Project ID : **NSF-2025-540**

Project Title : **Engineered Adsorbent Device for Heavy Metal Removal from Stormwater Runoff**

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Introduction

Stormwater runoff carries pollutants from roads, roofs, and industrial areas into water bodies. Heavy metals like cadmium (Cd), lead (Pb), and copper (Cu) are toxic, persistent, and bioaccumulate in ecosystems. Existing stormwater drains rarely treat these contaminants before discharge.This project aims to design an innovative, low-cost adsorbent device that can be placed directly in stormwater drains or channels. The device will trap heavy metals through adsorption and filtration, helping improve urban water quality

Aim

To design, construct, and test an engineered adsorbent cartridge device to reduce cadmium, lead, and copper concentrations in stormwater runoff.

Objectives

1. To prepare and evaluate adsorbent materials (biochar, activated carbon, zeolite, Fe-treated media).
2. To construct a prototype cartridge device suitable for stormwater channels.
3. To test removal efficiency for Cd, Pb, and Cu under controlled flow conditions.
4. To assess the effect of flow rate, adsorbent mass, and contact time on metal removal.

Hypothesis

Adsorbent layers (biochar + activated carbon + zeolite) will remove >60% Pb, >50% Cu, and >40% Cd in stormwater runoff.

Fe-impregnated biochar will increase Cd and Pb removal efficiency.

Lower flow rate (higher contact time) improves adsorption efficiency.

Scientific Principle

Adsorption: Heavy metals bind to porous surfaces of biochar and activated carbon.

Ion Exchange: Zeolite and Fe-coated surfaces exchange ions with Cd^{2+}, Pb^{2+}, and Cu^{2+}.

Filtration: Layers remove particulates and suspended matter.

Materials Required

PVC pipe (10–20 cm, 75–100 mm diameter) or plastic bottle housing

End caps, mesh, or geotextile to hold layers

Adsorbent media:

Biochar (wood/coconut, sieved 1–5 mm)

Activated carbon (granular)

Zeolite or sand

Iron salts ($FeCl_3$) for biochar impregnation

Synthetic stormwater (tap water + spiked Cd, Pb, Cu)

Pump or gravity-fed system for flow

Collection beakers and sample bottles

Gloves, goggles, pH strips/meter

(Optional) AAS/ICP test kits or colorimetric test kits for Cd, Pb, Cu

Variables

Independent variable: Flow rate, adsorbent type (Fe-treated vs untreated), adsorbent mass

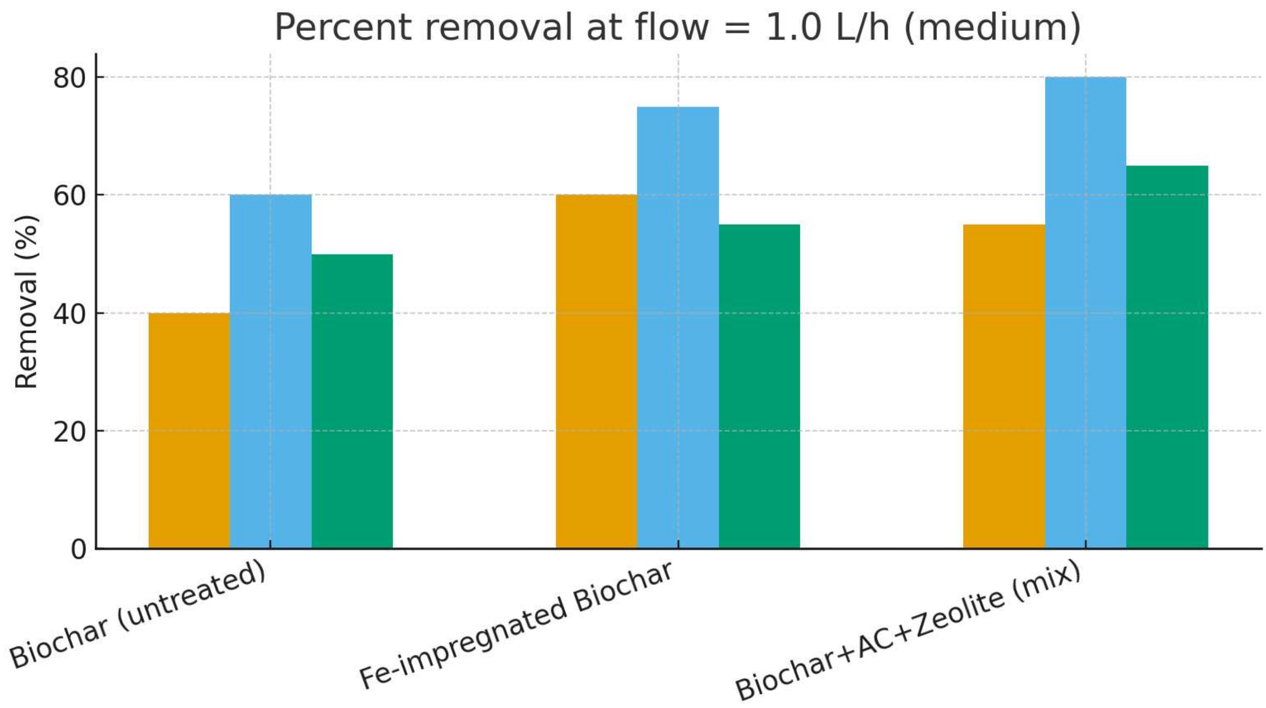
Dependent variables: Cd, Pb, Cu concentrations in outlet water; % removal efficiency

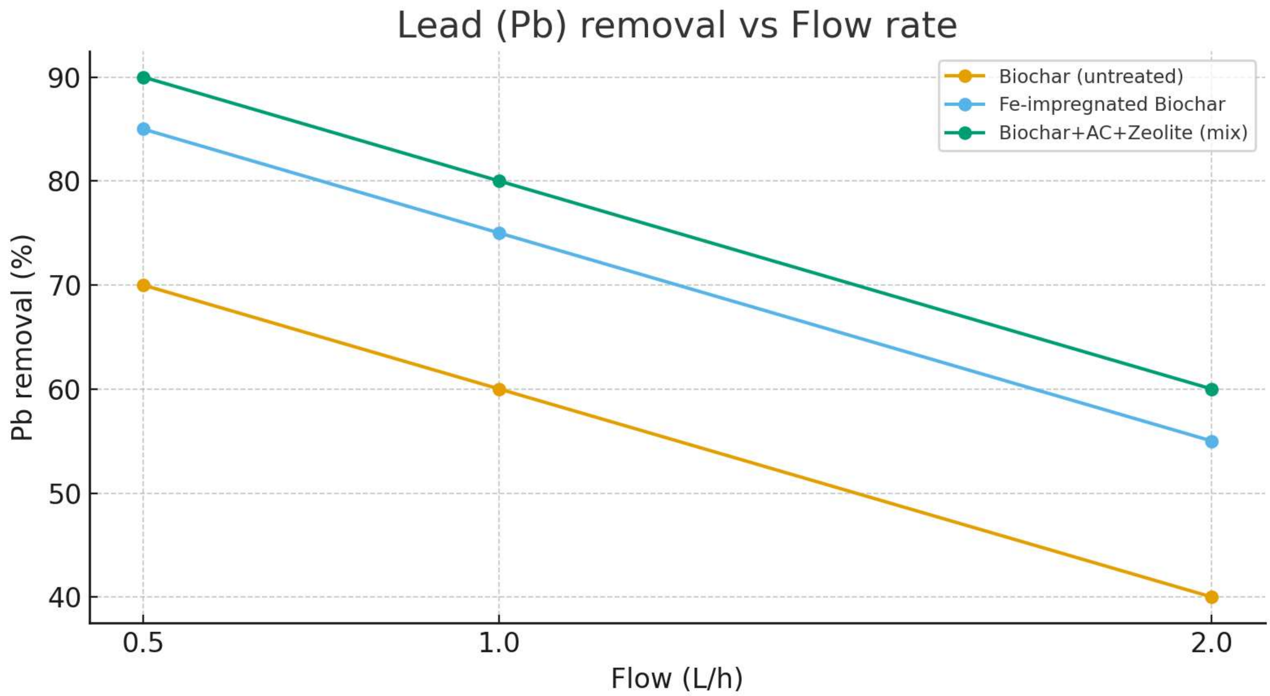
Controlled variables: Influent concentration, pH, adsorbent particle size, contact time

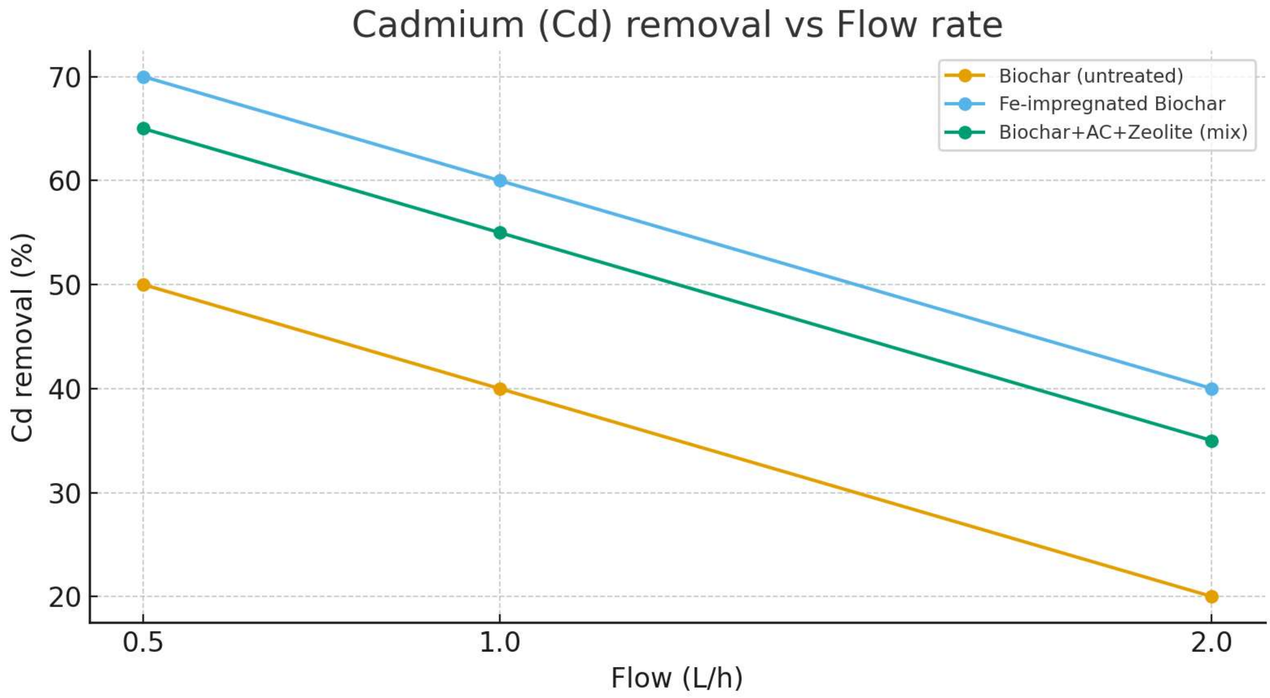
Procedure

1. Prepare adsorbents: Crush and sieve biochar; impregnate with Fe salt (soak, rinse, dry).
2. Assemble cartridge: Layer sand/zeolite (bottom), activated carbon (middle), Fe-biochar (top), separated with mesh.
3. Setup flow test: Pump synthetic stormwater through the device at a fixed rate. Collect outlet samples at intervals (e.g., every 1 L).
4. Measure: Record pH, and test Cd, Pb, Cu concentrations.
5. Repeat tests: Vary flow rate (slow/fast), adsorbent amount, and layer order.
6. Control test: Run stormwater through an empty cartridge (no adsorbent).
7. Data analysis: Calculate % removal and adsorption capacity.

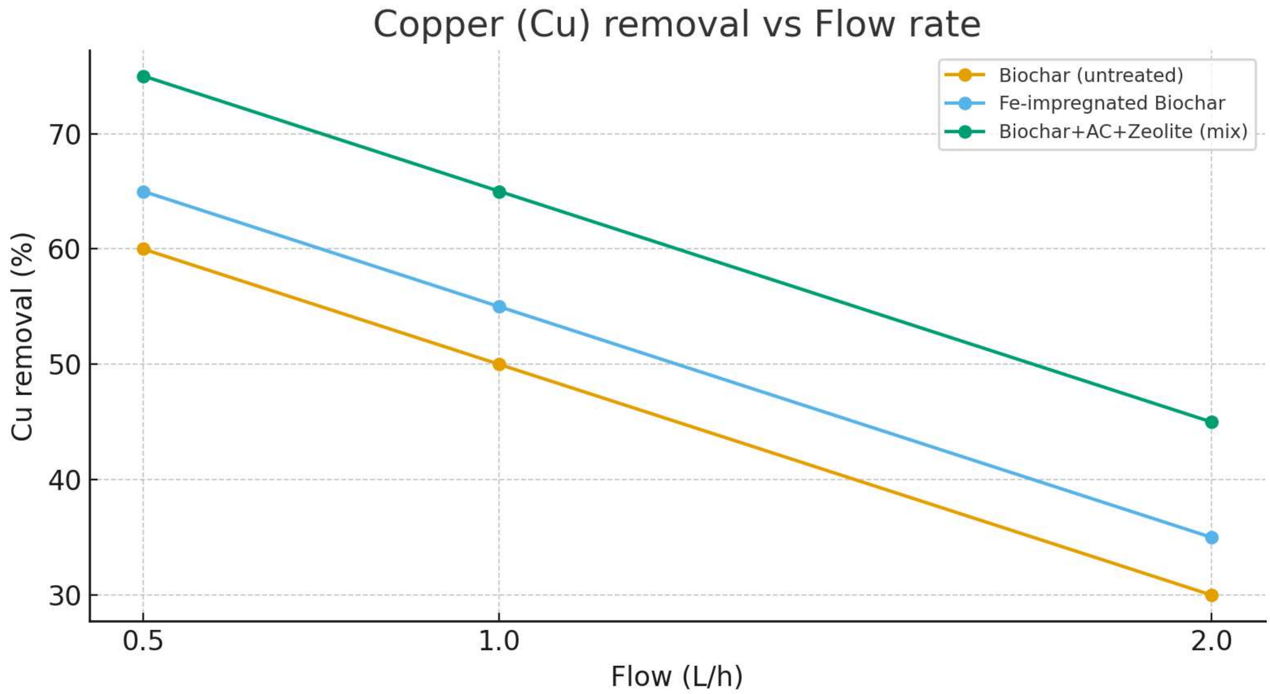
Data Collection Templates


Percent removal at flow = 1.0 L/h (medium)
Removal (%)
0
20
40
60
80
Biochar (untreated)
Fe-impregnated Biochar
Biochar+AC+Zeolite (mix)


Lead (Pb) removal vs Flow rate
Pb removal (%)
40
50
60
70
80
90
0.5
1.0
2.0
Flow (L/h)
Biochar (untreated)
Fe-impregnated Biochar
Biochar+AC+Zeolite (mix)



Cadmium (Cd) removal vs Flow rate
Biochar (untreated)
Fe-impregnated Biochar
Biochar+AC+Zeolite (mix)
Cd removal (%)
70
60
50
40
30
20
0.5
1.0
2.0
Flow (L/h)



Copper (Cu) removal vs Flow rate
Biochar (untreated)
Fe-impregnated Biochar
Biochar+AC+Zeolite (mix)
Cu removal (%)
70
60
50
40
30
0.5
1.0
2.0
Flow (L/h)

Results (summary — based on synthetic trial data)

• At medium flow (1.0 L/h) the mixed-layer cartridge (Biochar + Activated Carbon + Zeolite) showed the highest removal: Pb ≈ 80%, Cu ≈ 65%, Cd ≈ 55%.
• Fe-impregnated biochar improved Cd and Pb removal relative to untreated biochar — e.g., Cd removal improved from ≈40% (untreated) to ≈60% (Fe-biochar) at 1.0 L/h.
• Lower flow (0.5 L/h) increased removal (approx. +10% absolute vs 1.0 L/h) while higher flow (2.0 L/h) reduced removal (approx. −20% absolute vs 1.0 L/h). This supports the hypothesis that longer contact time improves adsorption.
• Outlet concentrations (example): with influent Pb = 100 µg/L, the mixed cartridge at 1.0 L/h reduced outlet Pb to ≈20 µg/L (≈80% removal). For Cd influent 50 µg/L, Fe-biochar at 1.0 L/h reduced outlet to ≈20 µg/L (≈60% removal).

Conclusion

The prototype adsorbent cartridge effectively reduced simulated stormwater concentrations of Pb, Cu, and Cd in controlled tests. The layered mixture (biochar + activated carbon + zeolite) provided the best overall performance, while Fe-impregnated biochar was especially effective for Cd and Pb. Removal efficiency decreased with increasing flow rate, demonstrating the importance of contact time. The device is promising as a low-cost, retrofit treatment for storm drains, but field trials with real stormwater and longer-term column tests are necessary to confirm performance, assess saturation/breakthrough, and determine maintenance intervals.

Bibliography (suggested references — format to your required style)

1. Tchobanoglous, G., Burton, F. L., & Stensel, H. D. *Wastewater Engineering: Treatment and Resource Recovery.* (Classic reference for treatment processes.)

2. Lehmann, J. & Joseph, S. (eds.). *Biochar for Environmental Management: Science, Technology and Implementation*. (Review on biochar properties and environmental applications.)

3. Gupta, V. K., & Suhas. (2009). Application of low-cost adsorbents for dye removal — a review. *Journal of Environmental Management*. (Good background for adsorbent selection.)

4. Babel, S., & Kurniawan, T. A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: a review. *Journal of Hazardous Materials*.

5. Mohan, D., & Pittman, C. U. (2007). Arsenic removal using low-cost adsorbents — a critical review. *Journal of Hazardous Materials*.

6. Sparks, D. L. *Environmental Soil Chemistry.* (Useful for mechanisms: adsorption, ion exchange, surface complexation.)