment, including its contamination levels and necessitates appropriate treatment measures. Process of solidification and stabilisation uses binders to physically strengthen the sediment for structural engineering use while also reducing the mobility and solubility of the contaminant. Different waste materials can be used as additional binders, in the remediation process. Their effectiveness is evaluated based on the microstructural properties and chemical integrity of produced aggregates. Transportation costs and regulatory frameworks further shape the economic landscape, impacting project viability and scalability. Market demand for recycled materials and technological advancements in sediment processing play pivotal roles in unlocking its economic potential. This research underscore the importance of a comprehensive understanding of sediment management strategies, balancing economic considerations with environmental sustainability goals. Through innovative approaches and collaborative efforts, sediment beneficial use can emerge as a cornerstone of circular economy principles, driving economic growth while preserving and enhancing natural ecosystems.

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Key words: *sediment beneficial use, economic assessment, environmental sustainability.*

1. Introduction

Dredging is essential for maintaining and developing waterways, ports, and navigation channels, as well as for land reclamation, flood management, and environmental restoration. Dredged material, composed of natural sediments such as clay, silt, sand, gravel, rock, and organic matter, is increasingly recognized as a valuable resource rather than a waste product [CEDA,2019a and 2019b]. Sustainable management of dredged sediments, with an emphasis on their beneficial reuse, offers both environmental and economic advantages [Yung et al,2024]. Beneficial reuse refers to the application of dredged or naturally occurring sediments in a way that aligns with human development goals while being compatible with environmental and ecosystem needs. In this context, dredged material should be considered a resource that can contribute positively to society, rather than waste requiring disposal. Its reuse can provide significant societal, environmental, and financial benefits, particularly given the large volumes of dredged material that are typically involved in such projects. Effective management of these materials represents a significant opportunity for sustainability [Suedel et al, 2021].

For construction projects such as the development of cycling paths, one potential application of dredged material is as a substitute for conventional materials like natural sand. The economic feasibility of using dredged sediment in such applications, however, depends on several factors, including the quality, quantity, and availability of the material, as well as its suitability for the intended purpose [Almokdad and Zentar, 2023]. Dredged material may require minimal or no treatment if it meets the appropriate specifications for use, but its suitability for construction purposes—such as compaction, drainage, and durability—needs to be carefully assessed [Almokdad and Zentar, 2023; Yung et al,2024]. The availability of dredged material is another critical factor, as it involves logistical considerations such as sourcing, transportation, and storage. Proximity to the construction site, the timing of material availability, and coordination with ongoing dredging activities can significantly influence the economic costs associated with using dredged sediments [Garbarino et al, 2016].

Although the initial costs of dredging, processing, and transporting sediments may exceed those of using natural sand, the long-term economic and environmental benefits of using dredged material should also be considered. These benefits may include reduced disposal costs, the potential for environmental impact mitigation, and contributions to sustainability through the circular economy [Wijdeveld, 2024]. Furthermore, the social acceptability of using dredged material is an important factor, as local communities and stakeholders may have concerns regarding environmental impacts or other issues. Engaging with stakeholders and conducting environmental impact assessments are essential for ensuring the broader social and environmental acceptability of dredged sediment reuse [Wijdeveld, 2024].

This study aims to assess these variables in order to provide a rough estimate of the relative economic costs of using dredged sediments versus natural sand in the construction of cycling paths.

1.1 Methodology

The economic section of the study pertains to the cost estimation for the construction of road infrastructure (cycling paths, access roads, etc.) on a selected watercourse, which needs to be dredged due to sediment accumulation. This study would be aimed at supporting tourism development and includes components with a social-societal aspect. The project budget is defined by differential costs, which include the transportation of the dredged material, considering that other costs (such as dredging costs, costs for testing the composition of the material, and others) are shared costs that exist in both options (Option 1 – disposal of dredged material, versus Option 2 – construction of a cycling path using the dredged material).

For the comparison of different sediment management options, the costs associated with constructing the landfill body were considered for the disposal option, while the total costs of constructing the cycling path were considered for the alternative option. All calculations were based on the same volume of sediment—1000 m^3.

When calculating the construction of a 2.5-meter wide cycling path, which can be built within the previously defined budget, the following construction activities were considered:

- The preparation works include marking the site. The contractor is required to protect all markers of the state trigonometrical network from damage during the execution of works and must replace any damaged or destroyed markers at their own expense. Before starting the main works, the contractor must, in the presence of the relevant organization, mark all underground utilities that intersect with the cycling path.
- Land clearing is performed on the areas where the cycling path will be constructed, or as instructed by the supervisor if modifications or adjustments to the original plan are required due to actual field conditions. Land clearing includes cutting shrubs, bushes, and vegetation using a bulldozer, followed by loading and transporting the cleared material to the landfill.
- Earthworks include the machine excavation of the humus layer, which is removed using a grader to level and smooth the ground. Additionally, material is spread and levelled for the embankment, using suitable material for constructing the embankment.
- The pavement structure is constructed by stabilizing the soil with hydraulic binders to create a bearing road structure.

2. Results

The Figure 1. compares the costs associated with two management options for 1000 m^3 of dredged sediment: disposal and the construction of a cycling path using the dredged material.

For the disposal option, the total cost is estimated at 4,665,506 RSD, which includes expenses related to the transportation and placement of the sediment in a landfill or designated disposal area. In contrast, the cycling path option, which involves using the dredged material for infrastructure development, is projected to cost 3,611,351 RSD. This lower cost reflects the potential reuse of the sediment as a construction material for the path. The cost for building the cycling path includes the preparation of the site, the earthworks required to integrate the dredged material into the path construction, and other associated infrastructure costs.

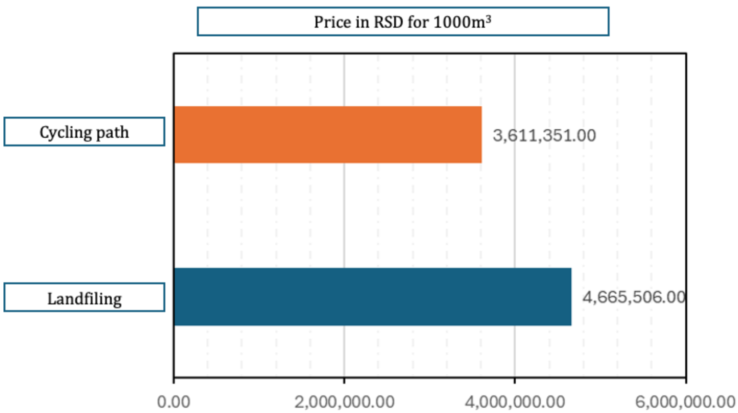

Figure 1: Cost Calculation of Different Sediment Management Options: landfilling vs. Cycling Path Construction

The significant difference in costs between the two options highlights the potential economic benefits of repurposing dredged sediment for construction projects. While the disposal option involves a higher expenditure, using dredged material for beneficial purposes, such as building a cycling path, not only reduces the financial burden of disposal but also contributes to sustainable infrastructure development. Additionally, the reuse of dredged sediment can mitigate the environmental impact of transporting and disposing of the material, supporting broader sustainability goals.

The Figure 2 presents a comparison of the costs for constructing a cycling path with a width of 2.5 meters using two different materials: natural material and dredged sediment. For preparation works, the cost per meter is the same for both materials, at 2,875 RSD. This includes tasks such as site marking and clearing, which do not vary depending on the type of material being used. In the earthworks category, which involves activities such as excavation and material leveling, the cost for using natural material is significantly higher at 26,829 RSD per meter compared to 8,073 RSD per meter when using dredged sediment. The lower cost for dredged sediment is attributed to the fact that it is being reused, thereby reducing the need to transport and source additional materials. For the pavement structure—which refers to the construction of the actual cycling path surface—the cost is lower when using natural material (7,520 RSD per meter) compared to dredged sediment (14,945 RSD per meter). This difference arises due to the additional processing and stabilization required to use dredged sediment as a construction material, making it more expensive in this stage of the process.

Total construction costs per meter, using dredged sediment results in a lower overall cost of 25,893 RSD per meter, compared to the 37,224 RSD per meter for natural material. This cost-saving is due to the reduced earthworks and material transport expenses associated with dredged sediment, which offset the higher costs of stabilizing the material for use in the cycling path.

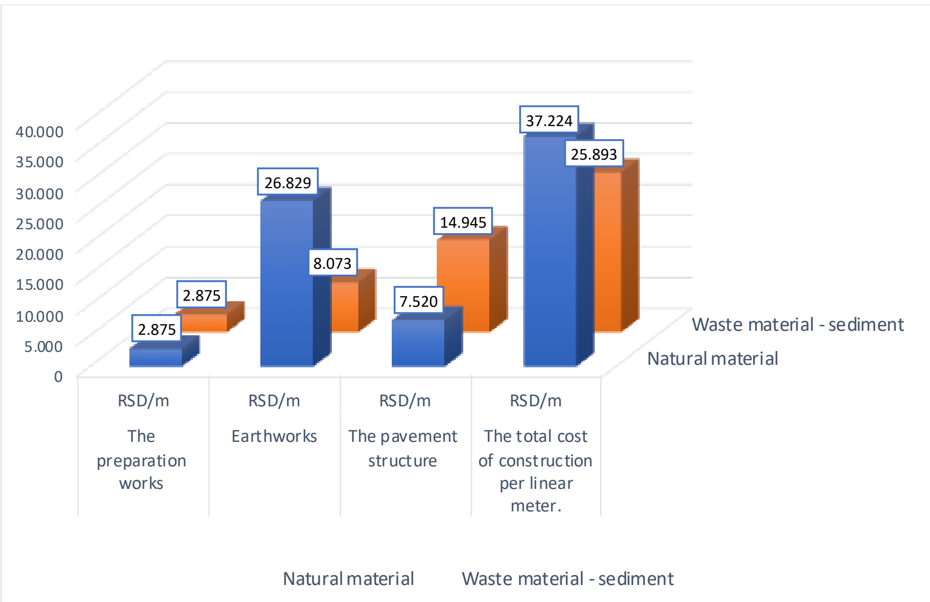

Figure 2. Economic Cost Comparison:
Dredged Sediment vs. Natural Material (Sand) for Cycling Path Construction

2.1 Environmental Benefits

From an environmental protection perspective, the project contributes to reducing the amount of sediment present at the bottom of the river. The implementation of the project activities increases the depth of the riverbed, which in turn increases the flow. By increasing the flow, sediment transport is enhanced, sedimentation is reduced, and the possibility of re-sedimentation of the riverbed is minimized. The increased flow positively impacts the active part of the channel, increasing the diversity of the riverbed, which in turn improves habitat variety, benefiting both plant and animal species.

Regarding global emissions, it is estimated that the construction industry accounts for about 10% of total CO_2 emissions. The construction and maintenance of transportation infrastructure not only entail significant administrative costs but also require large amounts of energy and water, deplete natural resources, and increase greenhouse gas (GHG) emissions [United Nations Environment Programme, 2024].

In 2016, the European Commission adopted a document titled "*Criteria for Green Public Procurement for the Design, Construction, and Maintenance of Roads*" aiming to promote the use of products, services, and works with a reduced environmental impact. Additionally, in December 2019, the *European Green Deal* was adopted, which aims to achieve net-zero greenhouse gas emissions by 2050.

In the context of these goals, the focus has shifted towards developing methodologies for assessing sustainability in the construction of transportation infrastructure. One of the key aspects is the beneficial reuse of materials, such as river sediment, which can have a wide range of applications in various construction projects. This approach not only reduces the need for transporting sediment over long distances but also promotes greater sustainability by lowering greenhouse gas emissions from transport.

4. Conclusions

This study has demonstrated the potential economic and environmental benefits of using dredged sediments for the construction of cycling paths, as compared to the conventional use of natural materials like sand. The analysis of construction costs reveals that, while the initial stages of dredging and processing may involve higher costs for dredged sediment, the overall cost of using dredged material for infrastructure projects can be significantly lower than the costs associated with disposal. This is particularly evident in the case of constructing a 2.5-meter wide cycling path, where the use of dredged sediment results in reduced earthwork and transportation expenses, ultimately leading to lower total construction costs.

From an environmental perspective, the project offers multiple advantages. The use of dredged sediment reduces the need for disposal, mitigating the environmental impact of transporting and landfilling large quantities of material. Moreover, the increased riverbed depth resulting from dredging enhances sediment transport and minimizes re-sedimentation, contributing to the overall health of the waterway ecosystem. The reuse of dredged sediment also supports sustainability goals by reducing the consumption of natural resources and minimizing carbon emissions, especially when considered in the context of broader transportation infrastructure development.

The findings underscore the importance of considering dredged material not as waste, but as a valuable resource that can support both economic development and environmental protection. The financial savings from repurposing dredged sediment, combined with the potential to reduce environmental impacts and enhance sustainability, highlight the importance of incorporating beneficial reuse practices into infrastructure projects.

In conclusion, this study contributes to the growing body of knowledge on the sustainable management of dredged sediments, offering a practical framework for decision-makers to consider the economic viability and environmental benefits of reusing dredged material in infrastructure projects. The results suggest that, with careful planning and regulatory support, the use of dredged sediment in projects such as cycling path construction can be a highly beneficial approach, providing long-term economic, environmental, and societal benefits.

Acknowledgments

This research was supported by the Science Fund of the Republic of Serbia, IDEAS call, Grant No. 7753609, BEuSED.

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