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ECOLOGY

Investigation of soil pollution with Heavy Metals in Mosul forests, Mosul City, Iraq

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ABSTRACT. A total of eight heavy metals (lead (Pb), cadmium (Cd), nickel (Ni), arsenic (As), zinc (Zn), cobalt (Co), chromium (Cr), and copper (Cu), were investigated and analyzed to assess their concentrations and potential environmental implications. Compared with the global average index, The results revealed that the concentrations of cadmium (Cd: up to 0.12 ppm), nickel (Ni: up to 231.93 ppm), zinc (Zn: up to 99.61 ppm), and copper (Cu: up to 55.98 ppm) exceeded global average thresholds, indicating significant contamination. Statistical analysis using independent samples t-tests showed significant seasonal and depth-based variations ($p < 0.005$) for most metals. The elevated concentrations are likely linked to the 2014–2017 conflict in Mosul, which contributed to heavy metal accumulation through destruction, fire, and munitions. These findings underscore the urgent need for remediation efforts to restore soil health and protect the ecological and recreational value of Mosul's urban forests.

Keywords: Heavy metals; Mosul Forest; XRF analysis; post-conflict environment; urban soil.

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Introduction

Soil contamination by heavy metals has emerged as a pressing environmental issue globally, particularly in urban and peri-urban ecosystems. Industrial activities, urbanization, vehicle emissions, and agricultural practices have significantly contributed to elevated levels of heavy metals in soils (Alloway, 2013). These contaminants can persist for extended periods, accumulate in the food chain, and pose severe threats to ecosystem health and human well-being (Kabata-Pendias & Mukherjee, 2007).

In Iraq, and specifically in Mosul City, rapid urban expansion and anthropogenic activities have raised concerns regarding the extent of environmental pollution. Forested areas in and around Mosul, originally established for ecological balance and urban beautification, may be increasingly vulnerable to heavy metal accumulation due to their proximity to traffic routes, industrial zones, and municipal waste sites.

Forests represent one of the most vital ecosystems on Earth, playing a key role in mitigating atmospheric pollutants such as carbon dioxide and contributing to climate regulation. They also provide habitat for a wide range of living organisms, making their conservation essential (Blanco & Lo, 2012).

The city of Mosul witnessed a war during the year 2014-2017 that resulted in the destruction of large parts of the city's infrastructure and ecosystems. One of these ecosystems that were damaged is the Mosul forests, which were destroyed as a result of fires and cutting of trees, all of which led to the destruction of its soil and the concentration of heavy metals in it (Brown 2004; Mohammed et al. 2010).

Forest ecosystems are often perceived as relatively pristine environments; however, they are increasingly affected by atmospheric deposition and anthropogenic activities, making them susceptible to heavy metal accumulation (Zhang et al., 2012). Forest soils can act as both sinks and sources of heavy metals, depending on the physicochemical properties of the soil, the composition of the vegetation, and external inputs such as air pollutants and surface runoff (Adriano, 2001).

Heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), and chromium (Cr) are among the most commonly reported contaminants in forest soils. Unlike organic pollutants, heavy metals are not biodegradable and can persist in the environment for decades, posing long-term ecological risks (Kabata-Pendias, 2011). These metals can impair soil microbial activity, hinder plant growth, and enter food chains, affecting herbivores and ultimately humans (Nagajyoti et al., 2010).

Urban and peri-urban forests are particularly vulnerable due to their proximity to industrial zones, vehicular traffic, and human settlements. Metals such as Pb and Cd are often deposited from vehicle exhaust and industrial emissions, accumulating on leaves and eventually transferring to the soil through litterfall and leaching (Fitzgerald et al., 2003). Once in the soil, metals may bind to organic matter or clay minerals, or remain in exchangeable forms available for plant uptake (Zhou et al., 2016).

The interaction between forest vegetation and heavy metal contamination is complex. While some tree species can tolerate or accumulate heavy metals, prolonged exposure may lead to physiological stress, reduced biomass, and altered nutrient cycling (Alfani et al., 2000). Understanding the dynamics of heavy metals in forest ecosystems is therefore critical for assessing ecosystem health, guiding reforestation efforts, and implementing pollution mitigation strategies.

Heavy metals are found freely or bound in nature, in addition to that they are produced by natural disasters that occur such as volcanoes, and are also produced by human activity, but their danger in their high concentrations that exceed the permissible limits, in addition to that they are not degradable no matter how much they pass It has the years and the circumstances because of its high specific weight (Parizanganeh et al. 2010; Mmolawa et al. 2011).

Some operations lead to the release of heavy metals into the soil environment, such as pollution with agricultural pesticides, pollution through industrial activity such as oil spills and some industries such as the production of batteries and dyes, pollution as a result of wars and what the munitions contain of heavy metals such as white phosphorous and arsenic (Sayadi 2014).

The danger of heavy metals is not only soil pollution, but also their transmission through the food chain to reach humans through agricultural crops that humans feed on, and which accumulate in cells and organs of the human body, causing their destruction (Van and Krivolutsky 1996; Habib et al. 2012). As for soil contamination, (Znad and Al-Sinjary, 2020) conducted a study in Mosul's main industrial areas, assessing heavy metal concentrations in surface soils and employing geospatial mapping to determine their spatial distribution and potential environmental impacts on nearby regions.

The increase of Heavy metals is linked to the global economic development and the industrial revolution, which led to the depletion of natural resources and in return the release of pollution irresponsibly and harmful to the needs of future generations (Figure 1). (Shutzendubel and Polle 2002; Jean-Philippe et al. 2012).

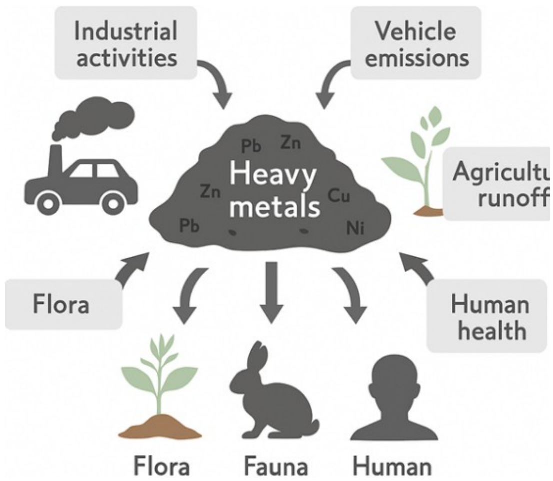

Figure 1. Conceptual framework of soil pollution pathways and their ecological impacts.

Several studies indicated the possibility of treating pollution with heavy metals by using microorganisms (bioremediation) such as fungi and bacteria, as well as using plants in treatment such as reeds, for example, but all these attempts remain promising (Mei et al. 2011; Serbula et al. 2013). (Fadhel et al. 2022) reported elevated concentrations of Ni, Cu, and Zn in the blood serum of workers from Mosul's Eastern Industrial Region, highlighting significant occupational exposure to toxic heavy metals Methods

Location

Mosul forests were selected as the study area due to their ecological and social significance, as well as their vulnerability to environmental degradation. These urban forests serve as vital green spaces within Mosul City, offering ecological services such as carbon sequestration, biodiversity support, and climate regulation.

Moreover, they are located in close proximity to major urban, industrial, and transportation corridors, making them particularly susceptible to anthropogenic pollution. Importantly, the area suffered extensive environmental damage during the 2014–2017 conflict, including deforestation, infrastructure destruction, and possible contamination from military activities. These factors collectively make Mosul forests a critical and representative site for assessing the impact of heavy metal pollution in post-conflict urban ecosystems.which is located in the north of Iraq (Figure 2).

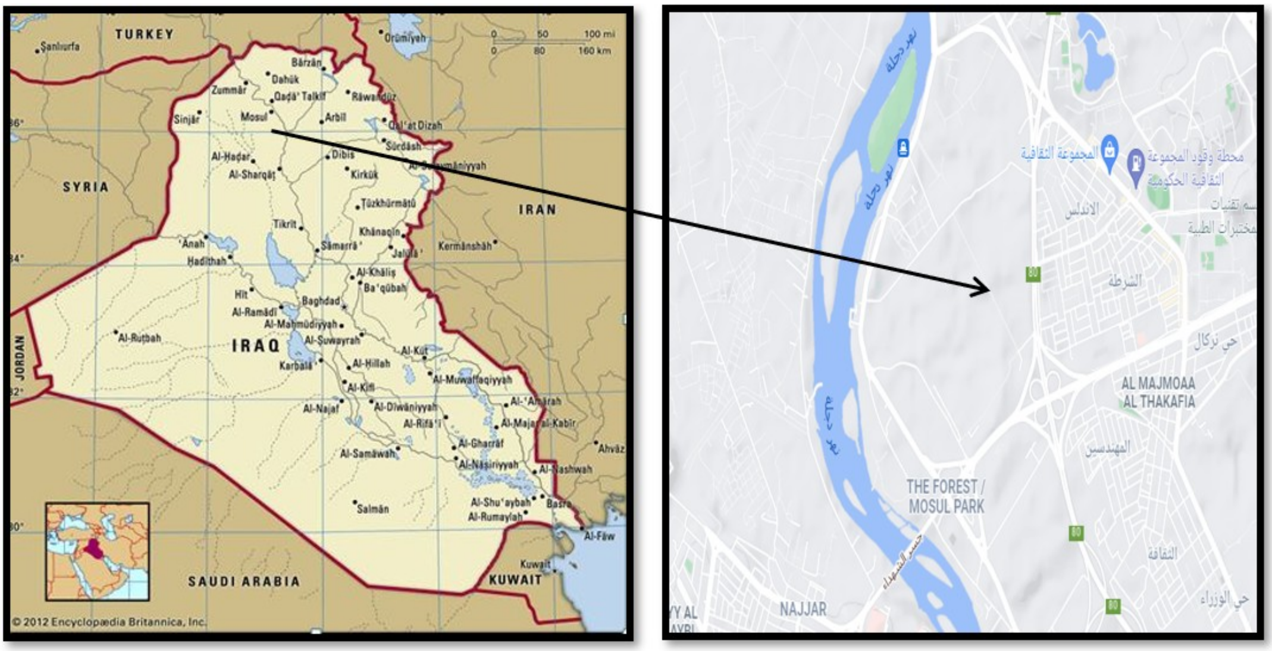

Figure 2. Location.

Sampling

Following preliminary field visits and environmental assessment, five forest sites were selected within Mosul City for soil sampling. These sites were chosen based on their exposure to potential pollution sources, including traffic, urban development, and industrial activity.

At each site, 10 soil samples were collected. Sampling was carried out over two different periods: October 2019 and February 2020, to account for possible seasonal variations in contamination levels.

Samples were extracted at a uniform depth of 15 cm (The 15 cm soil depth was chosen because it represents the biologically active layer of forest soils, where the majority of root systems, microbial activity, and organic matter decomposition occur. This surface horizon is particularly sensitive to external contamination sources such as atmospheric deposition, vehicular emissions, industrial activities, and anthropogenic disturbances. Sampling at this depth enhances the ability to detect recent and surface-level heavy metal accumulation, which is critical for assessing the extent of pollution and its potential ecological impact. Moreover, this depth is widely adopted in soil pollution studies, ensuring the comparability of results with established international benchmarks and previous research findings). using a standard soil auger. This depth was chosen to target the active root zone where heavy metals are most likely to interact with plant systems and microbial communities. Each sample was placed in a clean, labeled polyethylene bag and immediately transported to the laboratory for preparation and analysis.

In the laboratory, all samples were air-dried at room temperature to remove excess moisture. The dried soil was then cleaned manually to remove debris, crumbled to break up compacted clumps, and passed through a 2 mm stainless steel sieve to standardize particle size and ensure consistency across all samples.

A representative sub-sample was then taken from each sieved sample for analysis. The concentrations of heavy metals were determined using X-ray Fluorescence Spectrometry (XRF), a non-destructive analytical technique that allows for precise multi-element detection with minimal sample preparation. XRF is widely used in environmental studies due to its reliability, speed, and ability to detect trace elements in complex matrices.

Statistical analysis using T-test

The statistical analysis of heavy metal concentrations in soil samples was performed using SPSS software To determine whether there were statistically significant differences in heavy metal concentrations between different forest sites or between sampling periods, the Independent Samples T-test was applied.

The T-test is a widely used method for comparing the means of two independent groups. In this study, it was used to assess differences in metal concentrations between specific sites or between the two sampling periods (October 2019 vs. February 2020). A significance level (α) of 0.05 was adopted, meaning that a p-value < 0.05 was considered statistically significant.

This analysis helped identify the sites most affected by contamination and supported the hypothesis that location and anthropogenic activities influence the accumulation of heavy metals in the soil.

Result and discussion

In comparison with the global average of permissible concentrations of heavy elements in the soil, we note that the values of the elements (Cd, Ni, Zn, Cu) that were measured exceeded this indicator (Sommers and Lindsay 1979), These results have been included in Table 1 and Table 2.

Table 1. Heavy metals at Summer Season in unit (ppm).

Elements	Mean		Standard Deviation		Min		Max		Global Average
	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	
Pb	0.19	0.11	0.04	0.03	0.12	0.10	0.23	0.12	10
Cd	0.11	0.09	0.07	0.04	0.10	0.08	0.12	0.12	0.06
Ni	176.95	125.60	38.42	29.63	128.33	99.24	231.93	172.80	40
As	9.19	5.82	3.52	3.61	6.21	2.89	14.88	11.99	10
Co	12.14	7.35	2.47	2.09	8.67	4.11	14.51	9.76	8
Cr	100.51	72.97	33.08	29.90	66.76	41.87	154.31	121.21	100
Zn	96.24	66.04	3.43	5.39	90.80	59.68	99.61	70.86	50
Cu	47.13	31.25	7.63	9.09	38.75	19.90	55.98	43.29	30

Table 2. Heavy metals at Winter Season in unit (ppm).

Elements	Mean		Standard Deviation		Min		Max		Global Average
	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	
Pb	0.04	0.13	0.01	0.01	0.02	0.12	0.06	0.14	10
Cd	0.05	0.11	0.02	0.01	0.03	0.10	0.09	0.14	0.06
Ni	166.60	128	41.27	29.73	116	102	226	175	40
As	7.91	7.20	3.22	3.34	5.12	5	13.33	13	10
Co	7.20	8.60	1.30	1.81	5	6	8	11	8
Cr	98.27	76.60	32.67	29.92	64.12	45	151	125	100
Zn	91.48	69.20	2.67	5.01	87	64	93.22	74	50
Cu	40	36.60	6.63	7.23	30	27	47	46	30

The decrease in the concentration of heavy metals at a depth of 15 cm during the winter season is due to soil washing operations by rain, and this is something we did not notice in the summer season (Delpla et al. 2011; Noli and Tsamos 2016). (Table 3) expresses a high level of significance for the t-test statistical test.

Table 3. Statistical t-test.

Elements	Mean				Standard Deviation				t		df		sig	
	summer	winter	summer	winter	summer	winter	summer	winter						
	15 cm	15 cm	30 cm	30 cm	15 cm	15 cm	30 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm
Pb	0.19	0.04	0.11	0.13	0.04	0.01	0.04	0.01	6.232	6.532	4	4	0.003	0.003
Cd	0.11	0.05	0.09	0.11	0.07	0.01	0.07	0.01	5.674	5.880	4	4	0.005	0.004
Ni	176.95	166.60	125.60	128	38.42	29.73	38.42	29.73	6.023	5.604	4	4	0.004	0.005
As	9.19	7.91	5.82	7.20	3.52	3.34	3.52	3.34	5.668	7.256	4	4	0.003	0.002
Co	12.14	7.20	7.35	8.60	2.47	1.81	2.47	1.81	6.594	6.322	4	4	0.003	0.003
Cr	100.51	98.27	72.97	76.60	33.08	29.92	33.08	29.92	6.229	6.283	4	4	0.003	0.003
Zn	96.24	91.48	66.04	69.20	3.43	5.01	3.43	5.01	6.300	8.595	4	4	0.005	0.001
Cu	47.13	40	31.25	36.60	7.63	7.23	7.63	7.23	5.542	5.727	4	4	0.003	0.005

Conclusion

The study confirmed significant heavy metal contamination in Mosul's forest soils, particularly for lead (Pb) and cadmium (Cd), with levels exceeding global standards. This pollution is linked to the 2014–2017 conflict and intensified by anthropogenic activities such as vehicular emissions and industrial operations. Proximity to roads and residential areas was associated with higher contamination. The presence of heavy metals poses risks to soil health, biodiversity, and human well-being through food chain transfer. The findings highlight the urgent need for environmental monitoring, remediation efforts, and sustainable land management to restore ecological balance and preserve the forests' recreational and ecological functions.

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