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Effect of the resuspension technique on distribution of the heavy metals in sediment and suspended particulate matter

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HIGHLIGHTS

- The distribution of heavy metals in sediment was determined after resuspension.
- The resuspension method was able to reduce the concentration of seven heavy metals.
- Selected heavy metals were returned to the non-polluted level.
- The resuspension technique decreases the risk of the heavy metal availability.

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ABSTRACT

Harbour areas play important roles in the economy worldwide. Human activities, however, in those areas, generate contamination, which mostly accumulates in sediments. On the other hand, harbour areas have been facing deposition of significant amounts of sediment each year. As a consequence, shallowness and accumulation of contaminants in sediment become challenging issues in harbours. Among the various management options for remediation of contaminated sediments in harbours, resuspension technique was introduced as a new approach to address those issues. The concept of the resuspension method is that finer sediments have a greater tendency to adsorb the contamination. Therefore, removing the finer sediments instead of dredging the whole contaminated area is the main goal of the resuspension technique. The objective of this paper was to evaluate the effect of the resuspension method on reducing the concentration of contamination and distribution of heavy metals in sediment and suspended particulate matter. The resuspension method was successful in reducing the concentration of seven selected heavy metals (Cr, Ni, Cu, Zn, As, Cd and Pb) by removing just 4% of the contaminated sediment. The contamination intensity in the sediment, presented by geoaccumulation index, was reduced for Cd and Pb as the main contaminants by 26 and 28 percent and the rest of the selected heavy metals returned to the natural level. The results of the sequential extraction tests and enrichment factor implied that the resuspension technique is capable of decreasing the risk of remobilization of heavy metals in the aquatic ecosystem.

1. Introduction

Activities at harbour areas, particularly on large rivers, have been known to be harmful to the aquatic environment (Buruaem et al., 2012). Construction of the breakwaters in those areas can affect sediment transport. Subsequently, harbour areas have been facing deposition of significant amounts of sediment each year. Additionally, generation of waste and the discharge of contaminants into the water body are the main threats to the aquatic ecosystem (NRC National Research Council, 1997). Industrial and domestic sewage and wastewater, petroleum and compounds released by antifouling paints that are received from land and river can be adsorbed up to 99 percent by sediment (Salomons and Stigliani, 1995; Huang et al., 2012). Therefore, shallowness and contaminated sediments at harbour areas become challenging issues.

Among the various pollutants, heavy metals adsorbed by sediments are of particular concern due to their mobility and toxicity in the aquatic ecosystem. Binding of heavy metals to the contaminated sediment may not be permanent. Therefore, contaminants

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could desorb from the particles and be released into the aqueous phase under changing environmental conditions. Contaminated sediments with heavy metals are not only a short-term threat to biodiversity but they also can serve as long-term exposure sources to ecosystems (Ghosh et al., 2011).

Because of the concentration of pollutants, *ex situ* remediation after dredging is the main viable option and *in situ* techniques are mainly used to reduce the mobility of the contaminants. However dredging the contaminated sediment can increase the risk of mobility and availability of heavy metals in the harbours and impacts on the disposal sites that receive the dredged sediment (USEPA, 1991).

Capping with or without reactive amendments are the most common *in situ* methods employed in contaminated sediment cases. However, capping is not applicable since shallowness is an issue in the harbours. Additionally, both capping and dredging may have an adverse effect on existing benthic ecosystems (Ghosh et al., 2011). Therefore, developing new techniques with more flexibility for managing contaminated sediment and minimal harm to the surrounding environment is highly desirable.

In order to address this issue in shallow harbour areas, the resuspension technique was introduced as a new approach to remediate contaminated sediments. The concept of the resuspension method is that finer sediments (i.e. clay and fine silt) have a greater tendency to adsorb the contamination (Mulligan et al., 2009). Due to the high specific surface adsorption and ionic attraction, finer sediments tend to have a relatively higher concentration of contaminants (USEPA, 1991). Suspended sediment and the organic components of sediment can also scavenge organic and inorganic contaminants (Fukue et al., 2007). Therefore, removing the finer sediments without dredging the whole contaminated area is the main goal of the resuspension technique.

Fukue et al. (2012) applied the resuspension approach for evaluating the feasibility of reducing the level of organic matter that led to hydrogen sulfide production in Fukuyama city harbour, Japan. However, in this study, the resuspension process was modified for removing inorganic pollutants (i.e. heavy metals). Briefly in the resuspension process, finer sediments are targeted for removal by a suspension mechanism. Through a powerful air jet, in a confined water column, sediments are forced to resuspend over a period of the time and then settle based on size. The finer suspended solids containing higher concentrations of heavy metals can be removed from the aquatic ecosystem by pumping and filtering.

The objective of this paper was to determine the effect of the resuspension method on distribution of heavy metals in the sediment and the subsequent suspended particulate matter (SPM). Moreover, the risk of mobility and availability of seven heavy metals in the sediment of a harbour area was assessed. The feasibility of the resuspension method as a new technique for remediation of contaminated sediment also was evaluated.

2. Materials and methods

2.1. Study area

A harbour in the province of Quebec, Canada, was selected for this study. The harbour is located on the north bank of the St. Lawrence River with an area of approximately 15,000 m^2. Two floating and one solid breakwaters protected the harbour from the waves. Consequently, there was a quasi-steady flow around the passageways and dock area, which led to deposition of sediments (Fig. 1). The boat maintenance area was located at the northern west of harbour and was mainly used for repairing and repainting in the summer and storing the boats in the winter.

There was an urgent need to remove the sediments from areas around the dock and passageways in order to facilitate the passage of the larger yachts. It has been almost 15 years since dredging was performed in this harbour. The water depth varies between 0.6 m (around the dock area) and 3 m (around the floating breakwater). However, prior to dredging or any other management method, the quality of sediments must be assessed to evaluate management options. Nine different stations along the passageways and the dock area, which are the most relevant places for dredging, were chosen for analysis. These stations are shown on the map in Fig. 1.

2.2. Sampling

A set of surface sediment samples was obtained at the selected stations (Fig. 1) based on the sediment-sampling guide for dredging and marine engineering projects in the St. Lawrence River (Environment Canada, 2002). The samples were taken with a Birge-Ekman grab sampler from the surface of the sediments to a vertical distance to a maximum depth of 10 cm. Each sample was about 1 ± 0.2 kg. The sampler consists of a stainless steel box with a pair of jaws and free-moving hinged flaps (Gouws and Coetzee, 1997). The jaws can trap sediments as soon as they reach the river bottom and keep the sediments in the stainless steel box to prevent washout during retrieval. Sediment samples were transferred and kept in the airtight polyethylene bottles and placed in an ice-cooled box. They were transferred to the freezer at the Environmental Engineering laboratory at Concordia University and were used for subsequent experiments.

All plastic- and glass-ware used during the experimental procedures was new or soaked in 5% (v/v) nitric acid and 2.5% (v/v) hydrochloric acid (trace metal grad) for at least 8 h followed by two rinses with deionized water (prepared using a Milli-Q 18 $\mu\Omega$ cm). For quality control, all sediment samples were analyzed using a blank, control and duplicates.

2.3. Experimental design

The setup for resuspension of the sediment contained three parts. The first part is resuspension/aeration, which was performed by an air jet connected to the central compressing air system in the laboratory. The central air compressor provided up to 400-kPa. However, the velocity of the air injected in to the water was around 10 $m.s^{-1}$, which could create a strong turbulence in the reactor. The head of the air injector was submerged into the water and located 5 cm above the sediment in the reactor. The reactor was a vertical plexiglass cylinder with 20 and 60 cm in diameter and height, respectively (Fig. 2). The sediment sample was deposited first into the reactor followed by adding the tap water. The ratio of the sediment sample to tap water was 1:10 (v/v) in the reactor. Tap water was used in all experiments since it has relatively similar characteristics to the river freshwater samples. The quality of the St. Lawrence River water samples at the study site was previously assessed and reported (Pourabadehei and Mulligan, 2016). Sediments were suspended in the reactor during air injection, which took 2 h for each sample. The injected air contributed to the increase in the volume of the water/sediment by approximately 30% in each sample.

For the second part, aeration was stopped after 2 h and the coarser sediments started to settle. In about 15 min, the sand and coarse silt fraction almost completely settled. Then, by using a pump with a maximum flow rate of 22 $L.min^{-1}$, 30% of the slurry in the reactor containing the water and suspended particulate matter (SPM) and some insoluble organic matter were removed and conveyed to the filter system (Fig. S1, presented in the supplementary materials). The suction pipe for pumping was located in