Removal of Metal Ions from Storm-Water Runoff by Low-Cost Sorbents: Batch and Column Studies

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Abstract: The possibility of using the sorption technology to reduce the levels of metal ions present in urban storm-water runoff was investigated in this study. Seven sorbent materials including Amberlite XAD7, chitosan, crab shell, peat, Sargassum, sawdust, and sugarcane bagasse were initially examined for removal of 11 metal ions (Na, K, Ca, Mg, Mn, Co, Ni, Cu, Zn, Cd, and Pb) from simulated storm-water runoff at different concentrations. Among these sorbents, crab shell performed well with removal efficiencies exceeding 93% for all heavy metal ions examined and thus selected for further studies. Based on scanning electron microscopy/energy-dispersive x-ray analysis, microprecipitation of metal carbonates followed by adsorption onto the surface of crab shell was identified as the major mechanism responsible for removal of heavy metal ions by crab shell. Crab shell exhibited rapid removal of meal ions with attainment of biosorption equilibrium within 20 min. A crab-shell-packed column was used to study the continuous metal retention process. The column performed very well in the removal of heavy metal ions and was able to operate up to 192 h at a flow rate of 10 mL/min before outlet concentrations of Mn and Co reached 0.3 times of their respective inlet concentrations. Other metal ions such as Pb, Zn, Ni, Cd, and Cu were only in trace levels in the final effluent until 192 h. These findings would form the basis for the future development of crab-shell-based biofilters for removal of dissolved heavy metal ions from storm-water runoff.

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Introduction

The storm-water runoff from urbanized lands has the potential to change the health of water bodies, impacts on aquatic habitats, recreation, and aesthetics, or cause algae to grow uncontrollably (NSW-EPA 1998). Pollutants found in urban storm-water runoff originate from a number of sources: washings of road surfaces, parking lots, motor vehicles, building materials, air pollutants, exhausts from industrial operations, and lawn fertilizers. Among the pollutants, heavy metals are a serious concern because of their tendency to bioaccumulate. These metals are either dissolved in the storm water or are bound to particulates (Sansalone and Buchberger 1997). However, their presence and concentrations are strongly site-specific. Studies done in Ashdod, Israel (Asaf et al. 2004) showed that the trace metal concentrations in storm-water runoff were in the following ranges: manganese (0.001–0.516 mg/L), zinc (0.008–0.720 mg/L), copper (0.001–0.079 mg/L), and lead (0.003–0.010 mg/L). In another characterization study, Walker et al. (1999) summarized the concentrations of heavy metals in urban runoff in the following concentration ranges: zinc (0.0007–22.0 mg/L), copper (0.0006–1.41 mg/L), and lead (0.00057–26.0 mg/L).

Storm-water runoff, because of the pollutant level, is considered toxic and unacceptable for discharge into receiving surface waters without some treatment (U.S. EPA 1983). Typically, a number of devices, collectively known as structural best management practices (BMPs), are employed to treat these contaminated runoffs. However, the majority of these structural BMPs (e.g., wet ponds) rely exclusively on physical separation processes such as sedimentation. Thus, only a majority of the suspended solids and associated pollutants are removed without any significant decrease in colloidal and truly dissolved pollutant fractions. Hence, there is a need for secondary treatment of storm water after passing through the BMPs. Several methods are available to remove trace quantities of dissolved metals from water. However, only a few treatment methods such as sorption using low-cost materials have received increased attention based on their cost effectiveness and performance (Veglio’ and Beolchini 1997; Vijayaraghavan and Yun 2008). In recent years, several waste materials of biological origin have also been identified to bind and remove metal ions from wastewater (Vieira and Volesky 2000; Vijayaraghavan and Yun 2008). The results of metal removal by these biosorbents are almost comparable to some of the well established commercial adsorbents or ion-exchange resins (Volesky and Holan 1995; Veglio’ and Beolchini 1997).

Although numerous studies of metal removal using a variety of sorbents exist, they are typically restricted to single metal solution and unrealistic metal concentrations. Only limited studies have been conducted to investigate the real potential of sorption technology under realistic experimental conditions (Vijayaraghavan and Yun 2008). In terms of storm-water runoff, few past...
studies used sorption technology for the removal of metal ions from storm-water runoff (Liu et al. 2005; Genc-Fuhrman et al. 2007). However, it is important to gain insights into the underlying removal mechanisms when a number of metal ions coexist. Also, an exhaustive investigation is required before suggesting a suitable sorbent for its potential use in secondary storm-water treatment systems.

The present study was carried out to examine seven different sorbents (Amberlite XAD7, chitosan, crab shell, peat, Sargassum biomass, sawdust, and sugarcane bagasse) for their potential to treat simulated storm-water runoff containing 11 different metal ions. Among these sorbents, Amberlite XAD7 is a commercial ion-exchange resin used for metal removal (Benamor et al. 2008). Crab shell mostly comprises of calcium carbonate, chitin, and proteins (Lee et al. 2004) and used for the biosorption of various metal ions in single-solute systems (Vijayaraghavan and Yun 2008). Chitosan is a well-known metal sorbent for single metal solutions (Guibal 2004); however, its performance in multimetal solutions is relatively unknown. Chitin and chitosan are long linear polymeric molecules of β (1→4)-linked glycan. The repeating unit in chitin is 2-acetamido-2-deoxy-D-glucose-(N-acetylgulcosamine), while chitosan comprises a nonhomogenous mixture with the deacetylated form (glucosamine) (Onsosyen and Skagrud 1990). Peat is a low-cost and effective adsorbent for various heavy metal ions (Brown et al. 2000). It is mainly comprised of lignin, cellulose, and fulvic and humic acids and does not require activation, unlike activated carbon. Sawdust, obtained from wood industry, is an abundant by-product which is easily available in the countryside at negligible price. It contains various organic compounds (lignin, cellulose, and hemicelluloses) with polyphenolic groups that could bind heavy metal ions through different mechanisms. Chitosan is a well-known metal sorbent for single metal solutions (Guibal 2004); however, its performance in multimetal solutions is relatively unknown. Sugarcane bagasse consists of cellulose (50%), polyoses (27%), and lignin (23%) (Karnitz et al. 2007). The presence of these three biological polymers renders sugarcane bagasse rich in hydroxyl and phenolic groups and these groups play a vital role in metal binding.

Materials and Methods

Sorbents

Amberlite (Amberlite XAD7, Sigma) and chitosan (from crab shells, Practical grade, Aldrich) were commercially obtained and used in their original form. Waste crab shells of Portunus sandvicensis were collected from the local markets in Singapore, washed extensively with de-ionized water, sun-dried, and crushed to a particle size in the range of 0.5–1 mm. Peat (150 μm sieve size) was collected from Sungai Sembilan peat deposit, a sub-province, 200 km away from the city of Dumai in Sumatra, Indonesia. On the other hand, sawdust and sugarcane bagasse were collected locally. They were washed extensively with de-ionized water, dried, and sieved to obtain particles in the range of 0.5–1 mm. Fresh biomass of Sargassum sp. was collected from the beaches of Labrador Park in Singapore. The biomass was extensively washed with de-ionized water and sun-dried. The dried biomass was then grounded to particle sizes in the range of 0.5–1 mm.

Storm-Water Runoff

The composition of storm-water runoff was simulated by adding different metals at different concentrations in real rain water. The metal concentrations were loosely based on the composition of storm water reported by Asaf et al. (2004) (for urbanstorm-water in semiarid climates) and Walker et al. (1999) (for temperate climates). The simulated storm-water runoff consisted of the following metals in mg/L: 52.4 ± 1.63(Na), 51.2 ± 0.99(K), 48.2 ± 0.99(Ca), 51.7 ± 1.77(Mg), 20.6 ± 0.07(Mn), 4.96 ± 0.12(Co), 4.85 ± 0.03(Ni), 5.14 ± 0.13(Cu), 4.39 ± 0.38(Zn), 3.22 ± 0.13(Cd), and 1.01 ± 0.01(Pb). The pH of rain water and that of simulated storm-water runoff were found to be 4.7 ± 0.2 and 4.9 ± 0.1, respectively.

Batch Experiments

For screening the sorbents based on their metal removal potential, 0.2 g of each of the sorbent was contacted with 100 mL of storm-water runoff in 250-mL Erlenmeyer flasks. The reaction mixture was agitated in a rotary shaker at 160 rpm and 22 ± 1°C. After 60 min, the reaction mixture was filtered through a 0.45-μm PTFE membrane filter. Each filtrate was acidified and analyzed for aqueous metal content by ICP-AES (Perkin Elmer Optima 3000 DV). The instrument detection limits were insignificant as compared to the concentration of metal ions used except for lead; the detection limit of the latter is 50 μg/L, which is significant compared to initial concentration used (1.01 mg/L). The detection limit of Pb was therefore used in the calculations. Also, matrix effects did not interfere with the chemical analysis. For kinetic experiments, samples were withdrawn at fixed time intervals and analyzed for different metal ion concentration in ICP-AES. For desorption experiments, 0.2 g of sorbent was exposed to 100 mL of storm-water runoff at pH 4.9 ± 0.1. After 60 min of agitation at 160 rpm, the metal-loaded sorbent was separated from the solution by filtration. The sorbent was then brought into contact with 100 mL of de-ionized water or 0.01 M HCl or 0.1 M HCl for 60 min on a rotary shaker at 160 rpm. The remaining procedure was the same as previously explained. All batch experiments were done in duplicates and the data are the average values of two independent experiments.

Scanning Electron Microscopy Analysis

To determine the major mechanism responsible for metal removal, the metal-loaded sorbents were dried, coated with a thin layer of platinum, and analyzed by scanning electron microscopy (SEM) equipped with energy dispersive x-ray analysis (JEOL, JSM-5600 LV).

Continuous-Flow Experiments

A glass column with an inside diameter of 2.4 cm and a height of 35 cm was employed to perform the continuous-flow experiments. The column was initially packed with 71.2 g of crab shell particles for a bed height of 25 cm. The storm-water runoff was fed into the column using a peristaltic pump at a flow rate of 10 mL/min. Effluent samples were collected at different time intervals and then analyzed for their metal concentration concentrations. Due to practical difficulties in collecting large quantities of rain water, column experiments could not be carried out repeatedly.
Results and Discussion

Screening of Different Sorbents

Initial experiments were conducted with seven different sorbents for metal removal from storm-water runoff (Fig. 1). The sorbents demonstrated different removal efficiency for each metal ion with crab shell and Sargassum being able to biosorb most of the metal ions. The commercial ion-exchange resin, Amberlite XAD7, did not sorb any of metal ions examined while the remaining sorbents were able to sorb only a limited number of metal ions. In the case of chitosan, it performed well for some metal ions such as Mn, Cu, and Pb. However, it showed very little potential to decrease the concentration of light metals (metal cations of low atomic weight and abundantly found in the environment, such as Na, K, Ca, and Mg). Other low-cost sorbents such as bagasse, peat, and sawdust showed only modest adsorption capacity toward most of the metal ions. Conversely, the marine algae Sargassum performed reasonably well in the biosorption of heavy metal ions and exhibited more than 90% removal toward Cu and Pb. The seafood industry waste, crab shell, displayed a superior performance in heavy metal biosorption, with more than 93% removal efficiency for all heavy metal ions. However, it is worth noting that the concentrations of most of the light metal ions in the final effluent were greater than the inlet storm-water runoff for most of the examined sorbents. This is because most of the sorbents were previously loaded or comprise light metal ions on their surface, which when contacted with runoff were released the ions into the solution. For instance, the marine algae acquires Na, K, Ca, and Mg from seawater, which when contacted with metal solution exchanges these light metal ions with heavy metal ions from solution due to ion-exchange mechanism. Based on the experimental results obtained, the crab shell was selected for further studies.

Sorption Mechanism of Crab Shell

Initially, the surface of crab shell and its constituents were analyzed using SEM/EDX (Fig. 2). The SEM micrograph revealed that the surface of crab shell was not smooth and contained protuberances [Fig. 2(a)]. In energy-dispersive x-ray (EDX) analysis, strong Ca peaks were observed, which implied that shell particles contained calcium carbonate. The peaks corresponding to carbon, nitrogen, sulfur, oxygen, and phosphorous were recorded in the EDX spectrum. These elements were present in the crab shell as the main constituents of chitin and protein. The presence of calcium carbonate in crab shells is mainly responsible for their excellent metal removal efficiency (Lee et al. 1998; Vijayaraghavan et al. 2009). Calcium carbonate dissociates into calcium and carbonate ions, depending on the solution pH, which in turn leads to the formation of metal carbonate precipitates upon contact with metal ions in solutions. It should be noted that the solubility of CaCO₃ may vary with the solution pH. The speciation of carbonate ions can be defined in three pH ranges, viz., pH<6.3, 6.3<pH<10.3, and 10.3>pK₂, which in turn correspond to H₂CO₃, HCO₃⁻, and CO₃²⁻, respectively (Morris et al. 1997). Among these species, HCO₃⁻ and CO₃²⁻ could be responsible for the formation of insoluble metal carbonates. It should be noted that the initial pH 4.9 ± 0.1 increased to 9.2 ± 0.2 within 15 min of contact. This increase in pH was presumably due to dissolution of carbonate species from calcium carbonate in crab shells (Lee et al. 1997). The SEM observation confirmed that after biosorption, considerable changes in the surface morphology of crab shells were apparent. Surface protuberances decreased and a thin layer of deposition was observed [Fig. 2(b)]. EDX analysis [Fig. 2(b)] revealed the presence of all the examined metal ions along with all other components identified in control crab shell sample.

The availability of metals was strongly controlled by their solution speciation, which was in turn influenced by the solution pH. Pb(II) exists as Pb²⁺ and PbOH⁺ at pH≤6, beyond which Pb(OH)₂ tends to dominate (Morris et al. 1997). In the case of Cd(II), it exists as Cd²⁺ up to pH~8.0, after which CdOH⁺ and Cd(OH)₂ start to form (Srivastava et al. 2004). On the other hand, Zn(II) is present mainly as Zn²⁺ at pH<7, and at pH≥9, it exists mainly as Zn³⁺ and Zn(OH)₂ and in less quantities as Zn(OH)⁺ (Carrott et al. 1997). The dominating Ni species is Ni²⁺ until about pH 9.5, followed by the hydroxide species Ni(OH)₂ and Ni(OH)₃ at higher pH (Ji and Cooper 1996). Cu(II) speciation is dominated by free Cu²⁺ and increasingly by carbonate and hydroxyl complexes as pH rises above 6.5 ( Lal 2006). Cobalt and manganese are mainly present as Co³⁺ and Mn²⁺ in acidic conditions (Cornelis et al. 2005). As the pH of urban runoff was around 4.9 ± 0.1, all of the heavy metal ions were in divalent form.

Thus, the removal mechanism could be attributed to be micro-
precipitation of metal ions onto the surface of crab shell particles. The presence of chitin in crab shells favors adsorption of metal microprecipitates (Lee et al. 2004). In particular, the –NCOCH3 group of chitin plays a significant role in the binding of metal precipitates (Lee et al. 1997, 1998). Thus, the mechanism of metal removal by crab shells is proposed to be as follows:

\[
\text{Crab shell(CaCO}_3 + \text{chitin}) + \text{H}_2\text{O} \\
\rightarrow \text{Crab shell(chitin)} + \text{Ca}^{2+} + \text{CO}_3^{2-} \\
\text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{OH}^- \\
\text{M}^{2+} + \text{CO}_3^{2-} \rightarrow \text{MCO}_3(s)
\]

\[
\text{MCO}_3(s) + \text{Crab shell(chitin)} \rightarrow \text{Crab shell(chitin)} - \text{solid}
\]

Crab shells showed varied affinities toward different metal ions. In general, the removal efficiency toward light metal ions was lower compared to that of heavy metal ions. It should also be noted that a major leaching of calcium and magnesium was observed during crab shell biosorption. This observation directly supports our finding that dissolution of calcium carbonate to Ca\(^{2+}\) and CO\(_3^{2-}\) was responsible for metal removal by crab shells. For the heavy metal ions examined, crab shells performed very well with removal efficiencies greater than 93%. Since the initial concentration of each metal ion was different in runoff, no effort was made to compare the selectivity of crab shells toward each metal ion. In previous research efforts, crab shells were identified as an excellent biosorbent for cobalt (Vijayaraghavan et al. 2006a), chromium (Niu and Volesky 2006), copper (Vijayaraghavan et al. 2006a), lead (Lee et al. 1997), and nickel (Vijayaraghavan et al. 2004). However, it should be noted that crab shells were effective only at very high metal concentrations and single-solute systems. In this study, the potential of crab shell in the remediation of dilute- and multmetal systems was identified for the first time.

**Kinetic Studies**

Kinetic experiments were conducted to examine the rate of metal removal by crab shell particles. The rate of heavy metal removal by crab shells was rapid and equilibrium was attained within 25 min [Fig. 3(a)]. The concentrations of calcium and magnesium ions increased with time [Fig. 3(b)]. This observation directly explains that heavy metal uptake by crab shells was directly associated with leaching of Ca and Mg ions from crab shells. Interestingly, crab shell exhibited a general trend for all heavy metal ions in that the metal uptake was a rapid process in the first few minutes followed by equilibrium attainment, indicating the high affinity of crab shell toward all heavy metal ions. This can be attributed to the low metal content of storm-water runoff and the high biosorption potential of crab shells. The rapid sorption kinetics observed with the crab shell serves as an advantage when storm-water treatment systems are to be designed and operated in a continuous column mode.

**Desorption**

The attractiveness of the sorption process is enhanced when the possibility of recovery of adsorbed solutes and thereby reuse of sorbents exists. Desorption was attempted using de-ionized water, 0.1-M NaCl, 0.01-M HCl, and 0.1-M HCl at a solid to liquid ratio of 2 g/L. Results revealed that de-ionized water and 0.01-M HCl were not able to desorb metal ions from crab shell. This clearly indicates that sorbed ions were strongly held onto crab shell and thus resistant to washing with water or even mild acidic solutions. On the other hand, NaCl also failed to perform well in desorption. Since the mechanism of metal removal by crab shell is microprecipitation followed by adsorption, the high ionic strength solution (0.1-M NaCl) was unable to facilitate desorption through ion exchange. However, 0.1-M HCl was very effective in desorption with elution efficiencies of 96.4, 97.0, 98.4, 98.9, 99.1, 99.6, and 99.6% in the case of Cu, Pb, Zn, Co, Cd, Mn, and Ni, respectively. For light metal ions, the eluant leached additional Ca and Mg from crab shell particles whereas Na and K concentrations remained constant. In order to analyze the stability of crab shell after sorption-desorption cycle, weight of shell particles was measured. The weight loss was found to be 17%. It is known that the mineral constituents of crab shell tend to dissolve under strong acidic conditions (Vijayaraghavan et al. 2006a). The main constituents of crab shell, calcium and magnesium, leached during both sorption [Fig. 3(b)] and desorption resulted in this significant weight loss.

**Packed Column**

For continuous treatment of storm-water runoff, a column packed with crab shell was employed. Table 1 summarizes the column capacity and % metal removal obtained for different metal ions in
storm-water runoff. In practical applications, operation of biosorption column has to be stopped as soon as the metal ion concentration in the effluent exceeds the regulatory limit (Vijayaraghavan et al. 2006b). Since different metal ions of varied regulatory limits have been present in the storm-water runoff, we fixed the column breakthrough when any of the outlet heavy metal ion concentration exceeded 0.3 times of its initial concentration.

It is evident from the results presented in Table 1 that crab shell performed very well in continuous removal of heavy metal ions from storm-water runoff. The total volume of storm water treated during entire sorption cycle was 115 L or 1,017 bed volumes. For the first 12 h, the crab shell was able to retain all heavy metal ions and no significant concentration of heavy metal ion was detected in the effluent. As the time progressed, the concentration of Mn²⁺ was found to increase in the effluent. It should be noted that the initial concentration of Mn²⁺ was higher than that of other heavy metal ions. After 29 h, cobalt appeared in the effluent in significant concentrations \((C_i/C_0)\) which steadily increased with time. Heavy metal ions such as Cu²⁺ and Cd²⁺ were detected in the effluent only after 82 h. On the other hand, Ni²⁺ and Zn²⁺ appeared only after 136 h. No evidence of Pb²⁺ (above 50 \(\mu g/L\)) was observed in the effluent during entire column operation of 192 h. A critical analysis of the performance of crab shell in terms of metal uptake revealed that this sorbent possesses very high uptake toward all heavy metal ions. Removal efficiencies were greater than 85% for all heavy metal ions. For light metal ions such as Na and K, as expected, very low capacity and removal efficiency were observed. It is worth noting that the effluent pH increased rapidly for the first few hours and then remained steadily at pH 8.1 (Fig. 4). The increase in effluent pH is due to dissolution of carbonate species from calcium carbonate in crab shells [Eqs. (1) and (2)]. As observed in batch experiments [Fig. 3(b)], excessive leaching of calcium and magnesium occurred from the crab shell. This resulted in very high concentrations of Ca²⁺ and Mg²⁺ in the effluent samples. A strong correlation between the inorganic leaching from crab shell and effluent pH can be seen in Fig. 4.

### Table 1. Performance of Crab Shell-Loaded Packed Column during the Treatment of Storm-Water Runoff

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Cu</th>
<th>Co</th>
<th>Cd</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>((C_i/C_0))</td>
<td>0.96</td>
<td>0.92</td>
<td>1.76</td>
<td>1.15</td>
<td>0.31</td>
<td>0.02</td>
<td>0.31</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Capacity (mg/g)</td>
<td>2.32</td>
<td>7.43</td>
<td>–90.9</td>
<td>–10.0</td>
<td>28.9</td>
<td>7.94</td>
<td>7.11</td>
<td>4.84</td>
<td>1.55</td>
<td>7.96</td>
<td>7.89</td>
</tr>
<tr>
<td>Removal efficiency (%)</td>
<td>2.86</td>
<td>9.23</td>
<td>–113.4</td>
<td>–12.6</td>
<td>86.9</td>
<td>99.3</td>
<td>85.8</td>
<td>98.7</td>
<td>≥95.0</td>
<td>99.8</td>
<td>99.8</td>
</tr>
</tbody>
</table>

\(^a\)Outlet metal concentration/inlet metal concentration.

**Suitability of Application**

With the biosorbent, crab shell, performing well in both batch and continuous modes, it is very important to address the mode of application needed for a full-scale treatment system. A variety of storm-water treatment technologies has been developed in recent years. Among these technologies, biofiltration (also known as biofilters, bioretention systems, and rain gardens) operates by filtering diverted runoff through dense vegetation followed by vertical filtration through filter media (Bratieres et al. 2008). Storm-water treatment is achieved via a number of processes including sedimentation, fine filtration, sorption, and biological uptake. Water is then collected in underdrains at the base of the filter media for discharge to receiving waters or storage for reuse (Hatt et al. 2009). The filter media usually consists of sand, bark or compost, and a drainage layer. It is well known that sand-based filter media remove TSS effectively (Bratieres et al. 2008). However, it is not effective in removing heavy metal ions. Crab shell with its high biosorption capacity toward different heavy metal ions, fast metal removal rate even at high flow rates, and good mechanical strength can act as a perfect additive in sand-based filter media. A separate layer of crab shell can be incorporated into biofilters, especially after the sand layer, so that suspended solids-free effluent can enter crab shell section. Once heavy metal ions are bound to crab shells, they cannot be washed out easily even under extreme natural acidic conditions which are commonly found in urban roof runoff. This finding is a very important factor in the context of developing and operating a continuous storm-water treatment scheme, as some ion-exchange-based filter media has the potential to give out metal ions in exchange of protons (Pitcher et al. 2004). A potential disadvantage of using crab shell in biofilters is its tendency to increase the effluent pH which is directly associated with the leaching of calcium and magnesium. Currently, research is underway to control excessive leaching of Ca²⁺ and Mg²⁺ from crab shell through surface functionalization.

**Conclusions**

In this study, seven low-cost sorbents were screened on the basis of their heavy metal removal efficiency from urban storm-water runoff. Of these sorbents, crab shell performed well with removal efficiencies over 93% for different metal ions including Co, Cu, Pb, Mn, Zn, Ni, and Cd. Being abundantly generated as waste in seafood industries, the disposal routes of crab shells have become increasingly restricted. For example, landfill is not permitted for raw or untreated seafood waste disposal. Hence, an alternative route such as efficient reutilization of these seafood wastes for
environmental applications is highly desired by seafood industries. The results of this study indicate that crab shells can be used for the removal of trace amounts of heavy metal ions from stormwater runoff. The current study also highlighted possible applications of crab shells in biofilters. However, additional research is needed to control the leaching of calcium and magnesium from crab shells.

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