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Review

# Toxicity assessment within the application of in situ contaminated sediment remediation technologies: A review

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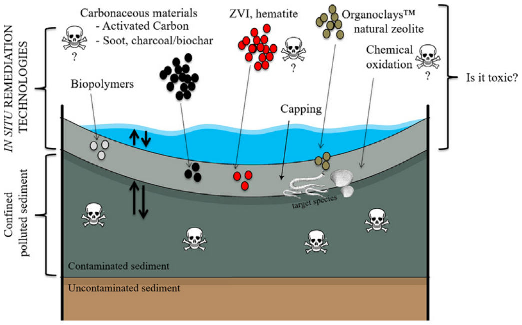
## HIGHLIGHTS

- Sediment as sink/source of pollution represents a great deal for aquatic ecosystems.
- In situ technologies are a chance for remediation but with unknown long-term effect.
- Reviewed toxicity data are fragmentary, incomplete or entirely missing.
- Activated carbon is a frequent amendment, but with potential undesired effects.
- Long-term toxicity data are necessary for remediated sites monitoring/maintenance.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Polluted sediment represents a great problem for aquantic environments with potential direct acute and chronic effects for the biota and can be tackled with both in situ and ex situ treatments. Once dredging activities are not compulsory, sediment can be kept in place and managed with techniques involving the use of amendment and/or capping. Before their application, the assessment of their potential impact to the target environment cannot ignore the safe-by-design approach. The role of toxicity in in situ sediment remediation was reviewed discussing about how it can be used for the selection of amendments and the monitoring of treatment technologies. Results evidenced that capping technology coupled to activated carbon (AC) is the most frequently applied approach with effects varying according to the rate of contamination in treated sediment, the amount of AC used (% v/v), and target biological models considered. Little data are available for zerovalent iron as well as other minor amending agents such as hematite, natural zeolite, biopolymers and organoclays. Current (eco-)toxicological information for in situ sediment remediation technologies is fragmentary and incomplete or entirely missing, making also the interpretation of existing data quite challenging. In situ sediment remediation represents an interesting potentially effective approach for polluted sediment recovering. As its application in some lab-based and field studies reported to induce negative effects for target organisms, amendments and capping agents

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*Abbreviations:* AC, activated carbon; BAF, bioaccumulation factor; BSAF, biota-sediment accumulation factor; DO, dissolved oxygen; EPA, environmental protection agency; GSH, glutathione; HOC, hydrophobic organic compound; LDH, lactate dehydrogenase; LPO, lipid peroxidation; NA, naphtenic acid; NP, nano particle; OC, organic carbon; OECD, Organisation for Economic Co-operation and Development; Ox, oxyde; OSPW, oil sands process-affected water; OSWER, office of solid waste and emergency response; PAH, polycyclic aromatic hydrocarbons; PCB, poly chloro biphenyls; PCC, powdered coconut coal; SOD, superoxide dismutase; ZVI, zero-valent iron.

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must be attentively evaluated for short- and long-term environmental effects, also in the perspective of the remediated site monitoring and maintenance.

**Contents**

## 1. Introduction

Sediment toxicity proved to be essential in monitoring studies to characterise the state-of-the-art of aquatic environments and to take decisions about contaminated areas according to the TRIAD approach (Chapman, 1990; Losso and Volpi Ghirardini, 2010; Libralato et al., 2008; Hurel et al., 2017).

Polluted sediment represents a great problem for fresh, brackish and marine ecosystems, especially coastal ones, due to the high human pressures (i.e. commercial and industrial port activities, human settlements and tourism) and sedimentation rates caused by solid discharges from catchment basins (Nikolaou et al., 2009a; Lofrano et al., 2016; Hurel et al., 2017).

Sediment drains and temporarily stores pollution with potential direct acute and chronic effects for benthic communities. Natural (i.e. bioturbation) or artificial (i.e. dredging) perturbative events can release the accumulated contamination causing acute concerns to water column populations and the re-allocation of contaminants within the same aquatic environment. Thus, contamination can be scattered in vaster areas or sometimes exported outside from the confined aquatic ecosystem (e.g. lake or lagoon) due to sediment loss (e.g. flooding events or tides) (Arizzi Novelli et al., 2006; Nikolaou et al., 2009b; Mamindy-Pajany et al., 2010a).

Currently, commercial and industrial ports must face up to contaminated sediment management because sedimentation rates can be substantial (Apitz et al., 2007), navigation must be guaranteed and, thus, sediment dredging from sea or riverbed is compulsory. Anyhow, this activity must be carried out in a highly efficient and environmentally friendly manner to reduce and keep impacts to a minimum. Dredged sediment can be treated ex situ "on site" or "off site" and, finally, transported to its destination (e.g. landfill) or second life (e.g. construction materials).

Sometimes the problem of polluted sediment can be tackled without dredging keeping them in place especially when it must not be removed like for assuring drafting ships and if site physical dynamics (i.e. current and wave actions) are not of concern. In this case, in situ sediment treatment(s) can be applied.

Lofrano et al. (2017) reviewed in situ remediation of contaminated marine sediment showing that, apart from the *no action* option, several methods involve the use of amendment. Amendment composition and combinations, its application techniques and rates, and its potential environmental implications have been only barely investigated. Particularly, fragmentary information exists about the role of (eco-)toxicity in assessing the best available in situ technology for sediment remediation (Lofrano et al., 2017) being generally reported as secondary side effects of treatment activities (Libralato et al., 2008; Rakowska et al., 2012).

Several questions remain open about the relative toxicity of amendments on their own like as their potential relative contribution to the final sediment toxicity. Current literature still does not describe extensive in situ applications (ISAs) for contaminated treatments as well as their potential undesired long-term effects.

This review paper stressed on how there is a mutual require by environmental alerts and environmentally friendly businesses to introduce new consistent methods for contaminated sediment treatment and management considering toxicity reduction/removal in the perspective of the zero-emission approach. The aim of this paper is to review the role of toxicity in in situ sediment remediation discussing about how it can be used for the selection of amendments and the monitoring of treatment technologies. Information was clustered based on the considered remediation technologies and, sub-grouped them according to testing organisms.

## 2. Remediation technologies

The implications of toxicity in sediment remediation were investigated considering in situ technologies referring to capping with amendments, nanoremediation, solidification and stabilisation, chemical oxidation, bioventing, thermal treatment, and sediment washing according to the review of Lofrano et al. (2017).

Capping can be used to cover submerged sediment by stable layers of natural or synthetic materials. The cap reduces the mobility of contaminants (i.e. apart when placing the first layer of capping material that can suspend sediment in the water column) and the subsequent interaction with biota. Generally, it can be considered applicable when the pollution source that led to the deposition of contaminants has been halted, the environmental effects of moving/treating contaminated sediment are too great and hydrologic conditions are favourable that is not disturbing the site (e.g. strong currents can displace caps). Capping requires long-term monitoring and maintenance to ensure that contaminants are not migrating, and thus cap integrity must be regularly verified and ad hoc designed to provide containment for as long as the contaminated sediment requires management (USEPA, 2014; Lofrano et al., 2017).

Further remediation methods like nanoremediation and solidification and stabilisation, chemical oxidation, bioventing, thermal treatment, and sediment washing are still in their infancy for in situ treatment and very scarce information is available about the assessment of toxicity and its reduction/removal from treated sediment (Lofrano et al., 2017).

Besides capping, only one case study proposing the in situ chemical oxidation based on ozonation ($O_3$) investigated sediment toxicity (He et al., 2012).