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1 Proposed research title

Exploring Biochar for Removing Heavy Metal Contaminants from Mine Spoil on Kilvey Hill, Wales

2 Abstract

This research investigates the effectiveness of biochar remediation in removing heavy metal contaminants from copper mine spoil. The effectiveness of biochar treatment will be assessed by comparing metal concentrations in treated vs. control plots over time. By analysing biochar's adsorption capacity and its influence on soil properties, the study aims to enhance the understanding of its potential as a sustainable solution for mitigating heavy metal pollution in mining-impacted environments.

3 Introduction

Mining activities have left a lasting legacy of soil contamination, particularly from heavy metals, which pose significant environmental and human health risks (Team, 2024). Copper mine spoil, in particular, contains elevated levels of toxic metals that can leach into surrounding ecosystems, disrupting biodiversity and limiting soil productivity (Izydorczyk et al., 2021). Potential environmental pollution from copper metallurgy and methods of management. Effective remediation strategies are essential to restore these degraded landscapes and prevent further environmental damage.

Biochar, a carbon-rich material produced from biomass pyrolysis, has gained attention as a promising solution for soil remediation. Its high surface area, porosity, and ability to adsorb heavy metals make it a potential candidate for reducing metal mobility and improving soil quality (Khater et al., 2024). However, further research is needed to fully understand its effectiveness in copper mine spoil environments.

This study investigates the use of biochar for remediating heavy metal contamination in copper mine spoil, focusing on its adsorption capacity and impact on soil properties. The research aims to contribute to environmental restoration efforts on Kilvey Hill while offering insights into cost-effective, sustainable remediation methods applicable to contaminated sites across Wales.

3.1 Background

Kilvey Hill, located in Swansea, South Wales, has a history of industrial activity that has contributed to heavy metal contamination in its soils. During the 19th and early 20th centuries, Swansea was a major centre for copper smelting, earning it the nickname "Copperopolis" (Environment Centre, 2023). The smelting and associated industries, including lead, zinc, and arsenic processing, released large amounts of heavy metal pollutants into the environment. Over time, contaminants settled into the soil on Kilvey Hill, which lies downwind of many historical smelting sites such as the copper works.

Even after the decline of heavy industry in the 20th century, residual contamination from metals such as copper, lead, zinc, and arsenic has persisted in the hill's ecosystem. These pollutants may have impacted soil quality, vegetation, and potentially local wildlife (MathuMitha *et al.*, 2021). Despite this, Kilvey Hill has undergone significant natural regeneration, with woodland and grassland gradually recovering due to planting of Fir trees which for a while was the only thing that succeeded

on the Hill (Natural Resources Wales, 2022). However, the legacy of industrial pollution remains an environmental concern for the area.

3.2 Aims

The aim of this research is to explore the effect of biochar in the remediation of heavy metal contaminants from mine spoil on Kilvey Hill.

3.3 Objectives

- Test soils in trees and heathland for heavy metals
- Treat soils with biochar and repeat testing after 6 months

4 Literature Review

Heavy metal contamination from mining activities poses a significant environmental challenge; affecting soil health, water quality, and biodiversity (Angon et al., 2024). Copper mine spoil, in particular, contains elevated concentrations of toxic metals that can leach into the surrounding environment, causing long-term ecological damage (Konanç et al., 2024). Conventional remediation techniques, such as soil excavation, chemical stabilisation, and phytoremediation, have been employed to mitigate these effects (Aparicio et al., 2022). However, these methods often come with high costs, require extensive management, and may have limited long-term effectiveness (Liu et al., 2018).

In recent years, biochar has emerged as a promising, sustainable remediation strategy due to its ability to adsorb heavy metals, improve soil properties, and enhance microbial activity (Kapoor, Ahmad and Rafatullah, 2024). Biochar's effectiveness in metal immobilisation and soil restoration has been demonstrated in various contaminated sites (Wang et al., 2021), yet its application in mine spoil remediation remains an area of ongoing research. This review explores existing studies on biochar as a remediation tool for heavy metal contamination, with a particular focus on its potential for copper mine spoil restoration.

Research shows that mining activities significantly alter the physicochemical properties of soil, often leading to extreme pH levels, nutrient depletion, and the accumulation of heavy metals such as copper (Cu), lead (Pb), cadmium (Cd), and zinc (Zn) (Angon et al., 2024). These contaminants persist in the environment due to their non-degradable nature and pose risks to plants, animals, and human health (Aravind Kumar et al., 2022). Heavy metals can enter food chains through bioaccumulation, leading to toxic effects such as organ damage and neurological disorders (Khan et al., 2015).

In mine spoil, metals are often present in highly mobile forms, increasing their leaching potential (Li et al., 2024). The degree of metal mobility depends on factors such as soil pH, organic matter content, and mineral composition. Thus, effective remediation strategies must not only immobilise heavy metals but also restore soil health to support vegetation growth and ecosystem recovery (Kumar et al., 2021).

Biochar is a carbon-rich material produced by the pyrolysis of organic biomass under limited oxygen conditions. It has been widely studied for its environmental applications, including carbon sequestration, soil fertility enhancement, and pollutant removal (Amalina et al., 2025). Biochar's porosity, surface area, and functional groups are dependent on the pyrolysis temperature and the feedstock used in production, this impacts its effectiveness in adsorbing heavy metals highlighting the need for site-specific studies (Leng et al., 2021).

A benefit of Biochar is its ability to increase soil pH, which can reduce the solubility of heavy metals by promoting their precipitation or adsorption onto biochar surfaces. Additionally, biochar enhances soil cation exchange capacity (CEC), allowing it to retain essential nutrients while immobilising toxic metals (Wakefield BioChar, 2024; Antonangelo et al., 2024). These properties make biochar a viable amendment for remediating mining-impacted soils, where acidity and metal toxicity often limit plant growth and microbial activity (Padhi et al., 2024).

Numerous studies have explored the role of biochar in heavy metal remediation, demonstrating its ability to reduce metal bioavailability in contaminated soils (He et al., 2019 ;Padhi et al., 2024). It was found that biochar derived from rice husks effectively immobilised cadmium and lead, significantly reducing their leaching potential (Asadi et al., 2021). Similarly, it was reported that biochar application in mine tailings decreased copper and zinc mobility, thereby preventing groundwater contamination (Ghosh and Kumar Maiti, 2024).

The mechanisms behind biochar's metal immobilisation capabilities include: heavy metals bind to biochar's negatively charged functional groups, such as carboxyl and hydroxyl groups. Metal ions react with biochar's alkaline components, forming insoluble metal precipitates. Biochar contains organic molecules that interact with metal ions, reducing their solubility (Chen et al., 2024).

Environmental factors such as soil composition, moisture levels, and biochar aging affect the effectiveness of Biochar (Yang et al., 2024). Long-term studies are necessary to assess whether biochar can maintain its metal immobilisation capacity under field conditions.

Mine spoil is characterised by poor soil structure, low organic matter content, and extreme pH conditions, making it a challenging environment for plant growth and ecosystem recovery (Olivo et al., 2024). Biochar amendments have shown promise in improving these degraded soils by increasing nutrient retention, enhancing microbial activity, and stabilising heavy metals (Lu et al., 2024). It was found that biochar amendments improved soil fertility and reduced heavy metal uptake in plants grown on contaminated soils (Rombel, Krasucka and Oleszczuk, 2021). Similarly, it reported that biochar increased soil pH and reduced cadmium and lead bioavailability in mine-affected lands (Wei et al., 2022).

In the context of Kilvey Hill, where historic copper mining has left significant soil contamination, biochar may provide a sustainable remediation approach. Its potential to immobilise copper and improve soil health could support long-term ecological restoration efforts in the area. However, further research is required to optimise biochar formulations and application methods for maximum effectiveness in this specific environment.

While existing literature provides strong evidence supporting biochar's role in heavy metal remediation ((Berglund et al., 2004; He et al., 2019; Ghosh and Kumar Maiti, 2024), gaps in the research remain; most studies have focused on short-term effects, with limited data on how biochar performs over extended periods in field conditions (de la Rosa et al., 2018). More research is needed to identify the most effective biochar types for copper mine spoil remediation. Large-scale field trials are necessary to assess biochar's real-world applicability and economic feasibility.

Biochar has emerged as a promising, sustainable solution for heavy metal remediation in contaminated soils, offering benefits such as metal immobilisation, soil improvement, and long-term carbon sequestration. While existing studies demonstrate its potential, further research is required to optimise its application for mine spoil environments, such as those found on Kilvey hill. This study aims to provide data to help fill in these knowledge gaps.

5 Methodology

Table 1: a table showing the procedure followed during the project

Research Stage	Procedure	Justification
One	Site selection and soil measurement. Four sites selected in total, two forested and two heathland	Each site will be paired by vegetation type – one will be an experimental plot treated with biochar, one will be a control
Two	Soil sample collection. Soil samples will be collected from the four sites in May 2025 this will be 500g	This will occur for testing of the heavy metal contaminants
Three	Heavy metal analysis. The collected samples will be analysed for copper, iron and manganese content this will be done using a photo spectrometer.	This is essential for the project to continue as a before analysis is needed for a comparison of the before and after to show the success of the project. Copper, iron and manganese is a common contaminant in mine spoil (Doku and Belford, 2024; Ivanov and Hristov, 2024; Mohan et al., 2024)
Four	Experimental Design. One of each different vegetation site will serve as the experimental group, treated with biochar, this immobilises heavy metals and improves soil health. The other will remain untreated as a control to allow for comparison of remediation effectiveness. . The application method (e.g., surface application vs. soil incorporation) will also be documented.	8grams of biochar will be in suspension with deionised water. This will be injected into 20x20cm plots, 10cm below the surface (Berglund et al., 2004). This is considered a better method for in the field as it is less destructive to the soil.
Five	Monitoring and testing Soil testing will be conducted in Autumn 2025 to assess short-term (four-month) changes in heavy metal concentrations. A follow-up soil test will be conducted in April 2026 to evaluate year-long effects, examining changes in metal mobility, soil pH, and overall remediation success.	The testing twice is valuable as it takes in consideration different weather patterns and seasonal changes

Figure 1 shows potential sampling points all landowner permissions will be obtained before testing

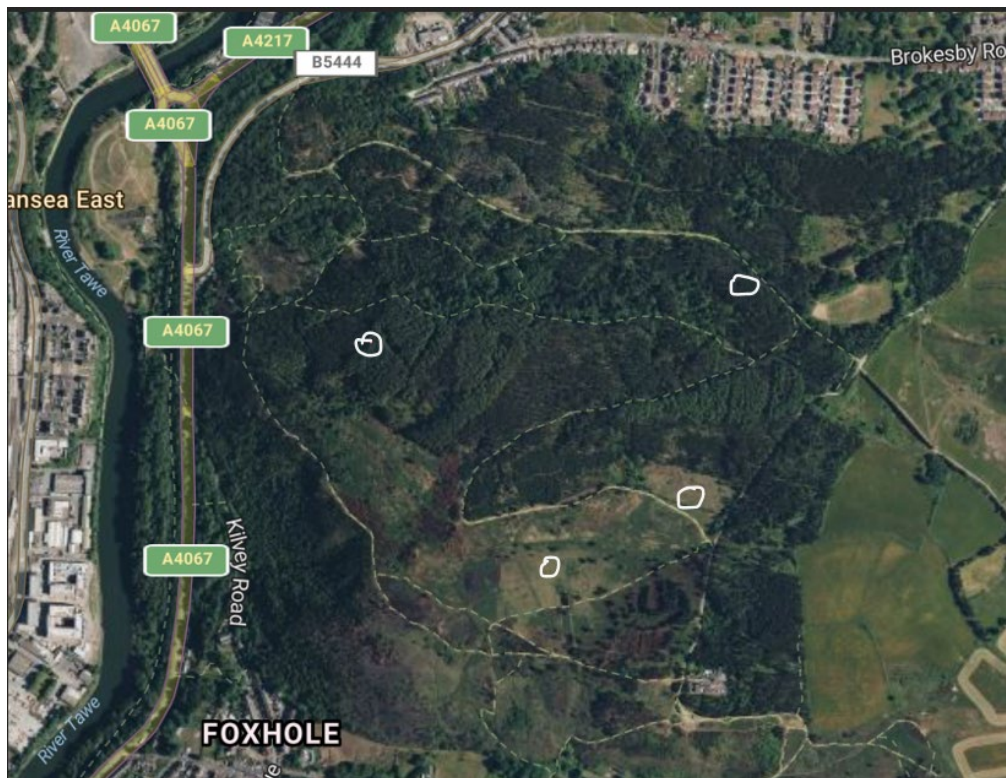


Figure 1: A map of Kilvey hill with sample plots

6 Results

The results will be shown in graphs and they will be compared to literature to see if the hypothesis was met.

The quantity of each contaminant in the soil before and after testing.

7 Data Analysis

Statistical analysis will be performed to determine the significance of observed changes. This will achieve a clearer understanding of the extent and distribution of heavy metal contamination on Kilvey Hill. Identification of the most effective bioremediation techniques for removing specific contaminants and practical recommendations for future remediation efforts to improve soil health and support ecosystem recovery.

Table 2: a table showing the different tests and what they are testing for

Test	What its testing for	Expected results
T tests	To compare the results of two tests, the effectiveness of biochar treatment will be assessed by comparing metal concentrations in treated vs. control plots over time	An increased rate of copper reduction in the heathland experimental condition when compared to the heathland control condition. A higher reduction rate in forest experimental than forest

		control. No difference is expected between results when comparing forest control and heathland control.
Graphs	Scatter graphs and bar charts will be used to show fluctuation of the nutrient levels.	Similar graphs in the controls, however fluctuation in the experimental groups.

8 Consent / Access / Ethical considerations

Potential secondary effects, such as changes in soil microbial communities and plant health, will also be documented to ensure that biochar application does not introduce unintended ecological consequences. Kilvey Hill is public access so council permission will be obtained

9 Timetable

Table 3- a Gantt chart showing the expected progress of the research project

Task	Start Date	Duration	Notes
Site selection and permission	April 2025	1 week	Permission requested from Sean Hathaway
Soil sample collection	May 2025	1 week	Samples to be collected from four sites
Heavy metal analysis	May 2025	1 week	Samples need to be dried over night and sieved before testing
Biochar treatment	May 2025	1 week	This can be done at the same time as soil collection
Literature review	Summer 2025	4 months	Complete literature review before academic year starts
5 month Monitoring	October 2025	1 week	Samples need to be dried over night and sieved before testing
Write up methodology	October 2025	1 week	
Analyse 5 month data	November 2025	1 month	Anayse initial data and discuss
10 month monitoring	March 2026	1 week	Samples need to be dried over night and sieved before testing
Analyse 10 month data	March 2026	1 month	Build on 5 month data and write up discussion
Finalise dissertation	April 2026	1 month	Submit

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