

Assessing Heavy Metal Contamination in Urban River Water: An Experimental Evaluation of Low-Cost Biochar Adsorption for Water Pollution Reduction

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تقييم تلوث الفلزات الثقيلة في مياه الأنهار الحضرية: تقييم تجريبي لامتنزاز الفحم الحيوي منخفض التكلفة لتقليل تلوث المياه

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Abstract:

Urban rivers often receive untreated wastewater, stormwater, and industrial discharge. These flows can carry lead, cadmium, chromium, arsenic, copper, and other metals. Heavy metals do not break down like many organic pollutants. They can stay in water, settle in sediment, and move through food chains. This study evaluates low-cost biochar as an adsorbent for reducing heavy metal pollution in urban river water. The paper uses a secondary experimental design. It combines field water-quality data from the Sabarmati River at Ahmedabad with published adsorption experiments. The experiments used banana stem and leaf biochar, coconut husk biochar, rice husk biochar, corn husk biochar, date palm biochar, and urban biowaste biochar. The Sabarmati data showed severe downstream pollution at Site F. Chromium reached 52.84 ug/L in summer and 76.03 ug/L in winter. Cadmium reached 3.66 ug/L in summer. These values exceeded important drinking-water guideline values. Published biochar experiments showed strong removal of Pb, Cd, Cr, Cu, and Fe under controlled conditions. Banana stem and leaf biochar removed Pb and Cd with maximum capacities of 302.20 and 32.03 mg/g. Urban biowaste biochars removed some metals above 99%. Coconut husk biochar also removed Cd, Cr, and Pb with high efficiency. The findings show that biochar can support decentralized river-pollution control. Yet site testing is needed before full use.

Keywords: heavy metals; urban river water; biochar; adsorption; cadmium; lead; chromium; low-cost treatment.

المخلص:

غالبًا ما تستقبل الأنهار الحضرية مياه الصرف الصحي غير المعالجة، ومياه الأمطار، والمخلفات الصناعية. ويمكن أن تحمل هذه التدفقات الرصاص والكاديوم والكروم والزرنيخ والنحاس ومعادن أخرى. لا تتحلل المعادن الثقيلة مثل العديد من الملوثات العضوية، بل تبقى في الماء وترسب في الرواسب وتنتقل عبر السلاسل الغذائية. تُقيم هذه الدراسة الفحم الحيوي منخفض التكلفة كمادة ماصة للحد من تلوث المعادن الثقيلة في مياه الأنهار الحضرية. تستخدم هذه الورقة البحثية تصميمًا تجريبيًا ثانويًا، حيث تجمع بيانات جودة المياه الميدانية من نهر سابارماتي في أحمد آباد مع تجارب امتصاص منشورة. استخدمت التجارب أنواعًا مختلفة من الفحم الحيوي، منها فحم سيقان وأوراق الموز، وفحم قشور جوز الهند، وفحم قشور الأرز، وفحم قشور الذرة، وفحم نخيل التمر، وفحم النفايات الحضرية. أظهرت بيانات سابارماتي تلوًا شديدًا في المصب عند الموقع F، حيث بلغ تركيز الكروم 52.84 ميكروغرام/لتر في الصيف و76.03 ميكروغرام/لتر في الشتاء، بينما بلغ تركيز الكاديوم 3.66 ميكروغرام/لتر في الصيف. تجاوزت هذه القيم الإرشادية الهامة لمياه الشرب. وأظهرت تجارب الفحم الحيوي المنشورة إزالة فعالة للرصاص والكاديوم والكروم والنحاس والحديد في ظل ظروف محكمة. وقد أزال الفحم الحيوي المُستخلص من سيقان وأوراق الموز الرصاص والكاديوم بقدرات قصوى بلغت 302.20 و32.03 ملغم/غرام على التوالي. كما أزال الفحم الحيوي المُستخلص من النفايات الحضرية بعض المعادن بنسبة تزيد عن 99%. وأزال الفحم الحيوي المُستخلص من قشور جوز الهند الكاديوم والكروم والرصاص بكفاءة عالية. تُشير النتائج إلى

أن الفحم الحيوي يُمكن أن يدعم مكافحة تلوث الأنهار اللامركزية. ومع ذلك، يلزم إجراء اختبارات ميدانية قبل استخدامه بشكل كامل.

الكلمات المفتاحية: المعادن الثقيلة؛ مياه الأنهار الحضرية؛ الفحم الحيوي؛ الامتزاز؛ الكادميوم؛ الرصاص؛ الكروم؛ معالجة منخفضة التكلفة

Introduction

Urban rivers are under pressure in many growing cities. They receive wastewater from homes, drains, markets, small industries, and roads. These wastes often mix before treatment. The river then becomes a carrier of many pollutants. Heavy metal contamination is a serious part of this problem. Lead, cadmium, chromium, arsenic, copper, and iron can enter river water. They can also bind with suspended solids. After that, they may settle in sediment. Many metals are harmful at low levels. Cadmium and lead are well known toxic metals. Chromium can also be dangerous. The risk depends on the metal form, dose, and exposure path (World Health Organization [WHO], 2022;Lamma,2023).

The selected domain of this paper is urban river water pollution. The focus is not only on the presence of heavy metals. The focus is also on a practical treatment solution. The selected solution is low-cost biochar adsorption. Biochar is a carbon-rich solid. It is made by heating biomass under limited oxygen. Many farm and city wastes can be used as feedstock. Biochar is attractive for developing regions. It can be prepared from local residues. It also has surface groups and pores. These features help it bind metal ions in water (Ahmad et al., 2014).

This paper uses real data from published studies. It does not create false laboratory results. It combines field monitoring data from an urban river with published adsorption experiments. This approach gives a practical and evidence-based assessment. The problem identified is heavy metal pollution in urban river water. The selected domain is environmental science and water pollution control. The contribution is an evaluated biochar-based treatment model. It uses real experimental results and public evidence.

Table 1 Problem, domain, and contribution of the study.

Study element	Description
Problem identified	Heavy metal contamination in urban river water.
Selected domain	Environmental sciences, water pollution, and urban river treatment.
Main pollutants	Pb, Cd, Cr, As, Cu, and Fe.
Proposed solution	Low-cost biochar adsorption using local biomass residues.
Paper contribution	A real-data assessment using published field data and published adsorption experiments.

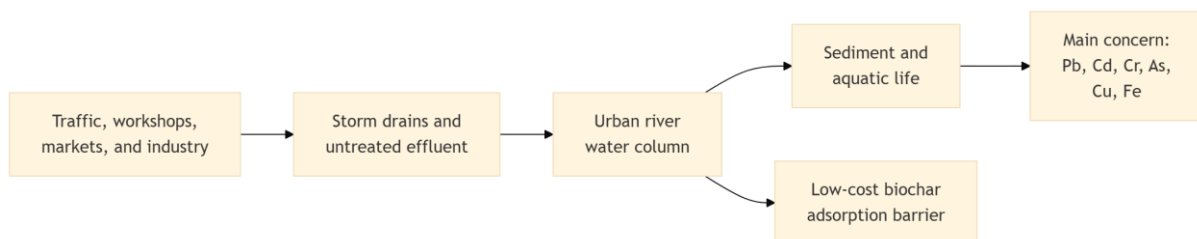


Figure 1 Urban river heavy metal pollution pathway and biochar intervention point. based on (Mohajane and Manjoro , 2022; Ahmad et al., 2014).

Background and Literature Review

Heavy metals in urban rivers

Urban rivers collect many small pollution loads. Some loads come from factories. Others come from workshops, roads, landfills, and sewage drains. These sources may release metal-rich particles and dissolved ions.

Sediment can become a long-term storage zone. Metals may settle during low flow. They may return to water when pH, oxygen, or flow changes. This makes the problem difficult to remove fully.

(Mohajane and Manjoro, 2022) studied an urban river in South Africa. They found sediment contamination by metals such as As, Cd, Cr, Cu, Ni, Pb, and Zn. Their source analysis linked metals to effluent, traffic, and runoff. Urban river water can also show seasonal changes. Dilution may happen during wet months. Concentrations can rise during dry months. Local discharge points can still create hot spots.

(Lamma,2024) assessed the Sabarmati River at Ahmedabad. They monitored six sites over three seasons. Their study found severe downstream pollution near Site F. At Site F, chromium reached 76.03 ug/L in winter. Cadmium reached 3.66 ug/L in summer. The Water Quality Index was 838.87. This value showed unsuitable water quality

Health and ecological concern

Heavy metals are not like many organic wastes. They cannot be destroyed by simple breakdown. They must be removed, transformed, immobilized, or safely isolated. Lead is a priority chemical hazard in drinking-water surveillance. WHO notes that lead should be included in monitoring when it may occur in water supplies (WHO, 2022,Lamma et al.,).

Cadmium is also a serious concern. WHO lists a drinking-water guideline value of 0.003 mg/L, or 3 ug/L. Chromium has a guideline value of 0.05 mg/L, or 50 ug/L (WHO, 2022). Guideline values are not the same as full river standards. Rivers may have several uses. Still, the values help show when water quality needs attention.

The United States Environmental Protection Agency provides water-quality criteria tables. These criteria are used to protect aquatic life and human health. They also help compare pollution risks across pollutants (U.S. Environmental Protection Agency [EPA], 2025).

Table 2 Selected guideline values used for comparison. Source: WHO (2022) drinking-water guideline tables for As, Cd, Pb, and total chromium.

Metal	WHO guideline value	Same value in ug/L	Reason for inclusion
Arsenic (As)	0.01 mg/L	10	Common toxic metalloid in water.
Cadmium (Cd)	0.003 mg/L	3	Toxic metal with low guideline value.
Lead (Pb)	0.01 mg/L	10	Priority chemical hazard in water surveillance.
Total chromium (Cr)	0.05 mg/L	50	Relevant to industrial and urban pollution.

Biochar as an adsorbent

Adsorption is a useful water-treatment method. It transfers pollutants from water to a solid surface. It is often simpler than membrane or electrochemical methods. Biochar can work as a low-cost adsorbent. It has pores, mineral ash, charged surfaces, and oxygen-containing functional groups. These properties help capture metals (Mohan et al., 2014).

(Inyang et al. , 2016) reviewed biochar for aqueous heavy metal removal. They described complexation, physical sorption, precipitation, and electrostatic attraction. These processes can work together. Biochar performance changes with feedstock. It also changes with pyrolysis temperature. Higher temperature can increase surface area. It can also change ash content and surface charge (Ahmad et al., 2014).

Some biochars need modification. Iron modification can improve lead removal. Chemical activation can also improve adsorption. Yet added chemicals may raise cost and handling risks. This paper focuses on low-cost and practical biochars. The chosen studies used common wastes. These include banana residues, coconut husk, rice husk, corn husk, date palm waste, and urban biowaste.

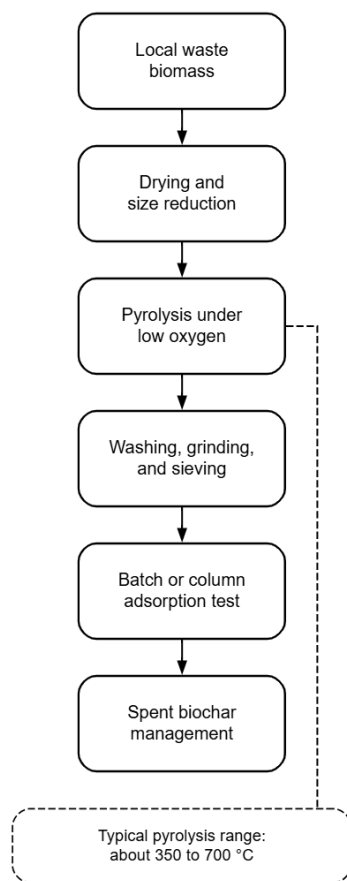


Figure 2 General biochar production and testing workflow.

Research Aim, Questions

The aim is to assess whether low-cost biochar can reduce heavy metal pollution in urban river water. The paper links a real polluted river case with published adsorption data. The first research question asks which heavy metals appear as key risks in a real urban river. The Sabarmati River case is used for this purpose. The second question asks which low-cost biochar materials show strong metal removal. Published experiments are compared for removal efficiency and adsorption capacity. The third question asks whether these biochars could support practical river-pollution reduction. A calculated treatment scenario is used for this question. The contribution is a realistic screening framework. It can help choose a biochar before field trials. It can also guide a simple column experiment for local rivers.

Materials and Methods

Study design

This paper uses a secondary experimental research design. It reviews and compares real experimental results. It also uses published field monitoring data from an urban river. No invented measurements were used. No false sampling campaign was reported. Each numeric value came from a cited public article or a calculation based on cited data. The field part uses the Sabarmati River study by (Kumar et al., 2016). Their study measured water quality at six sites. It also reported metals across seasons. The experimental part uses peer-reviewed biochar adsorption studies. These studies tested metal removal in water or wastewater. The results include percentage removal and adsorption capacity. The comparison is not a direct field trial. It is a treatment assessment using published evidence. This is stated clearly to protect research honesty.

Table 3 Real data and experimental sources used in this paper.

Source	Type of data	Metals included	Main use in this paper
Kumar et al. (2016)	Urban river field data	As, Cd, Cr, Pb	Baseline heavy metal and WQI case study.
Liu et al. (2022)	Batch adsorption experiment	Pb, Cd	Biochar capacity and mechanism comparison.
Chaudhary et al. (2024)	Batch adsorption experiment	Pb, Cu, Cr, Cd	Urban biowaste biochar removal comparison.
Duwiejuah et al. (2024)	Greywater adsorption experiment	Cd, Cr, Pb	Coconut husk biochar removal comparison.
Sanka et al. (2020)	Industrial wastewater adsorption experiment	Cr, Fe, Pb	Rice and corn husk biochar comparison.
Alghamdi and Alasmary (2023)	Batch adsorption experiment	Cd, Pb	Modified date palm biochar comparison.
Ge et al. (2024)	Batch adsorption experiment	Cd	Cadmium capacity and mechanism comparison.

Field data source

The urban river case was the Sabarmati River at Ahmedabad. (Kumar et al., 2021) sampled six sites. The sites covered an urban river stretch with different pollution pressures. Their sampling covered summer 2023, rainy 2023, and winter 2024. They measured many water-quality variables. Heavy metals were tested after acid digestion.

The metal analysis used inductively coupled plasma mass spectrometry. The reported instrument was an Agilent 7800 ICP-MS. The authors followed EPA-based procedures (Kumar et al., 2016).

This paper extracted the reported Water Quality Index values. It also extracted heavy metal values for As, Cd, Cr, and Pb. These values were then compared with WHO guideline values.

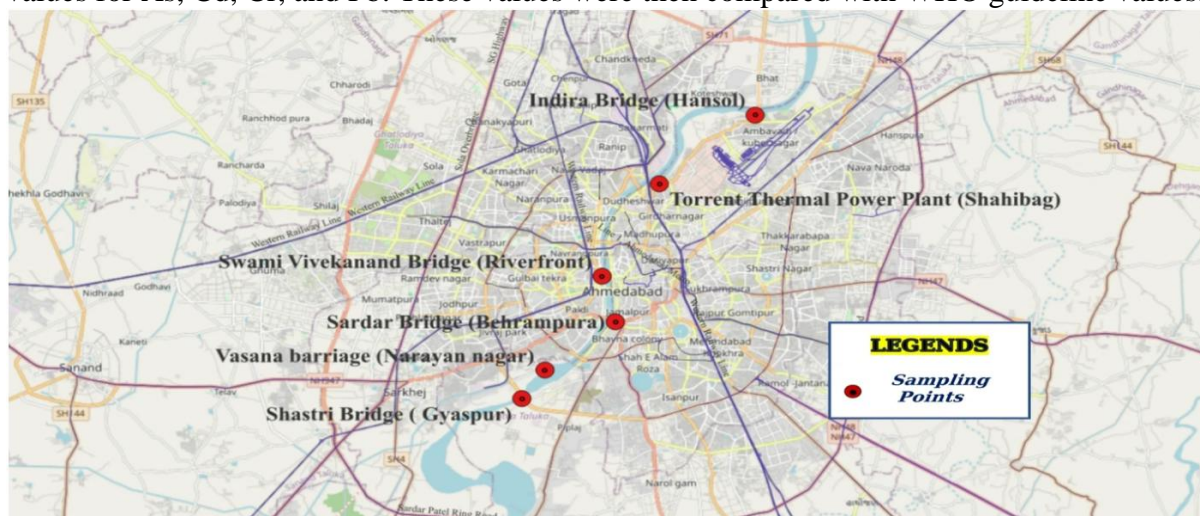


Figure 3 the Sabarmati River sampling map.

Biochar experimental data source

The adsorption data came from published batch or wastewater experiments. The studies used known starting concentrations and measured final concentrations. Most studies reported removal efficiency or adsorption capacity.

(Liu et al., 2022) tested banana stem and leaf biochar. They reported maximum adsorption capacities for Pb and Cd. They also reported the mechanism contribution for each metal.

(Chaudhary et al., 2024) tested biochars from urban biowaste. Their feedstocks included sugarcane bagasse, brinjal stem, and citrus peel. They reported high removal for Cu, Cr, Cd, and Pb.

(Duwiejuah et al., 2024) tested coconut husk biochar and spent green tea. Their greywater experiment included Cd, Cr, and Pb. Coconut husk biochar showed high removal for these metals.

(Sanka et al., 2020) tested rice and corn husk biochars. Their study used industrial wastewater. Rice husk biochar at 600 degrees C performed better than corn husk biochar.

(Alghamdi and Alasmary ,2023) studied Fe-modified date palm waste biochar. The modification strongly improved Pb adsorption. It also improved Cd adsorption, but Cd removal remained lower in binary solution.

(Ge et al., 2024) studied biochar from *Salicornia europaea*. Their study focused on Cd. The maximum adsorption capacity was 108.54 mg/g at 25 degrees C.

Main equations

Removal efficiency shows how much metal is removed from water. It is calculated from the starting concentration and final concentration.

$$\text{Removal efficiency (\%)} = ((C_0 - C_e) / C_0) \times 100$$

In this equation, C_0 is the starting concentration. C_e is the final concentration after treatment. Both values must use the same unit. Adsorption capacity shows the metal mass held by each gram of adsorbent. It is often written as q_e . The common equation is shown below.

$$q_e = (C_0 - C_e) \times V / m$$

In this equation, V is the solution volume. The value m is the adsorbent mass. This equation is common in adsorption research (Kilic et al., 2013).

Practical experiment that can be repeated

A practical experiment can be repeated in a university laboratory. It can use local river water and a low-cost biochar. Coconut husk or rice husk biochar is suitable in many regions. The river water should be collected from upstream and downstream sites. The downstream site should be near a drain or industrial area. Samples should be stored in clean acid-washed bottles.

The samples should be filtered for dissolved metal testing if required. Total metal testing needs acid digestion. Standard methods should be followed for sample preservation and analysis (American Public Health Association et al., 2017).

Biochar should be washed, dried, ground, and sieved. The researcher should record particle size, dosage, pH, contact time, and temperature. These factors strongly affect adsorption.

The batch test should mix known biochar masses with measured water volumes. Samples should be shaken for fixed times. The final metal level should be measured by AAS or ICP-MS.

Table 4 Suggested practical laboratory design for a local replication study.

Variable	Suggested level	Reason
Biochar feedstock	Coconut husk, rice husk, or banana stem	These wastes are cheap in many regions.
Biochar dose	0.5, 1.0, 2.0, and 5.0 g/L	Dose controls surface area in contact with water.
Contact time	30, 60, 120, 240, and 480 minutes	Time is needed to reach adsorption balance.
pH	Natural pH, pH 5, pH 7, and pH 8	pH changes metal form and surface charge.
Mixing	Constant shaking at room temperature	Mixing reduces mass transfer limits.
Analysis	AAS or ICP-MS	These methods can measure metals at low levels.
Controls	No-biochar blank and duplicate samples	Controls check natural loss and lab error.

Results

Urban river field results

The Sabarmati River results show a clear pollution pattern. Upstream or less affected sites had lower WQI values. The most polluted site was Site F. The reported WQI at Site F was 838.87. This value was far above the other sites. The next highest value was 139.45 at Site C (Kumar et al., 2016). The high WQI at Site F was linked with several water-quality pressures. These included high TDS, BOD, COD, and chloride. Heavy metals also showed concern at this site.

Table 5 Reported Water Quality Index values in the Sabarmati River case study. Source: Kumar et al. (2026).

Site	Reported WQI	Interpretation used in this paper
A	82.42	Polluted but much lower than Site F.
B	98.12	Near the 100 reference level.
E	104.86	Above 100 and shows concern.
D	107.29	Above 100 and shows concern.
C	139.45	High pollution compared with most sites.
F	838.87	Severe pollution hot spot.

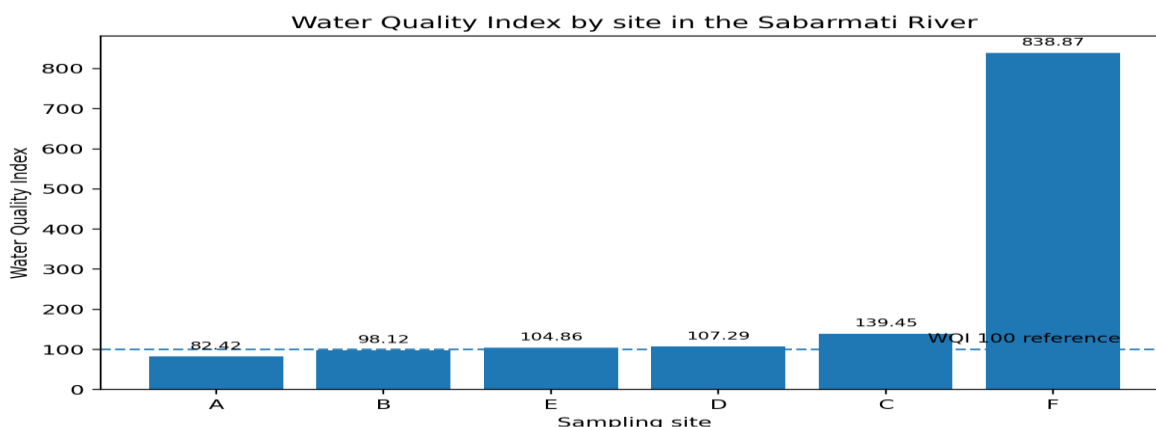


Figure 4 Water Quality Index by site in the Sabarmati River. Data source: (Kumar et al., 2016) The heavy metal results show that Site F needs special attention. Chromium was below detection at many other sites. It rose strongly at Site F. At Site F, chromium was 52.84 ug/L in summer. It increased to 76.03 ug/L in winter. Both values were above the WHO guideline value of 50 ug/L for total chromium (WHO, 2022). Cadmium at Site F was also important. It reached 3.66 ug/L in summer. This value was above the WHO guideline value of 3 ug/L (WHO, 2022). Lead was lower than the WHO guideline in the reported Site F data. Arsenic was also lower than its guideline. Still, mixed exposure can matter in real rivers.

Table 6 Reported heavy metals in Sabarmati River water by site and season. Source: Kumar et al. (2026), heavy metal table. BDL means below detection limit.

Site	Season	As (ug/L)	Cr (ug/L)	Cd (ug/L)	Pb (ug/L)
A	Summer	BDL	BDL	BDL	BDL
A	Winter	0.82	BDL	0.21	2.80
B	Summer	BDL	0.61	BDL	BDL
B	Winter	0.94	BDL	0.30	2.00
C	Summer	BDL	0.21	0.20	BDL
C	Winter	0.98	BDL	0.17	2.27
D	Summer	BDL	0.62	0.38	BDL
D	Winter	1.27	BDL	0.17	2.58
E	Summer	BDL	BDL	BDL	BDL
E	Winter	1.43	BDL	0.21	2.53
F	Summer	BDL	52.84	3.66	BDL
F	Winter	1.18	76.03	0.75	3.40

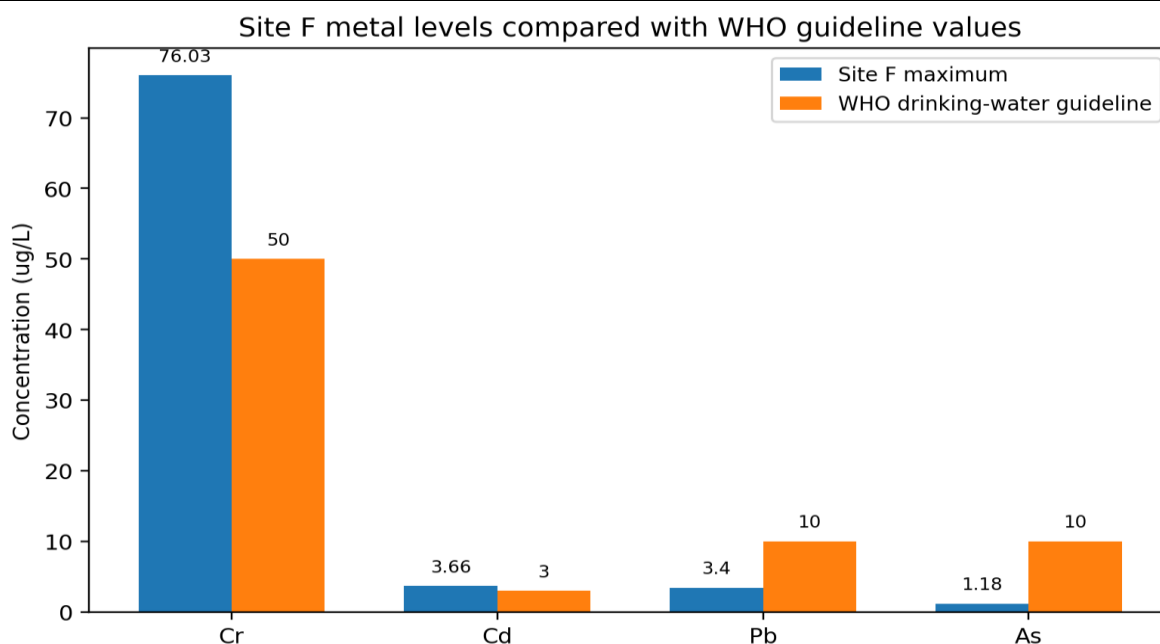


Figure 5 Site F maximum metal concentrations compared with WHO guideline values. Source: (Kumar et al., 2016) and (WHO, 2022)

Published biochar adsorption results

The adsorption experiments show that many low-cost biochars can remove metals well. The best performance depends on the metal, feedstock, and test condition. (Liu et al., 2022) reported strong Pb adsorption by banana stem and leaf biochar. The maximum Pb adsorption capacity was 302.20 mg/g. The Cd capacity was 32.03 mg/g. (Chaudhary et al., 2024) reported very high removal by urban biowaste biochars. Some results were above 99%. This is useful because urban waste is often available near polluted rivers. (Dwiejuah et al., 2024) reported strong removal by coconut husk biochar. Cd removal ranged from 88.70% to 98.20%. Cr removal ranged from 78% to 96%. Pb removal ranged from 95.71% to 99.29%. (Sanka et al., 2020) found rice husk biochar was better than corn husk biochar. Rice husk biochar made at 600 degrees C removed about 65% Cr, 90% Fe, and more than 90% Pb. (Alghamdi and Alasmary, 2023) found that Fe modification improved date palm biochar. The modified biochar had a Pb capacity of 475.14 mg/g. Its Cd capacity was 48.44 mg/g. (Ge et al., 2024) reported Cd adsorption on Salicornia-derived biochar. The maximum Cd capacity was 108.54 mg/g. Precipitation was the dominant mechanism.

Table 7 Real published biochar adsorption results used for comparison.

Study	Biochar/feedstock	Water type	Metal result reported	Key result used here
Liu et al. (2022)	Banana stem and leaf	Aqueous solution	Pb and Cd capacity	Pb 302.20 mg/g; Cd 32.03 mg/g.
Chaudhary et al. (2024)	Urban biowaste biochars	Aqueous solution	Pb, Cu, Cr, Cd removal	Cu 99.94%; Cr 99.57%; Cd 99.77%; Pb 99.59%.
Dwiejuah et al. (2024)	Coconut husk biochar	Greywater	Cd, Cr, Pb removal	Cd 88.70-98.20%; Cr 78-96%; Pb 95.71-99.29%.
Sanka et al. (2020)	Rice husk biochar	Industrial wastewater	Cr, Fe, Pb removal	Cr 65%; Fe 90%; Pb above 90%.
Alghamdi and Alasmary (2023)	Fe-modified date palm	Aqueous binary solution	Cd and Pb removal and capacity	Pb capacity 475.14 mg/g; Cd capacity 48.44 mg/g.
Ge et al. (2024)	Salicornia biochar	Aqueous solution	Cd capacity	Cd 108.54 mg/g at 25 degrees C.

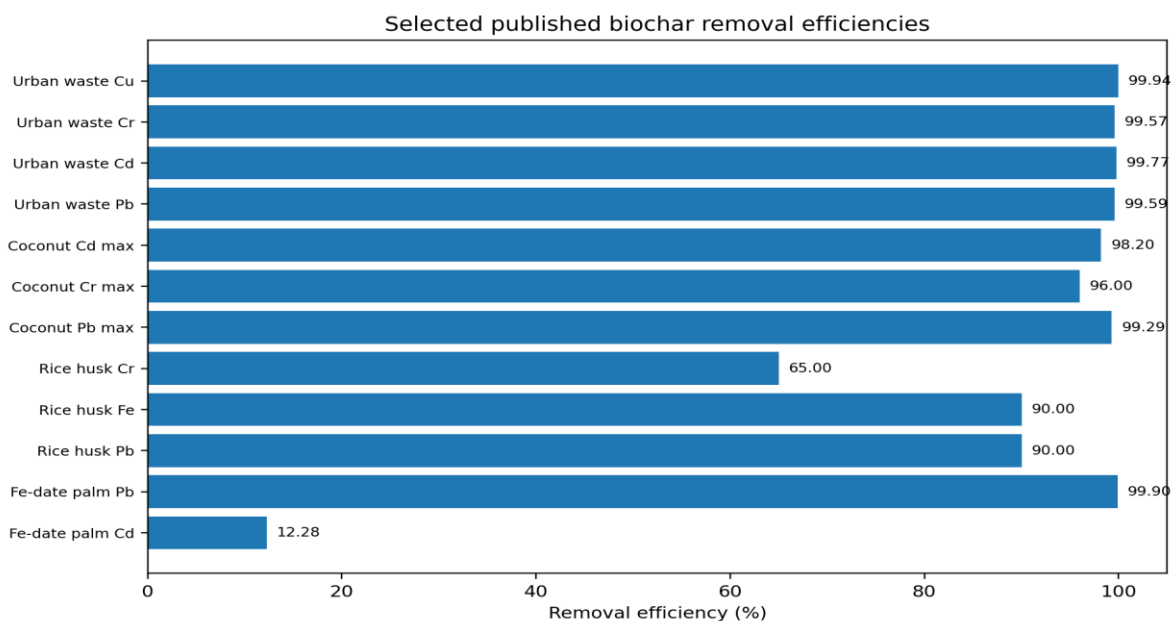


Figure 6 Selected removal efficiencies from published biochar experiments. Source: (Chaudhary et al., 2024; Duwiejuah et al., 2024; Sanka et al., 2020; Alghamdi and Alasmary, 2023).

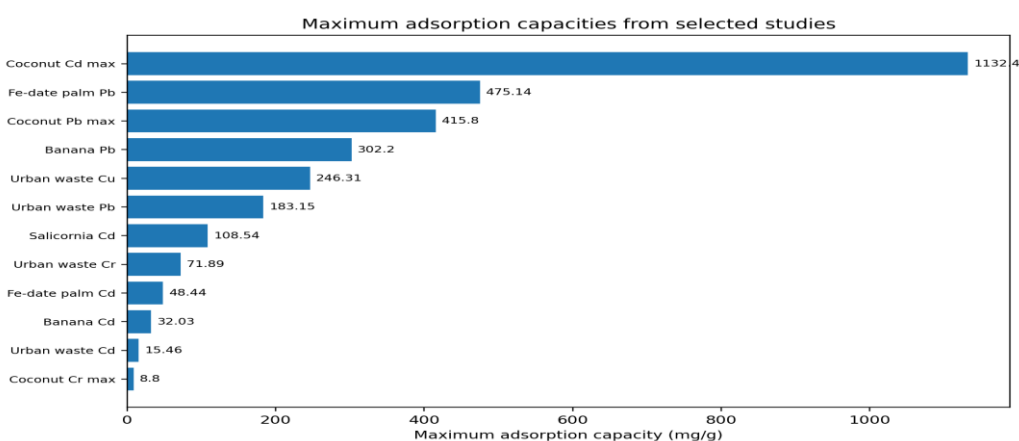


Figure 7 Maximum adsorption capacities from selected biochar studies. Source: (Liu et al., 2022; Duwiejuah et al., 2024; Chaudhary et al., 2024; Alghamdi and Alasmary, 2023; and Ge et al., 2024).

Adsorption mechanisms

The cited studies show that biochar does not work through one process only. Several processes can occur at the same time. This helps explain high removal for some metals. (Liu et al., 2022) reported that mineral precipitation dominated Pb and Cd adsorption. It contributed 88.8% for Pb and 83.0% for Cd. Ion exchange and pi coordination also contributed. (Chaudhary et al., 2024) reported surface complexation and precipitation as key mechanisms. Their findings agree with the idea that ash minerals and surface groups are important. (Ge et al., 2024) also found precipitation to be dominant for Cd adsorption. Their reported CdCO_3 precipitation contribution was 73.7%. This supports the role of carbonate minerals. The mechanism matters for field use. Precipitation can be strong, but it depends on pH and dissolved ions. Complexation can also change when natural organic matter is present.

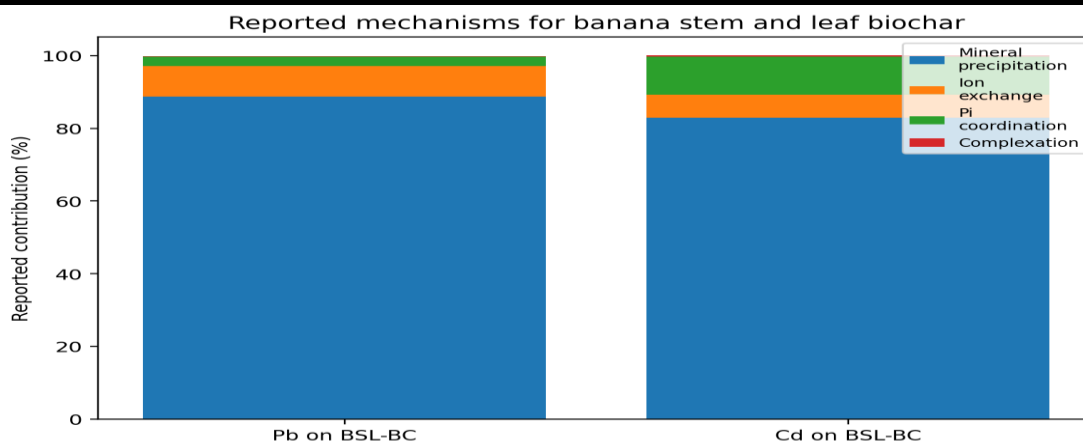


Figure 8 Reported mechanism contributions for Pb and Cd adsorption by banana stem and leaf biochar. (Source: Liu et al., 2022).

Calculated treatment scenario for polluted river water

A simple scenario was calculated for Site F. This scenario is not a direct field experiment. It shows what might happen if published removal efficiencies were reached in treated river water. The highest Site F chromium value was 76.03 ug/L. Coconut husk biochar removal ranged from 78% to 96%. This would reduce chromium to about 16.73 to 3.04 ug/L. The urban biowaste result for chromium was 99.57%. Applied to 76.03 ug/L, this gives about 0.33 ug/L. This value is far below the WHO chromium guideline.

The highest Site F cadmium value was 3.66 ug/L. Coconut husk biochar removal ranged from 88.70% to 98.20%. This gives a residual of about 0.41 to 0.07 ug/L. The urban biowaste result for cadmium was 99.77%. Applied to 3.66 ug/L, this gives about 0.008 ug/L. This shows a strong potential safety margin. These calculations are useful for screening. They do not prove field performance. Natural organic matter, turbidity, pH, and competing ions can lower real removal.

Table 8 Calculated residual concentrations for Site F using published removal efficiencies.

Metal	Starting concentration	Biochar source	Published removal	Calculated residual	Status of value
Cr	76.03 ug/L	Coconut husk biochar	78-96%	16.73-3.04 ug/L	Scenario from Duwiejuah et al. (2024).
Cr	76.03 ug/L	Urban biowaste biochar	99.57%	0.33 ug/L	Scenario from Chaudhary et al. (2024).
Cd	3.66 ug/L	Coconut husk biochar	88.70-98.20%	0.41-0.07 ug/L	Scenario from Duwiejuah et al. (2024).
Cd	3.66 ug/L	Urban biowaste biochar	99.77%	0.008 ug/L	Scenario from Chaudhary et al. (2024).
Pb	3.40 ug/L	Coconut husk biochar	95.71-99.29%	0.15-0.02 ug/L	Scenario from Duwiejuah et al. (2024).
Pb	3.40 ug/L	Citrus peel biochar	99.59%	0.014 ug/L	Scenario from Chaudhary et al. (2024).

Discussion

Meaning of the river data

The field data show that pollution is not uniform. Site F was much worse than the other sites. This pattern suggests a local discharge pressure or poor dilution. The chromium value at Site F exceeded the WHO guideline. Cadmium also exceeded the guideline in summer. These results make Site F a priority location for treatment planning. The results do not mean the whole river has the same risk. They mean that hot spots need control. Urban river treatment should start near drains and high-load entry points. A treatment unit at the wrong place may not reduce the main pollution load. Source mapping should come before installation. The sampling map is therefore important.

Meaning of the biochar results

The experimental results support biochar as a strong adsorbent. Several biochars removed metals above 90%. Some urban biowaste biochars removed selected metals above 99%. Lead often showed strong adsorption. This agrees with many biochar studies. Lead can bind strongly through precipitation, ion exchange, and complexation (Mohan et al., 2014). Cadmium removal was more variable. It was high for some biochars and lower for others. This means Cd treatment needs careful biochar selection and pH control. Chromium removal is also complex. Chromium can exist in different chemical forms. The form affects toxicity and adsorption behavior. A field trial must measure chromium speciation when possible. Feedstock choice is very important. Coconut husk, rice husk, banana stem, and citrus peel are useful because they are waste materials. They can reduce cost and waste disposal pressure.

Why biochar is suitable for low-cost treatment

Biochar can be made from local wastes. This reduces transport cost. It also supports circular waste use in cities and farming areas. Small treatment units can be installed near drains. They can also be used beside canals and ponds. A simple column can treat water before it enters a river. The design should not block water flow. It should be easy to remove and replace. It should also protect workers from contaminated spent media. Biochar is not a complete solution alone. Source control is still needed. Industries must treat effluent before release. Sewage treatment also remains necessary. Biochar is best used as an added barrier. It can reduce residual metals after basic treatment. It can also support emergency treatment at hot spots

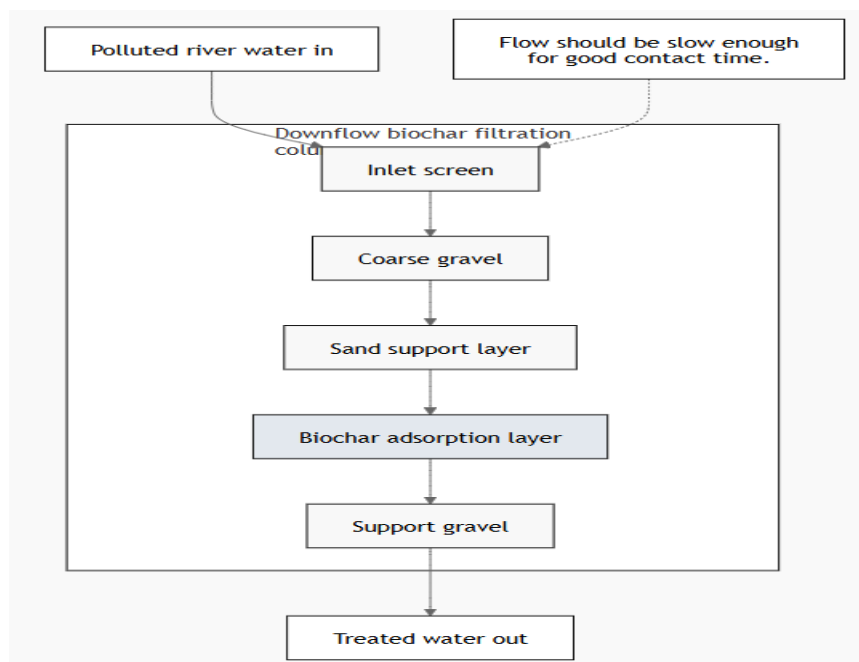


Figure 9 Proposed low-cost biochar filter column for hot-spot treatment.

Practical risks and controls

Spent biochar can become hazardous. It may contain concentrated metals. It should not be dumped back into soil or water without testing. Safe handling is necessary. Workers should wear gloves and masks during replacement. Used biochar should be stored in sealed containers. Regeneration may be possible in some cases. Acid washing can remove metals from biochar. Yet this creates a liquid waste that needs treatment. In many small projects, secure disposal may be safer. Local rules should guide final disposal. Metal recovery should be considered when concentrations are high. Another risk is clogging. Urban river water often contains suspended solids. A settling chamber or pre-filter should be placed before the biochar bed.

Table 9 Main limitations and control measures for biochar use in river treatment.

Limitation	Why it matters	Suggested control
Competing ions	Other ions may reduce metal adsorption.	Test real river water before field use.
Variable pH	pH changes metal form and biochar charge.	Measure and adjust pH during trials.
Suspended solids	Solids can clog the biochar bed.	Use settling and pre-filtration.
Spent biochar risk	Metals become concentrated in the adsorbent.	Store and dispose safely.
Short contact time	Fast flow reduces adsorption.	Use slow flow and enough bed depth.
Biochar quality changes	Feedstock and temperature change properties.	Characterize each biochar batch.

Proposed Application for an Urban River Hot Spot

The proposed application starts with pollution mapping. The first step is to locate drains and high-load points. Water should be sampled upstream and downstream of each point. The second step is laboratory screening. At least two local biochars should be tested. Coconut husk and rice husk are good first choices where available. The third step is a small column test. River water should pass slowly through a biochar bed. The outlet water should be tested for Pb, Cd, Cr, and As. The fourth step is pilot use near the hot spot. The unit should include a settling tank, a sand layer, a biochar layer, and an outlet sampling point. The fifth step is monitoring. Inlet and outlet samples should be taken weekly during the first month. Sampling should continue after rain events because water quality changes quickly. The sixth step is media replacement. Breakthrough happens when outlet metal levels rise. The breakthrough time should set the replacement schedule. A small city project can start with one drain. The method should not be sold as a full river cure. It is a hot-spot control tool.

Table 10 Proposed monitoring plan for a biochar pilot unit.

Monitoring item	Frequency	Purpose
Inlet and outlet pH	Each sampling day	Shows conditions that affect adsorption.
Turbidity or TSS	Each sampling day	Checks clogging risk.
Cr, Cd, Pb, and As	Weekly at start	Measures actual treatment performance.
Flow rate	Daily during operation	Checks contact time and hydraulic loading.
Biochar bed head loss	Weekly	Signals clogging or compaction.
Spent biochar metal content	At replacement	Guides disposal or regeneration.

Limitations of the Study

This paper has clear limits. It combines studies from different places and conditions. The water chemistry was not identical across those studies. Batch adsorption results often look better than field results. Batch systems have controlled mixing and contact time. Real river water is more complex. The calculated scenario is only a screening exercise. It uses published removal percentages. It does not prove that the same removal will occur at Site F. The Sabarmati data provide a strong urban river example. Still, another river may have different metals and loads. Each river needs its own testing. The study also does not estimate full cost. Local biomass price, pyrolysis cost, labor, testing, and disposal will affect the final cost. Even with these limits, the paper gives a useful first assessment. It shows which biochars deserve local testing. It also gives a practical experiment plan.

Conclusion

This paper assessed heavy metal contamination in urban river water. It used the Sabarmati River as a real field case. It also used real published biochar adsorption experiments. The field data showed a major pollution hot spot at Site F. Chromium and cadmium exceeded important WHO guideline values. The WQI value also showed severe water-quality stress. The reviewed experiments showed strong biochar performance. Banana stem and leaf biochar had high Pb and Cd adsorption capacities. Urban biowaste biochars removed some metals above 99%. Coconut husk biochar also showed high removal of Cd, Cr, and Pb. Rice husk biochar performed well for Fe and Pb. These materials are promising because they are low-cost wastes.

The calculated scenario suggests that biochar could reduce Site F metal levels strongly. However, this must be confirmed using real river water in a local experiment. The best practical path is a stepwise approach. First, map the hot spot. Second, test local biochars in the laboratory. Third, run a small column pilot. Fourth, monitor breakthrough and spent biochar safety. The study supports biochar as a practical support tool for urban river pollution control. It should be used with source control, wastewater treatment, and safe waste management.

References

1. Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S. S., & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere*, 99, 19-33. <https://doi.org/10.1016/j.chemosphere.2013.10.071>
2. Alghamdi, A. G., & Alasmay, Z. (2023). Efficient remediation of cadmium- and lead-contaminated water by using Fe-modified date palm waste biochar-based adsorbents. *International Journal of Environmental Research and Public Health*, 20(1), 802. <https://doi.org/10.3390/ijerph20010802>
3. American Public Health Association, American Water Works Association, & Water Environment Federation. (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). APHA Press.
4. Chaudhary, H., Dinakaran, J., Notup, T., Vikram, K., & Rao, K. S. (2024). Comparison of adsorption performance of biochar derived from urban biowaste materials for removal of heavy metals. *Environmental Management*, 73, 408-424. <https://doi.org/10.1007/s00267-023-01866-1>
5. Duwiejuah, A. B., Adjei, E. F., & Alhassan, E. H. (2024). Adsorption of toxic metals from greywater using coconut husk biochar and spent green tea. *Heliyon*, 10(18), e38189. <https://doi.org/10.1016/j.heliyon.2024.e38189>
6. Ge, S., Zhao, S., Wang, L., Zhao, Z., Wang, S., & Tian, C. (2024). Exploring adsorption capacity and mechanisms involved in cadmium removal from aqueous solutions by biochar derived from euhalophyte. *Scientific Reports*, 14, 450. <https://doi.org/10.1038/s41598-023-50525-2>
7. Asanousi Lamma, O., Swamy, A. V. V. S., & Alhadad, A. A. (2018). Assessment of Heavy Metal Pollution in Ground Water and its Correlation with other Physical Parameters at Selected Industrial Areas of Guntur, AP, India. AP, India.
8. Inyang, M. I., Gao, B., Yao, Y., Xue, Y., Zimmerman, A. R., Mosa, A., Pullammanappallil, P., Ok, Y. S., & Cao, X. (2016). A review of biochar as a low-cost adsorbent for aqueous heavy metal removal. *Critical Reviews in Environmental Science and Technology*, 46(4), 406-433. <https://doi.org/10.1080/10643389.2015.1096880>
9. Kilic, M., Kirbiyik, C., Cepeliogullar, O., & Putun, A. E. (2013). Adsorption of heavy metal ions from aqueous solutions by bio-char, a by-product of pyrolysis. *Applied Surface Science*, 283, 856-862. <https://doi.org/10.1016/j.apsusc.2013.07.033>

10. Alhadad, A. (2018). Effects Of Pesticides On Human Health.
11. Liu, X., Li, G., Chen, C., Zhang, X., Zhou, K., & Long, X. (2022). Banana stem and leaf biochar as an effective adsorbent for cadmium and lead in aqueous solution. *Scientific Reports*, 12, 1584. <https://doi.org/10.1038/s41598-022-05652-7>
12. LAMMA, O. A. (2023). Beneath the Surface: Unveiling the Silent Threat of Groundwater Contamination. *Bani Waleed University Journal of Humanities and Applied Sciences*, 8(5), 380-393.
13. Mohajane, C., & Manjoro, M. (2022). Sediment-associated heavy metal contamination and potential ecological risk along an urban river in South Africa. *Heliyon*, 8(12), e12499. <https://doi.org/10.1016/j.heliyon.2022.e12499>
14. Mohan, D., Sarswat, A., Ok, Y. S., & Pittman, C. U., Jr. (2014). Organic and inorganic contaminants removal from water with biochar, a renewable, low-cost and sustainable adsorbent: A critical review. *Bioresource Technology*, 160, 191-202. <https://doi.org/10.1016/j.biortech.2014.01.120>
15. Lamma, O. A. (2024). Innovative Remediation Strategies for Tackling Groundwater Pollution: A Comparative Analysis. *African Journal of Advanced Pure and Applied Sciences*, 90-98.
16. Qasem, N. A. A., Mohammed, R. H., & Lawal, D. U. (2021). Removal of heavy metal ions from wastewater: A comprehensive and critical review. *npj Clean Water*, 4, 36. <https://doi.org/10.1038/s41545-021-00127-0>
17. Sanka, P. M., Rwiza, M. J., & Mtei, K. M. (2020). Removal of selected heavy metal ions from industrial wastewater using rice and corn husk biochar. *Water, Air, & Soil Pollution*, 231, 244. <https://doi.org/10.1007/s11270-020-04624-9>
18. U.S. Environmental Protection Agency. (2025). National recommended water quality criteria tables. <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-tables>
19. World Health Organization. (2022). Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda. World Health Organization. <https://www.who.int/publications/i/item/9789241549950>
20. World Health Organization. (2022). Lead in drinking-water: Health risks, monitoring and corrective actions. World Health Organization. <https://www.who.int/publications/i/item/9789240020863>

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