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Managing Dredged Sediments: Evolution of Land Deposits and Assessment of Beneficial Use

Ahmed Benamar, Mohamed-Tahar Ammami, and Hussein J. Kanbar

Abstract

Sediments are periodically dredged to maintain waterways and to allow a safe shipping in channels and rivers. However, merely dumping dredged sediments in the sea or managing land deposits without any beneficial reuse does not fit within a circular economy perspective. This study aims to follow and monitor the evolution of dredged sediments that were deposited on land and to suggest their beneficial use. In this investigation, dredged sediments were collected from ten deposit sites in the Normandy region (Le Havre and Rouen ports, northwestern France) and analyzed in terms of physical, chemical, and organic contents; these parameters are used to determine how sediments can be managed in a safe and beneficial way. Among the 10 collected samples, one sediment was already deposited in a site (Tancarville) and was monitored for 10 years. The results showed that the deposited sediment became coarser, salinity and moisture decreased, and organic matter accumulated. This evolution is correlated with flora flourishing in the aged deposit and, thus, a first step toward soil formation from dredged sediment. Consequently, the dredged sediment naturally aged into a deposit and became suitable for agricultural use. Finally, adjusting standards and regulations can lead to better use of dredged sediments and other solid wastes that inspire to reach a circular economy and eventually attain environmental sustainability.

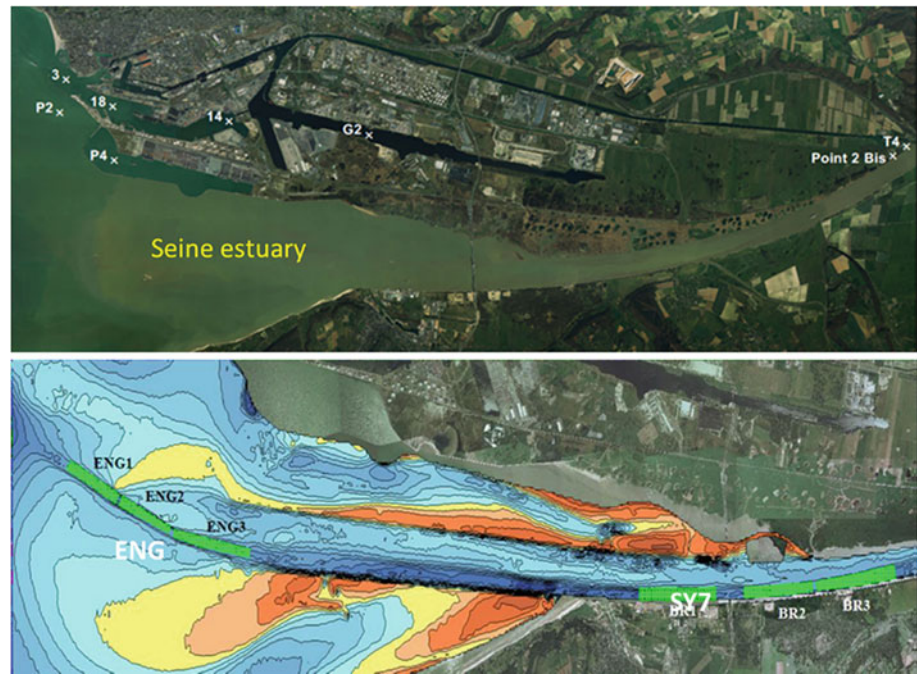
Keywords

Sediment evolution • Soil formation • Salinity • Circular economy • Environmental sustainability

1 Introduction

It is a challenge to find sustainable solutions for dredged sediments. Harbors and channels are periodically dredged to maintain the depth of the waterways. In Europe, 200 million m³ of sediments are annually dredged, while it is approximately 55 m³ in France among which 24 m³ are contaminated (Pedersen et al., 2021). Moreover, the volume of dredged sediments in France is expected to increase to 70 m³ within the next 10 years. In Normandy (northwestern France), almost 10 m³ of sediments are annually dredged from the ports of Le Havre and Rouen (Ammami et al., 2020; Benamar et al., 2020). Dredged sediments can be directly dumped into the sea if they respect the threshold metal contents (GEODE, 2014). So, a large part of these materials is dumped into the sea, and a very small volume is deposited on land; the latter is considered as waste according to French regulations. The use of the deposited materials depends on regulations, such as the presence and contents of contaminants and their bioavailability. Land deposit can be managed in controlled area for further beneficial use. In this regard, sediments need to be analyzed before they can be used in an environmentally safe way. The aim of this work is to investigate the evolution of an aged sediment deposit in Tancarville (France) and evaluate how the material properties were improved without any specific treatment. This new approach of dredged sediment management showed how the aged material can be reused in construction materials like fired bricks (Mesrar et al., 2021) or in reconstructed soils (Interreg, 2022), providing a significant approach toward a circular economy. Alternatives of using dredged sediments are included elsewhere (Chen et al., 2009; Hamer & Karrius, 2002). A large part of sediments dredged in the investigated area originates from the silty geological cover in Normandy during run-off. Therefore, sediments contain the nutrients necessary for plant growth. Furthermore, sediments are usually enriched in organic matter, which is

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Fig. 1 Sampling map view

helpful in overcoming soils with low organic contents. When deposited in land, dredged sediments can be a promising material that can be used in agriculture or construction.

2 Materials and Methods

In the framework of a project aimed to investigate how marine sediments dredged in the Normandy area can constitute a homogeneous deposit for bricks manufacturing (Benamar et al., 2020; Mesrar et al., 2021), ten sediment samples were collected from the ports of Le Havre and Rouen (France) (Fig. 1) and were characterized in terms of the particle size distribution (PSD by laser diffraction), physico-chemical parameters (pH and electric conductivity), and organic (loss on ignition), carbonate (calcimeter method), and metal contents (Inductively coupled plasma mass spectrometry). Based on these results showing a slight parameters variability, a dredged sediment deposit site which was monitored for nearly 10 years (Tancarville, France) was selected to serve as a reference site. The main parameters that were monitored over the decade were water content, electric conductivity, organic and carbonate contents, grain size properties, and metal contents. It is interesting to know how dredged sediment can evolve in a raw deposit without any specific treatment.

3 Results and Discussion

3.1 Initial Sediment Characterization

All the collected sediments are fine-grained material (Fig. 2) which represent silty soils in terms of texture. Additionally, the sediments were rich in organic matter ($\sim 6\%$) and carbonate contents ($\sim 19\%$). These characteristics do not vary significantly among the different collection points in Le Havre and Rouen ports, indicating uniform properties of the sediments in the watershed. Anyway, such sediments are able to overcome low water holding capacity in

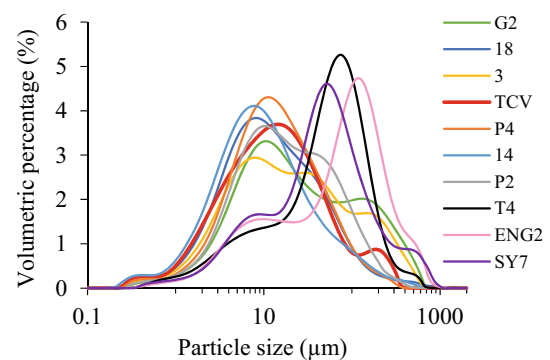
**Fig. 2** Particle size distribution of collected sediment samples

Table 1 Metals concentration in sediment and limit values that trigger sludge use in land

Element	Cd	Hg	Cr	Cu	Ni	Pb	Zn
C (mg/kg dry)	1.4	–	83.2	40.1	–	67.1	190
Sludge use in land (NF 44-041)	2	1	150	100	50	100	300

coarse-grained soils on the one hand and are useful for agriculture due to their relatively high organic and carbonate contents. Indeed, such characteristics make sediments, after treatment in some cases, as good candidates as amendments for agricultural soils. The metal contents of the sediments lay below the limit values admitted for sludge use in land according to French regulations (Table 1).

3.2 Sediment Evolution in the Tancarville Land Deposit

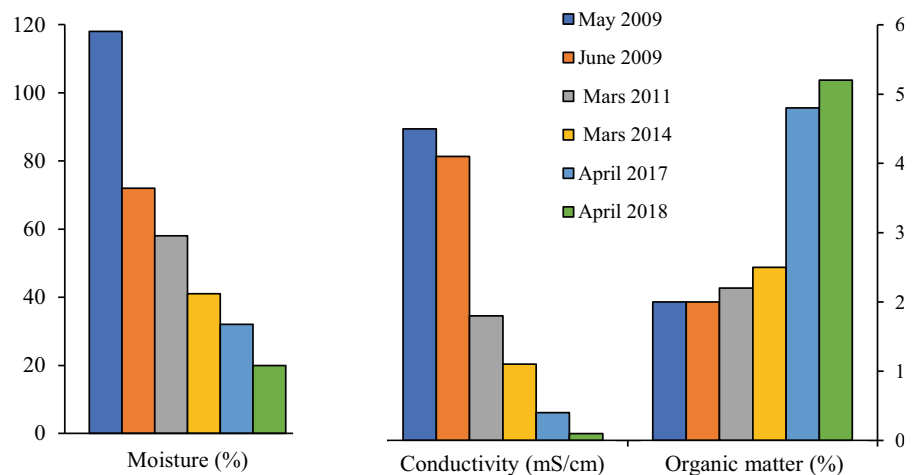
Due to the deposition of large volumes of dredged sediments in Tancarville land deposit, this site was monitored between 2009 and 2018. The evolution of the deposit area showed rapid dewatering and fast drainage followed in the first years of aging by plants growth. Samples were collected periodically and analyzed regarding water, organic, and carbonate contents. The water content in the sediments decreased with time (Fig. 3) due to water drainage. During the time, fine particles are expected to reach lower depths, leaving relatively coarse particles on top. Consequently, coarser particles will have less water holding capacity. Many processes occurring during the sediment deposit contribute to changing the material structure. Additionally, the electrical conductivity, an indicator of salinity, significantly decreased to a value less than 0.1 mS/cm, owing to the leaching process. The high decrease in salinity was achieved after two years, and the residual value is close to that involved in farming soils. The organic matter strongly increased especially after

the conductivity decreased, i.e., between 2014 and 2017. This is due to the extended plants growth in the deposit area. Indeed, the relatively low water content and conductivity of the sediment make it suitable for use (e.g., construction materials). In addition, the high organic matter content makes the aged sediment suitable for agricultural amendment or as a component in reconstructed soils. As regards to the metal traces, a slight decrease was recorded, but the initial values (Table 1) showed that the concentrations are lower than that allowed for sludge use in agricultural land (Baize et al., 1997). Aged dredged sediments from the Normandy ports, which contain 5% clay, 6% organic matter, and are rich in carbonates showed to be suitable components that can be used in agriculture.

4 Conclusions

Ten samples of dredged marine sediments were collected and analyzed in the Normandy region (France). The preliminary results showed less variability among their geotechnical parameters and homogeneous characteristics, which validate the material used on a large scale as material construction, soil amendment, or replacements in agriculture. Among the collection sites, the deposit at Tancarville (France) was monitored for a decade, and the evolution of the characteristics was investigated. Interestingly, the sediment naturally evolved into coarser, less saline, and more organic-rich material. These characteristics promoted the formation of a material suitable for plant growth. Although

Fig. 3 Evolution of water content, conductivity, and organic matter



this aged dredged sediment can also be used in construction, due to low salinity, it showed to be a suitable medium that can be used as an alternative or a complement in reconstructed soil from waste. The latter case then brings us closer to reaching a circular economy and achieving environmental sustainability, both desired in environmental management approaches.

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