



The Role of Earthworms in Heavy Metal Remediation of Selected Soil in Baghdad Governorate/Iraq

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Abstract

This study examined the earthworms' role in removing heavy metals and their impact on soil degradation in some regions of Baghdad City/Iraq. Six sites named agricultural (S1), Plastic factory (S2), Oil factory (S3), Barren (S4), Residential soil (S5), and landfill soil (S6), between February and June 2024 were collected. In the dry period, the total concentration of Pb, Cu, Zn, Mn, Cd, and Fe heavy metals in the soil samples range from 3.13 to 26.4mg kg⁻¹, 4.2 to 33.6mg kg⁻¹, 15.9 to 114mg kg⁻¹, 319 to 715mg kg⁻¹, 0.81 to 5.19mg kg⁻¹, and 603 to 5142 mg kg⁻¹; in the wet period, it ranges from 3.07 to 24.7mg kg⁻¹, 13.3 to 31.13mg kg⁻¹, 23.17 to 106.9mg kg⁻¹, 299.2 to 690mg kg⁻¹, 0.35 to 2.05mg kg⁻¹ and 565 to 4822 mg kg⁻¹. The results show that the conditions of 50 earthworms and 28 days, had the best reduction rate in the concentrations of heavy elements (cadmium and copper) in the three contaminated soils (S3, S5, and S6). The worms' high ability and maturity during the 28 days before their death were the causes of these rates and the treatment was affected by contamination level, soil moisture, and Aeration. At the 5% probability level, the results revealed a negative and significant correlation, with an efficiency (R² x 100) ranging from 67 to 99.0. The regression analysis's findings also demonstrated that employing a large number of earthworms (50) reduced the cadmium concentration in the three polluted soils by -0.044, -0.057, and -0.0929 units per day of treatment, respectively, with use efficiencies of 89.9%, 67.0%, and 99%. the copper content in the polluted soils (S6, S5, S3) decreased by -0.0444, -0.227, and -0.141 one unit per unit. With a usage efficiency of 89.9, 91.1, and 84.3

Keywords

Baghdad, earthworms, biodegradation, heavy metals, cadmium and copper.

Article history:

Received: 23/04/2025, Revised: 23/05/2025, Accepted: 12/07/2025, Available online: 30/08/2025

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Introduction

Soil pollution is a major environmental issue brought on by a variety of natural and human-caused processes (Bhadauria & Saxena, 2010). Waste management, agricultural practices, and fast industrialization are all contributing factors to this pollution. Pollutants from industries can contaminate nearby soil, including petroleum hydrocarbons, heavy metals, and persistent organic pollutants (Mahdiraji & Ramezani 2019; Al-Sudani et al., 2021; Mandal et al., 2017). Another factor that contributes to soil contamination is the widespread use of chemical pesticides, herbicides, and fertilizers in agricultural operations (Mora et al., 2003). Hazardous substances were released into the soil as a result of the treatment and disposal of hazardous waste, putting human health and the ecosystem at risk. (Oliver and Gregory, 2015; Brevik et al., 2017; Yuan, 2023; Mahdiraji & Ramezani, 2019). Because contaminants move more easily through the atmosphere and water than through soil, soil pollution is more likely to accumulate over time compared to air and water contamination. (Shi et al., 2021; Yuan, 2023).

Contamination of soil poses several hazards and is a major environmental concern (Pavel & Gavrilescu, 2008). First of all, it has an immediate effect on water supplies and agricultural goods, endangering human health via the food chain (Oliver & Gregory, 2015). Second, it may result in significant monetary losses. Furthermore, ecological degradation, surface and groundwater contamination, air pollution, and other environmental problems can all be exacerbated by soil pollution (Mousa 2022; Satchell, 1967). To remediate contaminated soil, various treatment methods are employed, such as biological treatment, chemical-physical washing, and soil restoration (Pavel & Gavrilescu 2008; Dadrasnia, et al., 2013; Wu et al., 2021; Black & Evans, 1965).

Beginning in the mid-1980s, remediation technology research saw successful implementation in the 1990s. The process of using different organisms in the soil (such as plants, animals, and microbes) to absorb, break down, and change the contaminants in the soil to either reduce the contaminants' content to acceptable levels or turn the hazardous and poisonous contaminants into harmless materials is known as bioremediation technology (Ramos et al., 2005). The bioremediation of contaminated soil can be categorized into three main approaches: microbial remediation, plant remediation, and animal restoration (Mohsen Jabbar et al., 2019). Among these, microbial and plant remediation are the most widely utilized methods. (Ramos et al., 2005; Mandal et al., 2016; Sarwar et al., 2017; Page et al., 1982). In agricultural soils, earthworms are typically the most prevalent soil organisms (Abishek et al., 2023; Kamboj et al., 2021). They are known to enhance soils' biological, chemical, and physical characteristics and can significantly improve soil fertility when combined with soil microbes (Lee et al., 1985; Khyade & Wanve 2018). In temperate climates, the majority of earthworms prefer pH values between 5.0 and 7.4.

Satchell, (1967) Earthworms play a crucial role in enhancing both abiotic and biotic soil properties, providing several benefits to farmers, including improved nutrient availability, increased water retention, reduced soil erosion, and enhanced agricultural productivity (Otieno & Wanjiru 2024). The earthworms interact with the soil microbial population both directly and indirectly, which raises nitrogen levels. (Villenave et al., 1999; Mora et al., 2003; Bhadauria and Saxena, 2010; Villenave et al., 1999).

Because heavy metals (HMs) are harmful and persistent in the environment, they are the main source of soil pollution (Subramanian & Malhotra, 2023; Rai et al., 2019). Heavy metals (HMs) are found in soils due to a variety of causes, including the extensive use of synthetic fertilizers, air deposition, sewage sludge, farmyard manure, and fast industrialization (Zang et al., 2017; Shi et al., 2021). Copper (Cu), zinc (Zn), lead (Pb), mercury (Hg), nickel (Ni), cadmium (Cd), arsenic (As), and chromium (Cr) are the main heavy metals.

Properties and concentrations of these metals in soil vary throughout the environment. (Uchimiya et al., 2020). On the other hand, chronic exposure to heavy metals can result in bone fractures and lung cancer. (Al-Paruany et al., 2018; Rai et al., 2019). In Iraq, some researchers have studied the treatment of heavy metals and oil in soil using bioremediation (Ali, 2010; Mohsen et al., 2019; Ibrahim et al., 2025; Khyade & Wanve, 2018; Wu et al., 2021). This study highlighted earthworms' role in removing heavy metals and their impact on soil degradation in some regions of Baghdad city (Subramanian & Malhotra 2023).

Methodology

Site Description

This study includes soil samples from various locations within the Baghdad Governorate (Figure 1). The study area's coordinates range from 44°31'–44°17' E and 33°14'–33°25' N. Baghdad is divided into two sections, Karkh and Risafa, by the Tigris River, which flows from north to south. With an estimated area of 890 Km² and an average height of 32–36 m above sea level, the land surface slopes south at a rate of 0.1 m/km. The study area is distinguished by the presence of both agricultural lands and industrial complex sites (Lee, 1985). The area of uninhabited lands, including agricultural lands, was 33%, while the area of inhabited lands, including the beaches that encircle the boundaries of industrial facilities, was 67%. The climate in Baghdad is arid to semi-arid, with cold winters and dry, hot summers, with 151.8 mm of rain that falls on average each year. Table 1 displays the soil samples' geographic locations.

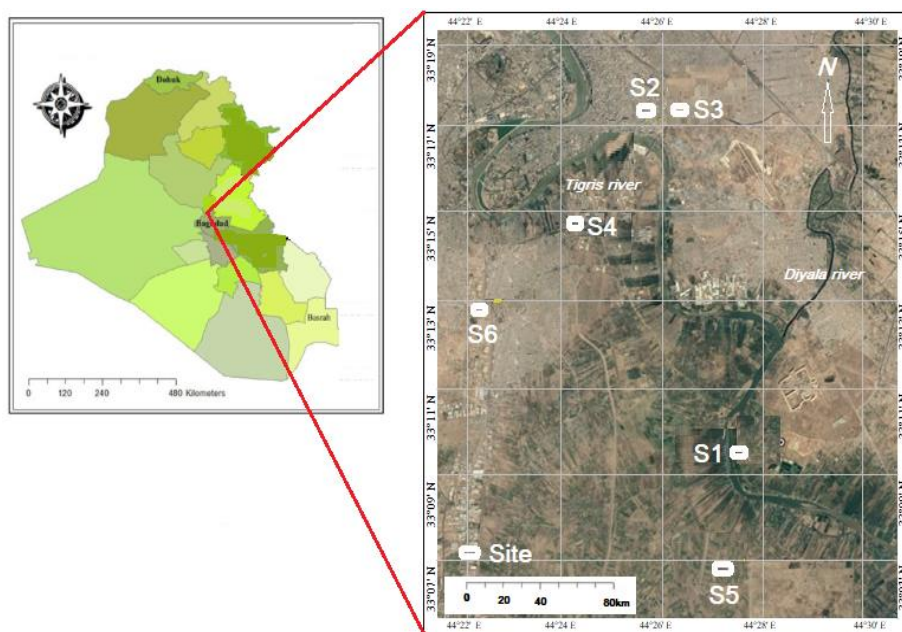


Figure 1. Map of the study area and sample location

Table 1. The name, type and geographical location of the studied samples

Sites	Symbol	E	N
Agriculture soil	S1	44° 28' 49"	33° 10' 45"
Plastic factory	S2	44° 27' 10"	33° 17' 47"
Oil Factory soil	S3	44° 27' 11"	33° 17' 58"
Residential	S4	44° 24' 41"	33° 15' 28"
Barren soil	S5	44° 29' 01"	33° 08' 10"
Landfill soil	S6	44° 22' 31"	33° 13' 38"

Sampling, Extraction, and Analytical Techniques

Six sites in Baghdad city, Agricultural, Plastic factory soil, Oil factory soil, Residential, Barren soil, and landfill soil, were used to gather soil samples between February and June 2024. Using a hand auger, all soil samples were taken from the surface at a depth of 0 to 30 cm. They were then stored in plastic bags with labels. After being stored in aluminum, the samples were submitted to the laboratory for additional analysis.

The extraction process began with the removal of large debris, stones, and pebbles. The soil samples were then disintegrated using a porcelain pestle and mortar. To eliminate moisture, the samples were either air-dried or oven-dried. For non-volatile heavy metals such as Cd, Cu, Pb, and Zn, soil samples can be dried either in air or in an oven at temperatures between 50 and 105°C. Oven drying is preferred as it accelerates the drying process and minimizes alterations in sample composition caused by microbial activity. After drying, the samples should be air-dried in the laboratory, homogenized, and sieved through a 2-mm polyethylene sieve. These samples were then stored in immaculate self-sealing plastic bags for further analysis in the chemical labs of the Scientific Research Commission and the Agriculture University's soil and water lab (Ibrahim & Al-Mashhadani, 2025). To analyze heavy metal concentrations in soil using atomic absorption spectroscopy (AAS), the soil matrix must be decomposed and heavy metals dissolved into solution. This process requires strong acid digestion, typically using HF, HNO₃, HCl, HClO₄, or H₂SO₄, in combination with high temperatures and, in some cases, high pressure, to ensure complete dissolution of the soil components.

Analytical Techniques

A. Following the dissolution of heavy metals in solution, heavy metal measurements were carried out using Atomic Absorption Spectrometry (AAS 6300, Shimadzu, Japan).

B. Additional methods and instruments were employed to assess the physico-chemical properties of soil samples, as outlined in Table 2.

Table 2. Methods and instruments that were used to estimate and measure the physico-chemical properties of soil samples.

Variables	Method and Instruments	Refer.
pH	pH-meter	Page et al., 1982
EC and TDS	EC-meter	Page et al., 1982
Sand, Silt, and Clay	Hydrometer	Black et al., 1965
O.M	Wet digestion	Jackson, 1958
Heavy metals	Atomic absorption spectrometer after digestion	Jones, 2001

Conditions of the experiment:

1. Evaluate the soil's properties for three different kinds of soil contamination (S3, S5, and S6).
2. Worms are provided with food, water, darkness, and adequate ventilation when cultivated in their native soil.
3. We applied worm doses of 10, 20, 30, and 50 worms per kilogram of contaminated soil.
4. The treatment duration was 7, 14, 21, and 28 days during the wet period.
5. Heavy metal concentrations (Cd and Cu) were measured at each treatment stage.

Biological Remediation Stage

The worms and the contaminated soil were first prepared for the treatment stage. The soil was sorted into Three different types: S3, S5, and S6, and the results showed significant levels of copper and cadmium that were beyond the internationally acceptable limits (WHO) (Mousa, 2022). Following the selection and preparation of the worms, the environment was set up to ensure their prolonged survival, including providing food, darkness, and proper ventilation (Lee et al., 2009). Worms, weighing a total of one kilogram, were introduced to plastic boxes designed for the experiment. The boxes were perforated on the top and sides for ventilation and on the bottom for water drainage. To allow the worms free movement, the floor of the boxes was covered with contaminated soil to a depth of over 20 cm. Given that worms prefer moist conditions, the soil was watered, though not excessively to avoid flooding. The soil was periodically sprayed to maintain appropriate moisture levels. Worms were introduced at doses of 10, 20, 30, and 50 worms per kilogram of soil. The worms were left for 7, 14, 21, and 28 days, with soil samples being collected at random intervals for analysis. The trials were repeated using different worm doses, and the concentrations of copper and cadmium were measured in the soil.

Numerous natural laboratory tests were carried out with varying treatment circumstances, and the soil's constituent elements were then measured once more. The following formula will be used to calculate the percentage of removal:

$$\text{Removal \%} = \frac{\text{Initial Con.} - \text{Final con.} \times 100}{\text{Final con.}}$$

Results and Discussion

Tables 3 and 4 display the findings of the analysis of the physical, chemical, and heavy metals for six samples of the soil taken from Baghdad city for two periods (dry and wet), in 2024, also showing the soil's global limits (Jackson, 1958).

Table 3. The results of Heavy metals for six samples of soil in Baghdad in the dry period, 2024.

Sites	unit	S1	S2	S3	S4	S5	S6	World limits
Ph	-	7.70	7.14	8.04	7.61	7.32	6.98	-
EC	dSm ⁻¹	4.30	6.06	7.32	6.85	3.01	9.20	-
TDS	mg L ⁻¹	2.86	3.88	4.72	4.36	1.92	5.89	-
sand	(gm kg ⁻¹)	183	237	253	217	185	194	-
Clay	(gm kg ⁻¹)	412	336	376	396	410	430	-
Silt	(gm kg ⁻¹)	405	427	371	387	405	376	-
O.M	gm kg ⁻¹	1.29	0.291	0.409	0.225	0.714	1.78	-
Total Pb	mgkg ⁻¹	5.25	11.4	9.16	3.13	3.27	26.4	150
Total Cu	mgkg ⁻¹	14.2	21.9	24.16	20	21.9	31.6	20
Total Zn	mgkg ⁻¹	24.7	50.1	71.4	15.9	18.9	114	300
Total Mn	mgkg ⁻¹	390	585	609	417	319	715	50
Total Cd	mgkg ⁻¹	0.516	1.94	2.5	0.815	4.02	5.19	5
Total Fe	mgkg ⁻¹	3047	1681	2300	603	2802	5142	5000

Table 4. The results of Heavy metals for six samples of soil in Baghdad in the wet period, 2024.

Sits	unit	S1	S2	S3	S4	S5	S6	World limits
pH	-	7.24	6.72	7.56	7.16	6.89	6.57	
EC	dSm ⁻¹	4.05	5.70	6.89	6.44	2.83	8.66	
TDS	mg L ⁻¹	2.69	3.65	4.44	4.10	1.81	5.54	
sand	(gm kg ⁻¹)	179	230	249	219	191	198	
clay	(gm kg ⁻¹)	414	340	379	394	407	427	
silt	(gm kg ⁻¹)	407	430	372	387	402	375	
O.M	gm kg ⁻¹	1.21	0.27	0.38	0.20	0.67	1.67	
Total Pb	mgkg ⁻¹	4.92	10	8.59	3.03	3.07	24.76	150
Total Cu	mgkg ⁻¹	13.32	20	22.66	19.0	21.10	31.71	20
Total Zn	mgkg ⁻¹	23.17	46	66.97	13.67	17.73	106	300
Total Mn	mgkg ⁻¹	365	548	571	391	299	670	50
Total Cd	mg kg ⁻¹	0.48	1.82	2.3	0.76	4.0	5.05	5
Total Fe	mg kg ⁻¹	2857	1576	2157	565	2628	4822	5000

The pH values in the soil samples of the studied area range from 6.98 to 8.04 during the dry period and from 6.57 to 7.56 during the wet period. The S3 has the greatest pH value (8.04), while station 6 has the lowest pH values (6.57). The EC and TDS values in the soil samples during the dry period range from 3.01 to 9.20 dSm⁻¹, 1.92 to 5.89 mg L⁻¹, respectively, and during the wet period, from 2.83 to 8.66 dSm⁻¹, 1.81 to 5.54 mg L⁻¹, as shown in Figures 2 and 3. Both EC and TDS values in S6 are comparatively high, suggesting the presence of organic compounds.

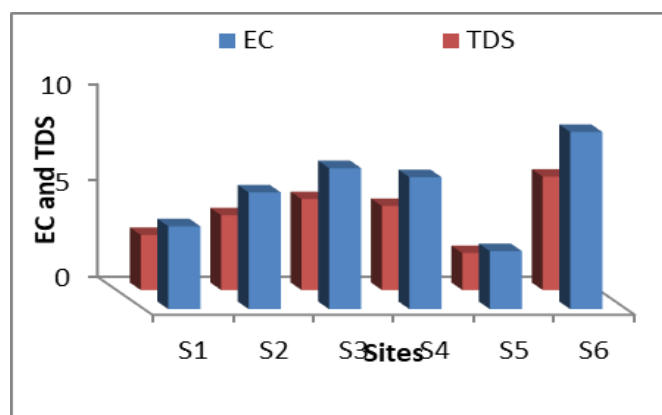


Figure 2. Distribution of EC and TDS values in the soil samples of the studied area during the dry period.

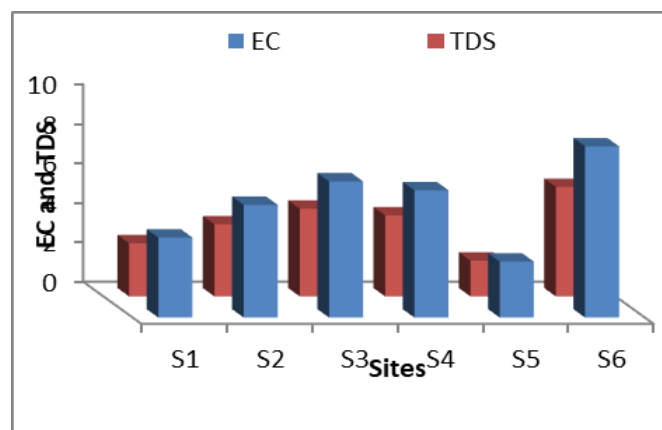


Figure 3. Distribution of EC and TDS values in the soil samples of the studied area during the wet period.

Figures 4 and 5 show that the soil type in the research region is loamy sand. According to a grain size analysis, during the dry period of 2024, the ranges for sand, silt, and clay were 336–430 mg kg⁻¹ of soil, 371–405 mg/kg of silt, and 183–253 mg/kg of clay. During the wet period, the ranges for sand, silt, and clay were 179–249 mg/kg of soil, 372–430 mg/kg of soil, and 430–427 milligrams per kilogram of soil, respectively.

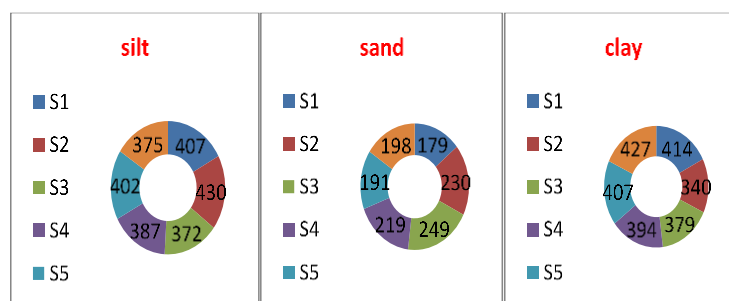


Figure 4. Distribution of sand, silt and clay in the studied area during wet period.

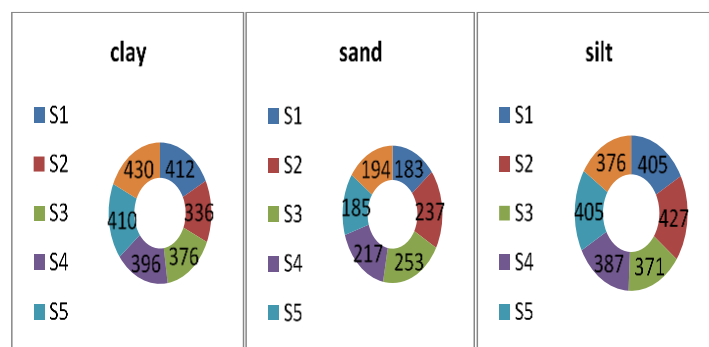


Figure 5. Distribution of sand, silt, and clay in the studied area during the dry period.

The organic matter (O.M.) content in the soil samples from the examined region during the dry period ranged from 0.22 to 1.78, with values of 0.20 and 1.67, respectively. These variations in organic matter values are attributed to differences in soil structure and the activity of soil organisms.

In the dry period, the total concentration of heavy metals of Pb, Cu, Zn, Mn, Cd, and Fe in the soil samples ranges between 3.13 and 26.4 mg kg⁻¹, 4.2 and 31.6 mg kg⁻¹, 15.9 and 114, 319 mg kg⁻¹ and 715, 0.81 and 5.19 mg kg⁻¹ and 603 and 5142, respectively, while in the wet period, it ranges between 3.0 and 13.32 mg kg⁻¹, 12.10 and 31.51 mg kg⁻¹, 23.17 and 106 mg kg⁻¹, 299.2 and 670 mg kg⁻¹, 0.76 and 5.05 mg kg⁻¹ and 565 and 4822 mg kg⁻¹ respectively. The landfill soil (S6) had the greatest heavy metal values, indicating that storing all the waste resulted in heavy metal accumulation. S5 had the lowest average values.

When comparing the concentrations of Pb, Cu, Zn, Mn, Cd, and Fe in the soil of the city of Baghdad with the global parameters, we find that the concentrations of Pb, Zn, Mn, and Fe did not exceed the permissible limits of 150, 20, 30, 50, 5 and 15000 ppm, respectively. This indicates that there is no pollution in the soil of the city of Baghdad, except in sites S3, S5, and S6, where the concentrations of Cd and Cu exceeded the permissible limits of 5 and 20 ppm, respectively. The cause of increased concentrations of copper in the soil of the city is due to industrial activities such as workshops, foundries, and smelting operations, in addition to the impact of irrigation water and drainage. The increasing concentrations of cadmium in the soil can be attributed to the accumulation of organic matter, industrial activities, the use of soil conditioners and pesticides, as well as the impact of water drainage. (Andre et al., 2009; Otieno & Wanjiru, 2024).

When comparing the concentrations of Cu and Cd in the soil of Baghdad with those in other governorates (Basra, Mosul, and Al-Anbar), as shown in Table 5, the results indicate that sites S3, S5, and S6 exhibit higher concentrations of cadmium and copper in the Basra and Mosul Governorates, while the Al-Anbar Governorate shows lower concentrations for both metals during both periods (Khwedim, 2013).

Table 5. Provides a summary of the comparison of the soil's heavy metal concentrations. of the world's soils with soil in the city of Baghdad.

Regions	Cu	Cd	References
Basra	52	3.5	Khwedim,2013
Mosul	34	0.04	Znad and Al-Sinjary.,2020
Al-Anbar	63	10	Al-Sudani et al.,2021
Current study	33.6	5.19	

For Biological treatment. The results of experiments on Biodegradation using earthworms are shown in Tables, 6,7,8 and 9.

Table 6: The concentrations of copper and cadmium in contaminated soils when ten earthworms are used and the treatment periods (7, 14, 21, 28) days.

Conc. After 28 days		Conc. After 21 days		Conc. After 14 days		Conc. After 7 days		Conc. before Treatment		Soil
Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	
18	1.87	18	1.87	19	2.01	22	2.24	24.16	2.40	S3
17.1	2.58	17.1	2.58	18	3.43	20	3.57	21.10	4.01	S5
25	4.0	25	4.0	28	4.8	29	5	31.61	5.12	S6

According to the results of the first experiment (Table 6), which involved 10 worms and treatment periods of 7, 14, 21, and 28 days, the cadmium concentration decreased the most after 21 days, reaching 1.87, 2.58, and 4 mg kg⁻¹ in sites S3, S5, and S6, respectively (Dadrasnia et al., 2013). The lowest decrease was observed after 7 days, with concentrations of 2.24, 3.57, and 5 mg kg⁻¹. The copper concentration in the three sites (S3, S5, and S6) decreased the most after 28 days, reaching 18, 17.1, and 25 mg kg⁻¹, respectively, while the least decrease was observed after 7 days, with concentrations of 22, 20, and 29 mg kg⁻¹. The removal rates of cadmium in S3, S5, and S6 were 22%, 35.5%, and 21.8%, respectively, while the removal rates of copper were 25.4%, 18.9%, and 20.9% in the same sites.

Table 7. The concentrations of copper and cadmium in contaminated soils when 20 earthworms are used and the treatment periods (7, 14, 21, 28) days.

Conc. After 28 days		Conc. After 21 days		Conc. After 14 days		Conc. After 7 days		Conc. before Treatment		Soil
Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	
17.4	1.25	18	1.87	19	2.01	22	2.24	24.16	2.40	S3
17	1.95	17.1	2.58	18	3.43	20	3.57	21.10	4.01	S5
24.7	4.0	25	4.0	28	4.8	29	5.0	31.61	5.12	S6

The second experiment (Table 7) showed that, with 20 worms and treatment periods of 7, 14, 21, and 28 days, the cadmium concentration decreased the most after 21 days, reaching 1.25, 1.95, and 4 mg kg⁻¹ in sites S3, S5, and S6, respectively. The least decrease was observed after 7 days, with concentrations of 2.24, 3.57, and 5 mg kg⁻¹. The copper concentration in the three sites (S3, S5, and S6) decreased the most after 28 days, reaching 17.4, 17, and 24.7 mg kg⁻¹, respectively, while the least decrease was observed after 7 days, with concentrations of 22, 20, and 29 mg kg⁻¹. The removal rates of cadmium in S3, S5, and S6 were 47%,

51%, and 21.8%, respectively, while the removal rates of copper were 27.7%, 19.4%, and 21.8% in the same sites.

Table 8. The concentrations of copper and cadmium in contaminated soils when 30 earthworms are used and the treatment periods (7, 14, 21, 28) days.

Conc. After 28 days		Conc. After 21 days		Conc. After 14 days		Conc. After 7 days		Conc. before Treatment		Soil
Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	
15.10	1.15	16.00	1.50	17.00	1.80	19.00	2.14	24.16	2.40	S3
13.50	1.55	13.60	1.90	16.00	3.13	17.00	3.17	21.10	4.01	S5
21.10	3.11	21.00	3.10	26.00	3.60	28.00	4.20	31.61	5.12	S6

In the third experiment, 30 worms were used, with treatment periods of 7, 14, 21, and 28 days (Table 8). After 28 days, the cadmium concentration decreased the most, reaching 1.15, 1.55, and 3.11 mg kg⁻¹ in sites S3, S5, and S6, respectively, while the least decrease occurred after 7 days, with concentrations of 2.14, 3.17, and 4.2 mg kg⁻¹. The copper concentration in the three sites (S3, S5, and S6) decreased the most after 28 days, reaching 15, 13.50, and 21.10 mg kg⁻¹, respectively. The least decrease was observed after 7 days, with concentrations of 19, 17, and 28 mg kg⁻¹. The removal rates of cadmium in S3, S5, and S6 were 52%, 61%, and 47.9%, respectively, while the removal rates of copper were 62.7%, 55.9%, and 39.2% in the same sites.

Table 9. The concentrations of copper and cadmium in contaminated soils when 50 earthworms are used and the treatment periods (7, 14, 21, 28) days.

Conc. After 28 days		Conc. After 21 days		Conc. After 14 days		Conc. After 7 days		Conc. before Treatment		Soil
Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	Cu	Cd	
6	0.7	9.4	1.05	15	1.8	22	2	24.16	2.40	S3
5	1.0	9	1.6	14	2.9	16	3	21.10	4.01	S5
9	1.0	14	1.2	22	3.2	26	4	31.61	5.12	S6

The results of the fourth experiment, which involved 50 worms and treatment periods of 7, 14, 21, and 28 days, are presented in Table 9. After 28 days, the cadmium concentration decreased the most, reaching 0.7, 1.0, and 1 mg kg⁻¹ in sites S3, S5, and S6, respectively. The least decrease was observed after 7 days, with concentrations of 2, 3, and 4 mg kg⁻¹. The copper concentration in the three sites (S3, S5, and S6) decreased the most after 28 days, reaching 6, 5, and 9 mg kg⁻¹, respectively. The least decrease was observed after 7 days, with concentrations of 22, 16, and 26 mg kg⁻¹. Based on the obtained data, the removal periods for all conditions followed an ascending order: 7days<14days<21days< 28days.

The findings in Tables 6,7,8 and 9 show that the conditions of 50 earthworms and 21 days, during which the experiments recorded removal values of cadmium and copper, produced the best (S3, S5, and S6) reduction rate in the concentrations of heavy elements (Cadmium and Copper) in the three contaminated soils (Brevik & Sauer, 2015). The earthworms can change total metal concentrations (Cd and Cu) in soil due to their metal accumulation capability (Nahmani et al., 2007). Moreover, in the treatment after 28 days, the concentration of Cd and Cu constant effect on earthworm behavior was also observed as earthworms tried to avoid penetrating the contaminated soil. This behavior might also increase impaired earthworm growth or even death.

The results obtained from this study indicated a significant effect of the factors examined in reducing the concentrations of heavy metals (Cadmium and Copper) in the contaminated soils (S3, S5, and S6) across the different treatment periods (7, 14, 21, and 28 days). The effect of earthworms was clear in the pollution indicators, especially when compared to the comparison treatment (before treatment). The use of earthworms

(50) led to a reduction in the concentrations of heavy element pollutants in the initial soil over time, as the range of soil content values of cadmium and copper ranged from 2.40 to 0.7 and 24.16 to 6, respectively. The highest value of the decrease was at the 28 days of treatment, and the lowest decrease in the pollutant content was at the 7 days of treatment. The percentage of increase in the average reduction in the concentration of cadmium and copper in the first soil (3) after 28 days of treatment was 70 and 75, 65 and 72%, 61 and 60%, 30 and 33% compared to the control treatment, 7 days, 14, 21 days, respectively. (Table 9), while the percentage of increase in the decrease in the concentration of the two indicators above in the soil contaminated with S5 at the period of 28 days of using earthworms (50) was 75 and 76%, 66 and 68%, 70 and 64%, 37.5 and 44.4%, respectively. The decreased percentage in contaminated soil (S6) reached I Cd and Cu was 80. and 71%, 59 and 25%, 37.5 and 31.8, 16, and 35.0 % for the time of 28 compared to the control treatment, 7, 14, 21, and 28 days, respectively. The results also showed that the average decrease for cadmium and the four time periods after treatment reached 0.7, 1, and 1.0 for contaminated soils 3, 5, and 6, respectively. While the copper pollutant index reached 6, 5.0, and 9 for the above-contaminated soils.

The relationship between cadmium and copper pollution indicators in both soils was evaluated with treatment periods using several earthworms and for all periods using the last squares analysis technique. The results showed a negative and significant correlation at the probability level of 5% and with an efficiency ($R^2 \times 100$) ranging from 67 to 99.0. Figure 6 and 7. The results of the regression analysis also showed that the decrease in cadmium concentration using many earthworms (50) reached -0.044, -0.057, and -0.0929 one unit per day of treatment in the three contaminated soils, respectively, with a use efficiency of 89.9, 67.0 and 99%. Using many earthworms (50) for all treatment periods led to a reduction in copper concentration by -0.0444, -0.227, and -0.141 units per unit of treatment in the contaminated soils (6, 5, 3) with a use. Efficiency of 89.9, 91.1, and 84.3. Figure 7.

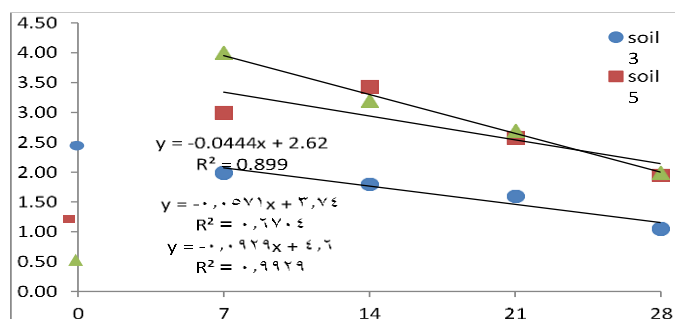


Figure 6. The relationship between cadmium pollution indicators with treatment periods using several earthworms (50) and for all periods using the last squares analysis technique.

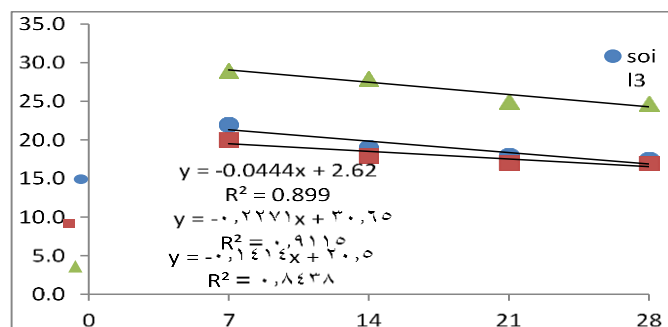


Figure 7. The relationship between Copper pollution indicators with treatment periods using several earthworms (50) and for all periods using the last squares analysis technique.

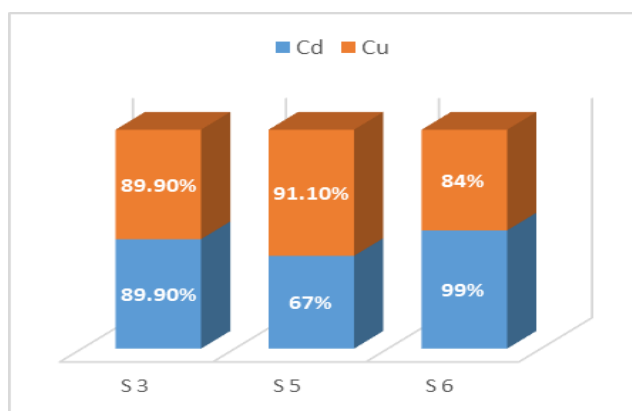


Figure 8. The removal efficiency of Cd and Cu from contaminated soil using worms.

To enhance the efficiency of biological removal, unpolluted soil can be mixed with contaminated soil. The high ability and maturity of the worms during the 21 days before their death contributed to the observed removal rates. Additionally, the effectiveness of the treatment was influenced by factors such as the level of contamination, soil moisture, and aeration. Furthermore, it was observed that the best treatment led to an increase in soil pH to 7, which in turn improved soil fertility.

Conclusion and Recommendations

In this study, contaminated soil in various parts of Baghdad was treated using earthworms to extract heavy metals (Cd and Cu). Six soil samples had different characteristics during the study period, and sites 3, 5, and 6 had Cd and Cu contamination. The heavy metals were removed using earthworms. Based on the obtained data, the ranking of the group's removal periods is in ascending order as 7 days < 14 days < 21 days < 28 days. The most effective heavy metal removal was observed in the sample, which was after 28 days with 50 earthworms. The relationship between cadmium and copper pollution indicators with treatment periods using several earthworms and for all periods was established using the last squares analysis technique (Znad & Al-Sinjary, 2020). The results showed a negative and significant correlation at the probability level of 5% and with an efficiency ($R^2 \times 100$) ranging from 67 to 99. The results of the regression analysis also showed that the decrease in cadmium concentration using many earthworms (50) reached -0.044, -0.057, and -0.0929 one unit per day of treatment in the three contaminated soils, respectively, with a use efficiency of 89.9, 67.0 and 99%. Using many earthworms (50) for all treatment periods led to a reduction in copper concentration by -0.0444, -0.227, and -0.141 units per unit of treatment in the contaminated soils (6, 5, 3) with a use efficiency of 89.9, 91.1, and 84.3. Numerous elements, including the degree of contamination, soil moisture, and aeration, were impacted during the removal process. However, the most effective therapy raises the pH to 7, which enhances soil fertilization. Lastly, to increase the efficiency of biological removal, unpolluted soil can be mixed with contaminated soil. Additionally, we suggest testing the growth of various plant species in the treated soil to further evaluate the effectiveness of the remediation process (Jones, 2001).

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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