Journal of Carcinogenesis
Covering Genesis to Therapeutics
Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 5s, https://carcinogenesis.com/

Bio-polymer in the Treatment of Oil-Soil Contaminated with Heavy Elements

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ABSTRACT

This research investigates the role of a bio-polymer in treating soils polluted with petroleum and heavy metals. Soil samples were taken from two sites contaminated with lead, zinc, and cadmium. To evaluate the polymer's efficiency, three doses—10, 14, and 18 grams—were applied. Results showed a clear reduction in heavy metal levels as polymer amounts increased. For zinc (Zn), Site 1 had about 25 mg/kg before treatment, which dropped to around 11 mg/kg with 10 g, 4–5 mg/kg with 14 g, and 3.2 mg/kg with 18 g. Site 2 started at 22–24 mg/kg and fell to about 12 mg/kg at 10 g, 5–6 mg/kg at 14 g, and around 3–4.5 mg/kg at 18 g. Cadmium (Cd) at Site 1 decreased from about 0.04 mg/kg untreated to 0.02 mg/kg at 10 g, near 0.01 mg/kg at 14 g, and down to 0.001 mg/kg at 18 g. Site 2 Cd dropped from about 0.02 mg/kg to 0.015 mg/kg at 10 g, close to 0.01 mg/kg at 14 g, and as low as 0.001 mg/kg at 18 g. Lead (Pb) in Site 1 declined from 21–25 mg/kg untreated to 15–19 mg/kg at 10 g, 8–10 mg/kg at 14 g, and 2–5 mg/kg at 18 g. In Site 2, Pb levels reduced from 30–40 mg/kg to about 22–25 mg/kg at 10 g, 15–20 mg/kg at 14 g, and around 8–13 mg/kg at 18 g. Overall, the findings confirm that increasing polymer dosages significantly lowers Zn, Cd, and Pb in contaminated soils, demonstrating the bio-polymer's strong potential for soil remediation.

Keywords: *Heavy metals, bio-polymer, contaminated soil, heavy element pollution, soil pollution treatment.*

How to Cite: Fatimah Mohamed Khaleefah , Naser Samadi, Morteza Bahram, (2025) Bio-polymer in the Treatment of Oil-Soil Contaminated with Heavy Elements, *Journal of Carcinogenesis*, *Vol.24, No.5s*, 708-716

1. INTRODUCTION

Soil contamination with petroleum hydrocarbons and heavy metals is a growing environmental concern, particularly in areas affected by oil spills and improper waste disposal. These pollutants not only degrade soil quality but also pose serious threats to human health, ecosystems, and agricultural productivity (Huang *et al.,* 2018). Traditional remediation techniques, such as chemical and physical treatments, often present limitations including high cost, secondary pollution, and limited efficiency in heterogeneous environments (Yang *et al.* 2019).

Some heavy metals, such as lead, cadmium, and zinc, significantly impact soil (Yadav, 2017), especially in oil well fields. Petroleum is a mixture of hydrocarbons with a large and diverse group of organic compounds. It is one of the most important environmental pollutants of soil, as it is toxic to most living organisms in the environment, especially aromatic hydrocarbons, which lead to soil pollution (Samir *et al.,* 2022). It is the presence of pollutants in the soil in quantities that directly or indirectly cause harm to human health. Its harm is characterized by its ability to combine with sulfur and attack the protein compounds that make up many enzymes and inhibit their activity within the living organism or destroy the ecosystems(ATSDR,1992; Uduma & Jimoh, 2014) or affect the plant or animal environments, or affect surface or groundwater (Sutirman *et al.,* 2018). Among the most important soil pollutants are: heavy metals (Jahan, S., 2023), radioactive materials, pesticides, solid waste, and sewage. In recent years, biopolymers have emerged as promising eco-friendly materials for the remediation of contaminated soils. Derived from renewable biological sources, biopolymers such as chitosan, alginate, cellulose, and starch possess unique physicochemical properties, including biodegradability, non-toxicity, and the ability to chelate heavy metals. When applied to oil-contaminated soils, these materials can aid in immobilizing toxic elements, enhancing microbial activity, and improving soil structure. This study explores the role of biopolymers in treating oil-polluted soils laden with heavy elements.

2. MATERIAL AND METHODS

Chemicals and instrumentation

The important chemicals were provided from the Scientific Research Commission in Baghdad, Iraq laboratories. Preparation of Bio-Cellulose Polymer from Palm Bark.

Collection and Preparation of Palm Sample

Palm bark is collected from farms. It is cleaned to remove impurities and cut into small pieces. The pieces are dried in an oven at 30°C for 72 hours and ground into a fine powder. Mixed the powder with solution (5–25%) of NaOH in a 1:10 w/v ratio, heat the mixture to 160°C for 30 to 120 minutes to remove unwanted materials. Hydrogen peroxide (H_2O_2) is used to obtain whiten the fibers. Acid Hydrolysis for Nano-cellulose Extraction, fibers are treated with sulfuric acid (H_2SO_4, 30%) at 45°C for 30–60 minutes, then wash the product with cold water and centrifugation .Nano cellulose is dried using freeze-drying to obtain a fine dry powder (Nazir *et al.,* 2013, Chew *et al.,*2024).

Preparation and Application of Bio-Polymer in Contaminated Soils

Three different dosages of bio-polymer (10 g,14 g, and 18 g) were prepared for experimental treatment using an analytical balance. dissolved in 200 mL of distilled water with continuous stirring at room temperature for 30 minutes (Midhun Dominic *et al.,* 2022, Chew *et al.,*2024).

Contaminated soil samples

Samples were collected from two different locations known to be polluted with Zn, Pb, and Cd (Zanin Lima *et al.,* 2023; Zhang *et al.,* 2025).The soil was air-dried, sieved through a 2 mm mesh, and homogenized for uniformity. For each polymer concentration, 1 kg of contaminated soil was placed in a clean plastic container The prepared bio-polymer solution was slowly added to the soil while mixing thoroughly using a mechanical stirrer or hand mixer for 15–20 minutes to ensure even distribution of the polymer throughout the soil matrix (Midhun Dominic *et al.,* 2022, Nazir *et al.,* 2013, Chew *et al.,*2024).

Incubation

Samples were incubated at room temperature (25°C) for 21 days, with regular moisture maintenance. After incubation, soil samples were collected and dried. A control sample (without polymer) was also maintained for comparison. Digest the contaminated soil sample for analysis. (Cheng *et al*., 2020) The concentrations of zinc (Zn), lead (Pb), and cadmium (Cd) were analyzed using Atomic Absorption Spectroscopy (AAS) (USEPA Method 3050B) :

•Add 10 mL of concentrated nitric acid (HNO_3, 65%) to the sample.

• Heat the mixture gently at ~95°C (without boiling) for 15 minutes.

•Cool the sample, then slowly add 2 mL of hydrogen peroxide (H_2O_2, 30%).

•Repeat heating and cooling, and add more H_2O_2 if necessary until the reaction subsides.

•Filter the digested sample using appropriate filter paper.

•Dilute the filtrate to a final volume (typically 100 mL) with deionized water.

•Analyze the extract using AAS to determine the concentrations of heavy metals (Zn , Cd and Pb) Cd (Zanin Lima *et al.,* 2023; Zhang *et al.,* 2025).

3. RESULTS AND DISCUSSION

Zinc concentration before and after treatment

The previous experiments were repeated on (2) samples of contaminated soil, namely Site No. (1) and Site No. (2). After the contaminated soil from the two sites was prepared and the concentration of the three heavy elements was measured, Table 1and Figure 1, related to the results for zinc concentration before and after treatment.

Table 1. The zinc concentrations at site No. (1) and site No. (2) before and after treatment.

Zinc concentration in soil using 18g of cellulos (mg/kg)	Zinc concentration in soil using 14g of cellulose(mg/kg)	Zinc concentration in soil using 10g of cellulose(mg/kg	Zinc concentration in soil before treatment(mg/kg	Sit name
3.2	5.11	12.5	25.00	**Site No.1**
3.1	4.22	10.21	24.26	
3.2	4.11	12.02	25.21	
3.42	6.65	11.05	22.26	**Site No.2**
4.51	5.12	12.56	24.31	
3.3	5.16	12.24	23.22	

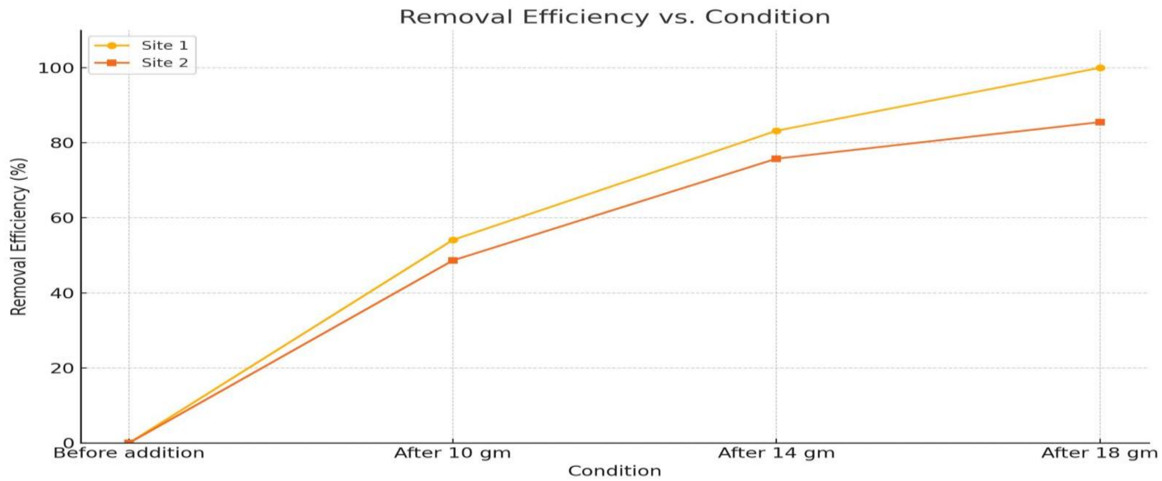

Fig. 1. Heavy Metal Removal Efficiency Using Biopolymer in Contaminated Oily Soil – Site 1

Initial concentration before treatment: 24.82 mg/kg.

Zinc removal efficiency at different biopolymers Doses

Site 1 – Initial concentration = 22 mg/kg

- 10g Biopolymer: $(22 - 15 / (22) * 100 = 31.82\%$
- 14g Biopolymer: $(22 - 9) / (22) * 100 = 59.09\%$
- 18g Biopolymer: (22 - 5.33) /(22) * 100 = 75.77%

Site 2 – Initial concentration = 35 mg/kg

- 10g Biopolymer: $(35 - 24) / (35) * 100 = 31.43$ %
- 14g Biopolymer: $(35 - 18.33) / (35) * 100 = 47.63\%$
- 18g Biopolymer: $(35 - 12) /(35) * 100 = 65.71\%$, Figure 2&3.

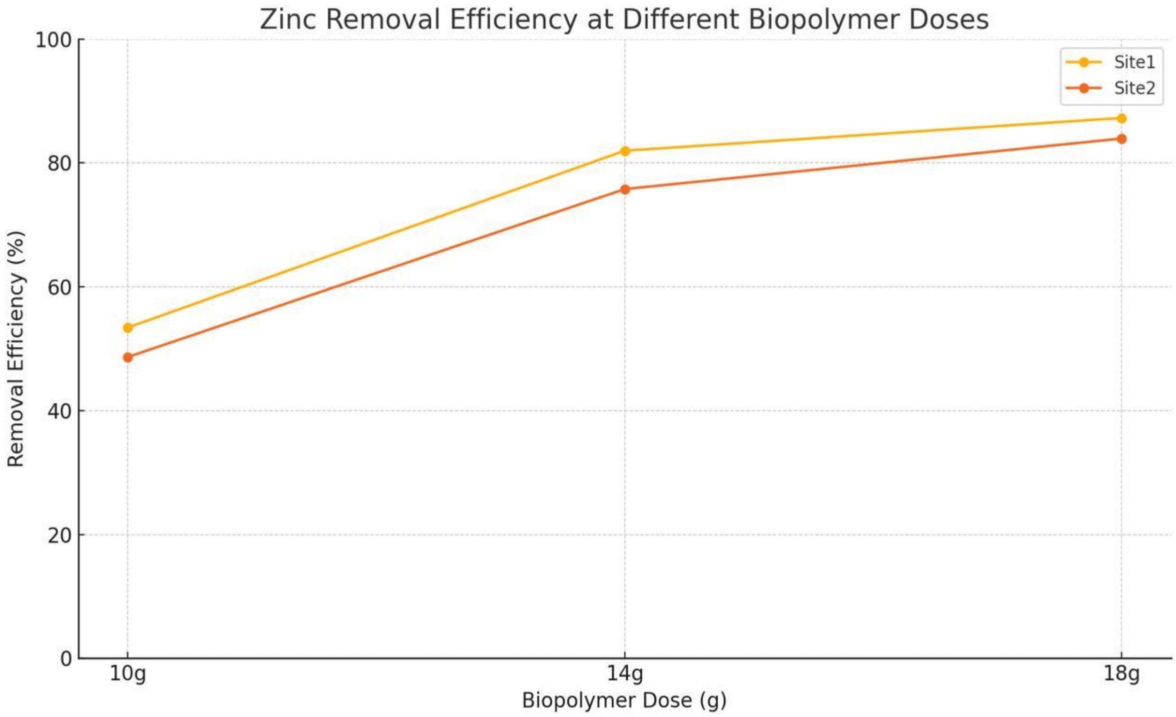

Fig.2. Zinc removal efficiency at different biopolymers Doses

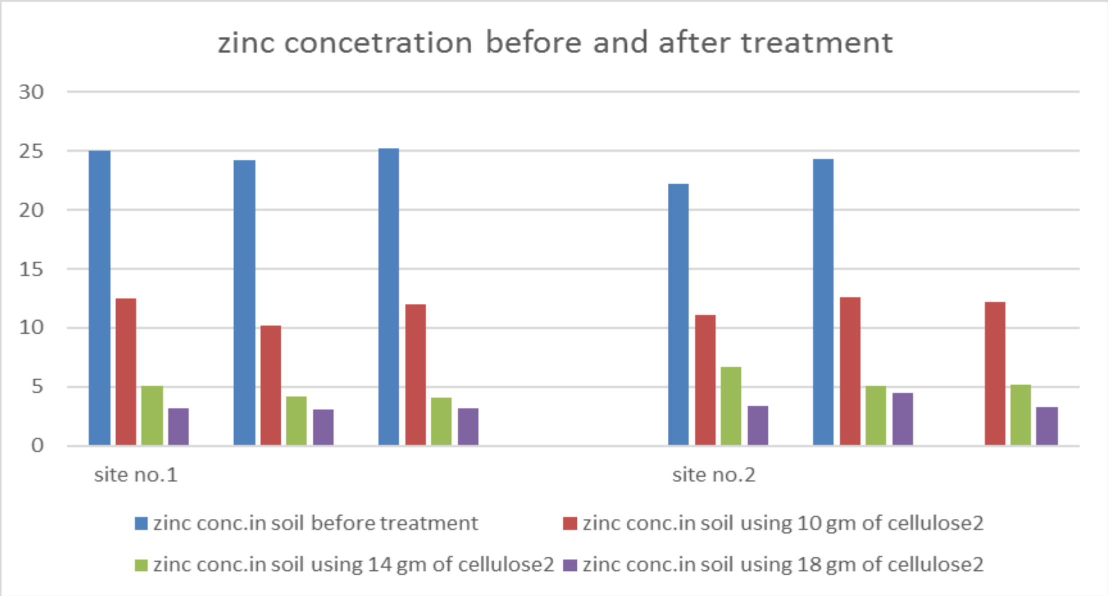

Fig.3. Zinc concentration before and after treatment with different concentrations of polymer(A3).

Cadmium removal efficiency at different biopolymers Doses

The contaminated soil from the two sites was prepared and the concentration of the three heavy elements was measured. The results for the cadmium concentration before and after treatment, Table 2, Figure 4 .

Table 2. The cadmium concentrations at site No. (1) and site No. (2)

Cadmium concentration with 18 gm of cellulose (mg/kg)	Cadmium concentration with 14 gm of cellulose(mg/kg)	Cadmium concentration with 10 gm of cellulose(mg/kg)	Cadmium concentration soil before treatment (mg/ kg)	Site name
0.0015	0.01	0.02	0.04	Site no.1
0.001	0.015	0.03	0.045	
0.001	0.014	0.025	0.041	
0.01	0.011	0.015	0.015	Site no.2
0.009	0.010	0.02	0.025	
0.0015	0.013	0.015	0.21	

Site 1 – Initial concentration = 0.042 mg/kg

- 10g Biopolymer: $(0.042\ -\ 0.025)/\,(0.042)\ *\ 100\ =\ 40.48\%$
- 14g Biopolymer: $(0.042\ -\ 0.013)/\ (0.042)\ *\ 100\ =\ 69.05\%$
- 18g Biopolymer: $(0.042\ -\ 0.0011)/\ (0.042)\ \backslash right)\ *\ 100\ =\ 97.38\%$

Site 2 – Initial concentration = 0.083 mg/kg

- 10g Biopolymer: $(0.083\ -\ 0.016)/\ \ (0.083)\ *100\ =\ 80.72\backslash\%$
- 14g Biopolymer: $(0.083\ -\ 0.0113)/\ \ (0.083)\ *\ 100\ =\ 86.39\backslash\%$
- 18g Biopolymer: $(0.083\ -\ 0.0068)/\,(0.083)\ *\ 100\ =\ 91.81\backslash\%$, Figure 4 &5.

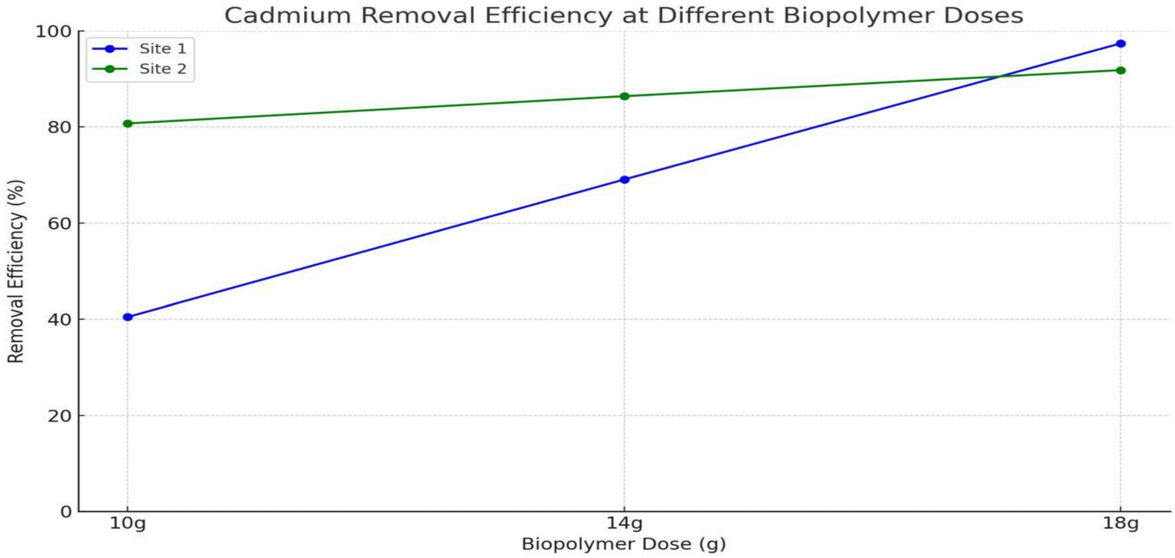

Fig 4. Cadmium Removal Efficiency Using Biopolymer in Contaminated Oily Soil – Site 1. chart (B2)

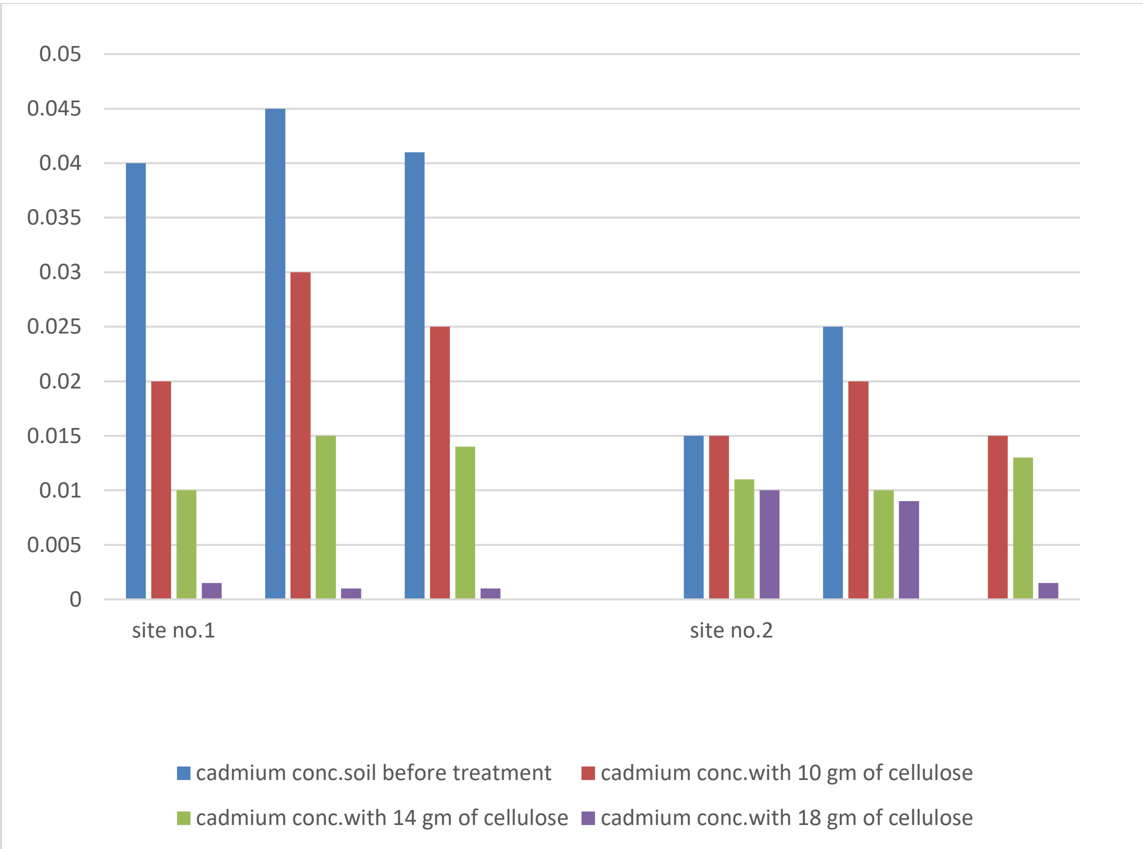

Fig. 5. Cadmium concentration before and after treatment with different concentrations of polymer(B3)

Lead removal efficiency at different biopolymers Doses

The contaminated soil from the two sites was prepared and the concentration of the three heavy elements in it was measured. The results for lead concentration before and after treatment, Table 3, Figure 6 .

Table 3. The lead concentrations at site No. (1) and site No. (2) before and after treatment

Lead concentration with 18 gm from cellulose(µg/kg)	Lead concentration with 14 gm from cellulose(µg/kg)	Lead concentration with 10 gm from cellulose(µg/kg)	Lead concentration in soil before treatment(µg/kg)	Site name
5	9	15	21	Site no.1
9	10	19	20	
2	8	11	25	
8	15	25	30	Site no.2
15	20	25	40	
13	20	22	35	

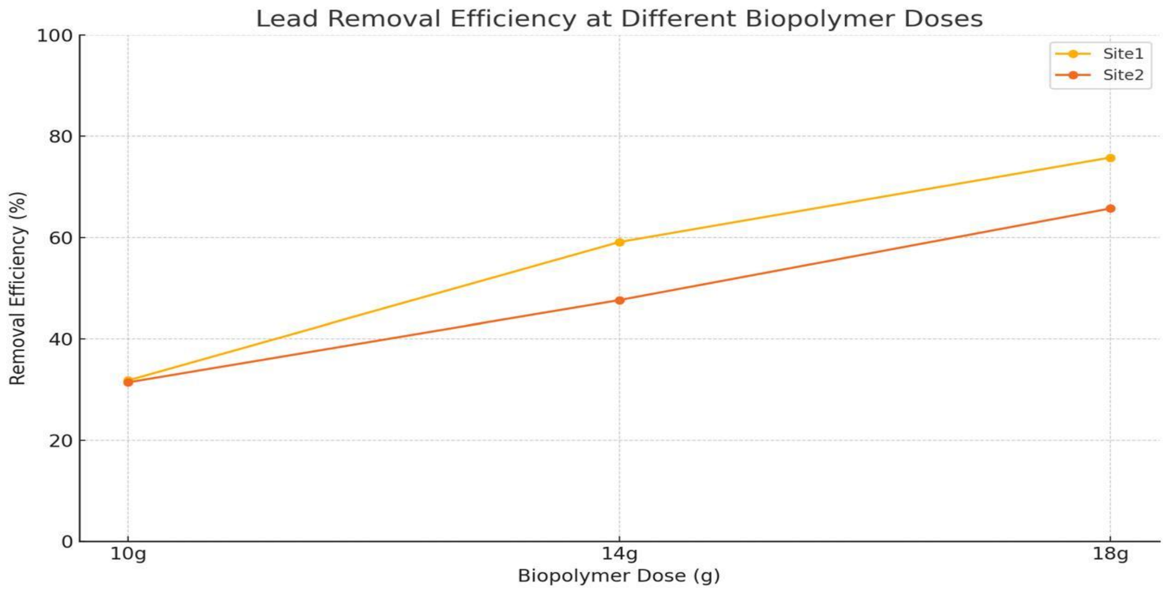

Fig. 6. lead Removal Efficiency Using Biopolymer in Contaminated Oily Soil – Site 1. chart (C2)

Site 1 – Initial concentration = 22 mg/kg

- 10g Biopolymer: $(22 - 15)/(22) * 100 == 31.82\%$
- 14g Biopolymer: $(22 - 9)/(22) * 100 == 59.09\%$
- 18g Biopolymer: $(22 - 5.33)/(22) * 100 == 75.77\%$

Site 2 – Initial concentration = 35 mg/kg

- 10g Biopolymer: $(35 - 24)/(35) * 100 == 31.43\%$
- 14g Biopolymer: $(35 - 18.33)/(35) * 100 = 47.63\%$
- 18g Biopolymer: $(35 - 12)/(35) * 100 == 65.71\%$, Figure 7.

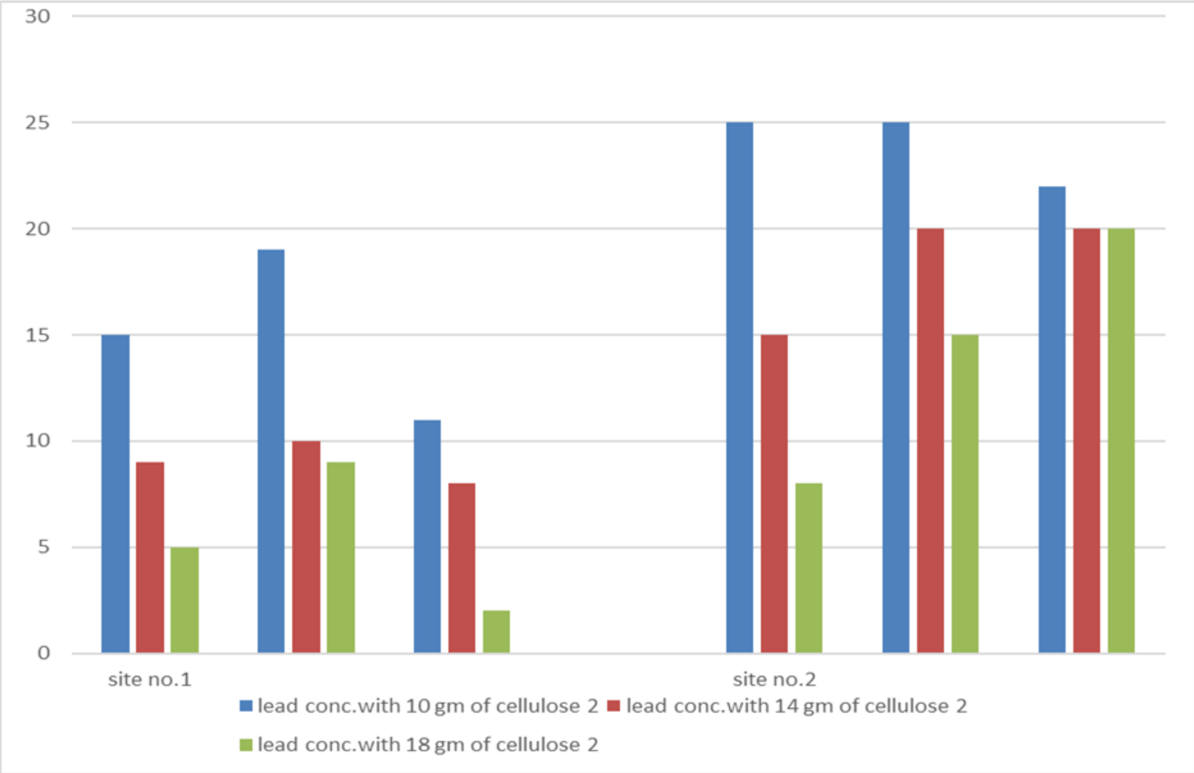

Fig.7.Lead concentration before and after treatment using different concentrations of polymer(C3).

4. DISCUSSION

The results obtained from this study demonstrate that the application of the biopolymer significantly reduces the concentrations of heavy metals such as zinc, lead, and cadmium in petroleum-contaminated soils (Wei *et al.,* 2023) The data indicate that removal efficiency increases proportionally with the amount of biopolymer applied; for example, zinc removal at Site 1 increased from 31.82% with 10 g of biopolymer to 75.77% with 18 g. Lead showed even higher removal rates, reaching over 97% when 18 g was applied (AL-Huqail *et al.,*2023).

These findings align with recent research confirming that increasing the dosage of biopolymer-based sorbents enhances their adsorption capacity and overall remediation performance. For instance, Latif *et al.* (2024) reported that biopolymer adsorbents derived from plant waste exhibit improved heavy metal removal as their concentration increases. Similarly, Mohanrasu *et al.* (2025) highlighted that biopolymer composites offer an eco-friendly and efficient alternative to conventional chemical treatments for contaminated soil and water. Therefore, the present results suggest that increasing the biopolymer dosage can be an effective strategy for improving the remediation of soils polluted with heavy metals (Arif *et al.,* 2025) .

5. CONCLUSION

In conclusion, the present study demonstrates that the use of a biopolymer is an effective and sustainable approach for remediating petroleum-contaminated soils laden with heavy metals such as zinc, lead, and cadmium. The results confirm that increasing the biopolymer dosage substantially enhances the removal efficiency of these metals, achieving removal rates exceeding 97% for lead under optimal conditions. These outcomes are consistent with recent literature, which emphasizes the superior adsorption performance of biopolymer-based materials as their concentration increases. Consequently, the findings support the feasibility of employing biopolymer sorbents as an environmentally friendly alternative to conventional remediation methods, offering a promising solution for mitigating soil pollution and safeguarding environmental health.

6. GRANT SUPPORT DETAILS

The present research did not receive any financial support.

7. CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

8. LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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