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Pollution Levels of Lead and Copper in the Areas Surrounding Diyala State Company, Iraq

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ABSTRACT

Pollution by toxic metals represents a great environmental concern. Industrial activities release high levels of metals into the environment, adversely affecting human health. This study aimed to assess levels of lead and copper contamination in the areas surrounding Diyala State Company as well as to evaluate the efficiency of roadside plants in absorbing these metals from soil by their leaves, thereby exploring their role in reducing environmental pollution. Soil and leaf samples were collected from four directions surrounding the company and at distances in each direction (100, 500, 1,000, 2,000 meters). Leaf samples were collected from four plants: *Eucalyptus camaldulensis*, *Ricinus communis*, *Dodonaea viscosa*, and *Malva parviflora* between June and August 2024. The findings revealed high concentrations of lead and copper. The highest lead concentration was in the eastern part (3 mg/kg) in *E. camaldulensis* at site E3. The highest copper concentration was in the northern part (1.36 mg/kg) in *R. communis* at site N2, and *D. viscosa* was recorded with the highest lead concentration (2.43 mg/kg) in the northern part at site N4. *M. parviflora* showed higher lead concentration in the western part (1.58 mg/kg) at site W1. The maximum bioaccumulation coefficient for lead uptake was exhibited in *E. camaldulensis*, followed by *R. communis*, which also demonstrated the highest uptake of copper in most locations, particularly in the northern part. According to their efficiency in heavy metal uptake and accumulation, the plants were ranked as follows: *E. camaldulensis* > *R. communis* > *D. viscosa* > *M. parviflora*. It is clear that these plants have shown a high capacity for absorbing heavy metals, which positively impacts the environment and allows for their inclusion in bioremediation programs.

HIGHLIGHTS

- The ability of roadside plants to absorb lead and copper was evaluated around Diyala State Company.
- Shrubby and herbaceous plants were tested for their capacity to absorb heavy metals.
- The highest bioaccumulation coefficient for lead revealed in *E. camaldulensis* whilst *R. communis* had the higher capacity for copper uptake.
- The examined Plants exhibited promise for phytoremediation with potential efficiency ranking as *E. camaldulensis* > *R. communis* > *D. viscosa* > *M. parviflora*.

1. INTRODUCTION

Industrial enterprises emit a wide range of pollutants during production processes, such as heavy metals, solid and liquid particulate matter, harmful gases, and high waste heat (Zhao and Yin, 2024). Industrial pollution poses a growing threat to health and ecosystems and this is expected to continue increasing, requiring effective remedial approaches and monitoring programs to significantly reduce its impact on health and the environment (Ondrasek et al., 2025). Diyala State Company is an industrial corporation located in Baqubah City, Diyala Province, Iraq. The company specializes in manufacturing electrical appliances such as fans, irons, electrical meters, power and distribution transformers. These devices contain toxic materials, including lead, cadmium, nickel, iron and copper, and therefore can affect the environment and human health (Alkouh et al., 2023).

Many of these metal ions are released into the environment, causing serious pollution. Heavy metal ions also negatively affect the aquatic and terrestrial

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animals and plants. It is well known that heavy metal toxicity causes various types of cancer, kidney and liver damage, skin problems, among others, as a result of toxic exposure to heavy metals (Kumar and Singh, 2024). As a result of its various industrial, domestic, agricultural, medical and technological applications, it has become widely spread in the environment (Mohammed et al., 2023).

Lead can enter water and soil through electrical waste and distribution or plumbing lines. Plumbing parts that contain lead, such as solder, galvanized pipes, and brass fittings, which can contain up to 8% lead, can leach lead (Fawkes and Sansom, 2021). Current studies show that the non-biodegradability of lead and continuous use lead concentrations accumulate in the environment and cause various harmful effects, such as neurotoxicity and alteration in the psychological and behavioral development of various organisms (Kumar and Singh, 2024). Pollution by copper is becoming increasingly severe and seriously threatens human health and ecosystems. It was reported that copper concentrations in wastewater range from about 2.5 mg/L to 10,000 mg/L, one of the risks posed by untreated industrial wastewater is (Liu et al., 2023). Metals are among the most dangerous pollutants as they are not biodegradable and easy to accumulate in the food chain (Hussein et al., 2021). Therefore, its pollution must be mitigated and its spread in the environment limited by using some eco-techniques. Biological technologies such as phytoremediation, agricultural waste, fruit peels, and algae are considered safe, much cheaper, economical, eco-friendly, and almost free of adverse effects (Zahra et al., 2020). There are some plant species with high phytoremediation capacity due to their ability to absorb heavy metals and reduce pollution, especially in industrial and residential areas (Mocek-Płóciniak et al., 2023). Plants are categorized by their short life cycle, high capacity to tolerate and absorb metals, and accumulate it in their root system (Mazumdar and Das, 2015). Many plant species were used as bio-adsorbent agents, such as *Calotropis gigantea*, *Sida cordifolia*, *R. communis*, *Spartina alterniflora*, *Alternanthera philoxeroides*, *Eichhornia crassipes* (Wang et al., 2021) and *E. camaldulensis* (Madejon et al., 2017).

Local studies in Iraqi and regional countries have evaluated soil and plant contamination with heavy metals such as lead and copper. Several studies have been conducted in Iraq on heavy metal pollution and phytoremediation in different areas. However, the impact of pollution from the Diyala State Industrial Company on the surrounding areas has not yet been studied. This study is the first to evaluate some of the local plants found in these areas, which have not been previously studied, such as *M. Parviflora*, *R. communis*, *D. viscosa* in terms of their quantitative capacity to absorb lead and copper. This approach enables the identification of plants suitable for local phytoremediation programs, providing new insights not covered in previous studies in the region.

A study revealed levels of lead in soil and plants estimated by 3.57 mg/kg and 1.97 mg/kg, respectively (Mahmood and Rathi, 2024). In Baghdad Province, Amer and Abdulhussein (2022), showed that the lead levels in soil are similar to those in the current study (2.2 mg/kg). The concentrations of lead and copper in Kirkuk, north of Iraq, were elevated in soil samples and some local plants by 2.2 mg/kg and 67 mg/kg, and 55 mg/kg and in plants 11 mg/kg for copper, respectively (Khurshid et al., 2022). Mahmood and Rathi (2024) found that the lead concentrations exceeded the internationally permissible limit in soil of Basra, south of Iraq, by 37.32 mg/kg. They also found 24.13 mg/kg concentration in soil in Maysan Province. In leaf samples, lead levels reached 0.17 mg/kg and 0.13 mg/kg in Basra and Maysan, respectively (Mahdi et al., 2020). A study conducted in Riyadh City in Saudi Arabia on palm soil exhibited lead levels of 5.08 mg/kg and copper levels of 11.36 mg/kg, affecting soil fertility and the quality of agricultural production (Alarifi et al., 2022). In Isfahan Province in Iran, lead concentrations in soil of Tang-e Douzan mine/Isfahan were estimated at 2,500 mg/kg, and were 298 mg/kg in local plants (Hesami et al., 2018).

Diyala State Company is among the biggest and oldest industrial facilities in the area, and due to its diverse industrial processes, heavy metals (e.g., lead and copper) and toxins are released to the surrounding environment and transported and accumulate in the human body, affecting the health of the residents in the area. Due to the current expansion in residential population, buildings are becoming close to the company boundaries and negatively affecting health and quality of people life in these areas causing health problems such as respiratory or skin diseases due to this pollution, therefore, this study was designed to determine the extent of pollution by lead and copper in the areas surrounding the company and identify the ability of some plant species as eco-friendly way to absorb and accumulate these metals in order to reduce pollution levels. This study offers scientific data to help decision-makers in the local governorate to deal with this pollution and promote future studies on the effects of heavy industries in Iraq on the environment and human health, and find eco-friendly solutions.

2. METHODOLOGY

2.1 Description of the study area

Diyala State Company is an Iraqi industrial company in Diyala Province, Baqubah District, located northeast of Baghdad Province. It is located southeast of Baqubah City between latitudes 33.7459° and longitudes 44.6390°. The area of Diyala State Company is estimated at 400,000 square meters. It is an industrial company that manufactures electrical appliances. It is an industrial area with no markets, and traffic is heavy and continuous. The population density is low. There are blacksmiths and car repair shops. The industrial density is very low and is considered a relatively distant area from the center of Baqubah city (Mahmood and Rathi, 2024), as shown in Figure 1.

2.2 Samples collection

The leaf samples were collected with the required measurements between June and August 2024 from four plants included *E. camaldulensis*, *D. viscosa*, *R. communis*, and *M. parviflora* located on the sides of roads in the areas surrounding Diyala State Company from four directions in Baqubah City (North, South, East, West) as shown in Table 1. The intact leaves were taken from bottom, middle, and top of the plants in clean bags labeled with the date and type of site and kept in the freezer until transported to the laboratory. The soil samples in which the plant grows were collected at depth of 10-15 cm from the surface in re-sealable plastic bags labeled with the date and site (Bibi et al., 2023; Jiang et al., 2023).

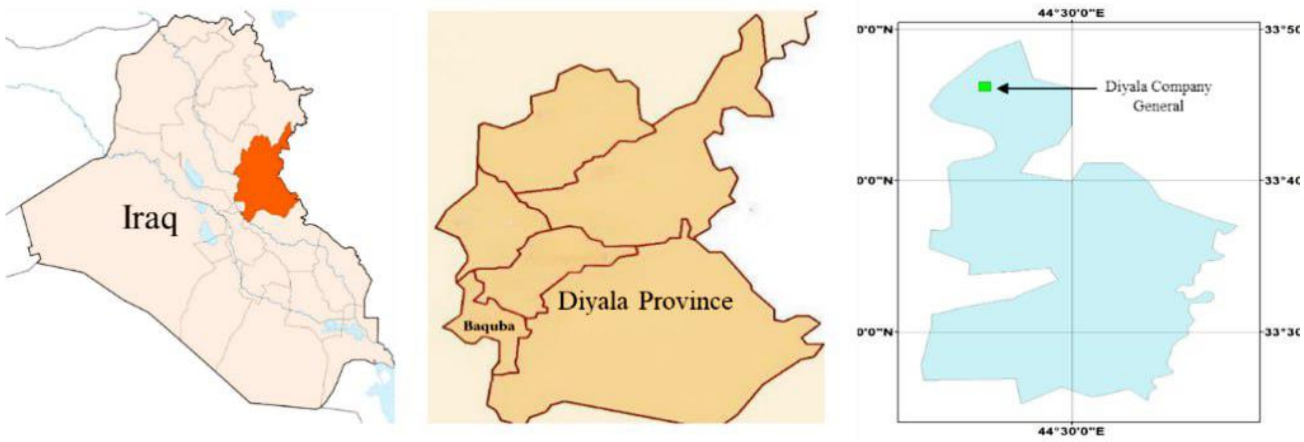

Figure 1. Sampling map of the study area surrounding Diyala Company State (Rasheed et al., 2024)

2.3 Estimating the concentrations of lead and copper in samples

The levels of lead and copper in leaves and soil were estimated via a flame atomic absorption spectrophotometer (FAAS) at Ibn Sina Center, Ministry of Industry and Minerals, Iraq according to Abdulhay and Rathi (2017).

2.4 Plant leaf samples analysis

The leaves were first washed with tap water to remove dust, then washed with distilled water to remove any contaminants. The samples were dried in an oven at 70°C. After that, they were ground using a coffee grinder to get fine powder and stored in airtight containers for chemical digestion. Half a gram of each plant powder sample was weighed and placed in a microwave digestion device with a mixture of nitric acid and hydrogen peroxide (HNO_3:H_2O_2) (5:1) until the solution became clear. The solution was left at 150°C for 25 min, then cooled to room temperature and shaken well before filtering. The volume of each sample was made up to 50 mL with deionized water to standardize the calculated elemental concentration. The recovery rate for both lead and copper was within the acceptable range (92-98%). A portion of the resulting solution was withdrawn and used for atomic absorption spectrometry analysis (Shi et al., 2023; Rawat et al., 2024).

Table 1. Sampling sites based on directions and distances

Sites	Directions	Distances (m)	Regions	Samples collection coordinates	
				N°	E°
N 1	North	100	Main Street of the Company	33.77056885003631	44.59013173172016
N2		500	Main Street of the Company	33.77280737955255	44.59007808754462
N3		1,000	Agriculture Floor	33.778586261010126	44.59031412199417
N4		2,000	Agriculture Floor	33.78755702369312	44.589917155166134
S1	South	100	Main Street of the Company	33.768722688111474	44.590206833570214
S2		500	Main Street of the Company	33.76506592139569	44.59018537589413
S3		1,000	Al-Rahma	33.76059731901732	44.590560885174455
S4		2,000	Al-Yarmouk	33.75169509745489	44.591322632494304
E1	East	100	Main Street of the Company	33.76961455874416	44.59126898826168
E2		500	Main Street of the Company	33.769623477404664	44.59560343805435
E3		1,000	Jerusalem Intersection	33.76955212809353	44.60104295793418
E4		2,000	Huwaider	33.76942726665334	44.61180398044811
W1	West	100	Main Street of the Company	33.76957888409708	44.58910176353766
W2		500	Main Street of the Company	33.76945402271635	44.58478877135697
W3		1,000	Jerusalem intersection	33.769445104035036	44.57934925160782
W4		2,000	Al-Hadid Village	33.76931132376585	44.56859895782609

2.5 Soil samples analysis

Soil samples were collected from the same sites where the plant samples were collected. The samples were first dried in an oven at 70°C to prevent evaporation of the elements and then passed through 2 mm sieve to remove large impurities and gravel. Finally, they were ground to a homogeneous consistency and were placed in clean, sealed containers. To perform the chemical digestion, 1 g of soil sample was digested in microwave using a mixture of HNO_3:HF:HCl (3:1:1) until a clear solution was obtained. The solution was then left at 150°C for 25 min and cooled to room temperature. The volume of each sample was made up to 50 mL with deionized water to standardize the calculated element concentration. The recoveries for both lead and copper were within the acceptable range (92-98%). A portion of the resulting solution was withdrawn and used for atomic absorption spectrometry analysis (Shi et al., 2023; Rawat et al., 2024).

2.6 Bioaccumulation factors (BAF)

The BAF was used to assess the ability of plants to absorb and remove heavy metals from soil and was calculated using equation (1) (Aladesanmi et al., 2019):

$$\text{BAF} = \frac{\text{C plant}}{\text{C soil}} \qquad (1)$$

Where: C_{plant}=level of the metal element in the plant (mg/kg); C_{soil}=level of the same metal element in the plant soil (mg/kg).

2.7 Statistical analysis

MS Excel® was used to analyze the data statistically and find the mean and standard deviation of the samples using a completely random design known as complete random distribution.

3. RESULTS AND DISCUSSION

3.1 Level of lead and copper in plant leaves and soil in the northern part

In this experiment, we tested the levels of the heavy metals in the north site of the company. The results indicated a high levels of the metals in this area. Compared with the approved standard values (0.3 mg/kg), all leaf samples collected fromthis area showed variable levels of contamination with lead. The highest level of lead in N4 site ranged between 2.43 mg/kg in leaves of *D. viscosa*, and the lowest level in *M. parviflora* leaves reached up to 1.96 mg/kg in N1 site (Table 2). In plant soil, the highest level of lead was in *R. communis* (2.59 mg/kg) in site N2, followed by *M. parviflora* and *D. viscosa* (2.42 mg/L and 1.62 mg/kg) in sites N1 and N4, respectively. *E. camaldulensis* revealed the lowest concentration (1.26 mg/kg) at site N3. The result was statistically significant ($p<0.05$), between the soil of *M. parviflora*, *E. camaldulensis*, and *D. viscosa*, and not statistically significant ($p\geq0.05$) in soil of *M. parviflora* and *R. communis*, and between soil of *E. camaldulensis* and *D. viscosa* compare with the natural abundance in Table 2.

As for copper, the highest concentration was in leaves of *R. communis* at site N2 (1.36 mg/kg), and the lowest level was in *M. parviflora* at site N1 (0.64 mg/kg). It was found that all the plant leaves were polluted with copper (0.2 mg/kg), with no significant differences between them and other plants. The highest concentration of copper in plant soil was in *D. viscosa* (6.90 mg/kg) at site N4, followed by *E. camaldulensis* and *R. communis* (5.22 mg/kg and 5.15 mg/kg) in sites N3 and N2, respectively. *M. parviflora* exhibited the lowest concentration (5.07 mg/kg) in site N1. No significant differences appeared between the soils of all plants and the concentrations obtained with the natural abundance of copper (23.13 mg/kg) (Abd Al-wahab, 2020).

The higher lead levels in the soil of the plant in the N1 and N2 sites may be attributed to the proximity of the two sites to the company, compared to N3 and N4, which are further away. Even if industries have relatively low levels of heavy metal emissions, they may contribute to the pollution of the surrounding agricultural soil through continuous emissions (Yao et al., 2024). The findings indicated that the sites with high copper pollution were the sites that were farthest from the company (N3 and N4) compared to the closer sites (N1 and N2). This could be explained by the transport of the pollutants to sites far from the manufacturing company by weather conditions (e.g., wind). Pollutants could accumulate by settling in soil or water in areas far from the pollution source and cause high pollution in those areas. In addition to the contaminants transported by the company, human activities in areas far from the manufacturing company may play a role in increasing pollution levels, such as agriculture or local manufacturing, because they are residential areas that are more exposed to pollution and have constant human traffic. In addition to the smoke emitted from cars resulting from the combustion of gasoline, to which tetramethyl lead or tetraethyl lead is added to improve the performance of the car engine (Kayiranga et al., 2023). These results are consistent with a survey conducted in Diyala Province by (Mahmood and Rathi (2024) in which lead reached its highest level in soil of the industrial area (2.34 mg/kg). The current study agreed with the study conducted in Morocco, Tadla Plain by Ennaji et al. (2020) which showed that the lead level exceeded the permissible limit in farm soil and reached 31.72 mg/kg. The findings of the current study conflicted with a survey conducted in Diyala Province by Abd Al-wahab (2020), in which the copper levels exceeded the average natural abundance, reaching 33.00 mg/kg. The reason for the consistency of our results with a study conducted in 2024 is that there was a decrease in element concentrations compared to another study conducted in 2022 in the same province. This could be attributed to a relative improvement in environmental conditions in recent years or the implementation of some measures to reduce pollution. Differences in climatic factors or the timing of sample collection, such as the season or the amount of rainfall, may also have played a role in this decrease, which helps in environmental restoration (Armiento et al., 2022).

Table 2. Lead and copper concentrations in soil and plant leaves at four sites in north of Diyala State Company

Site	Sample	Metals concentration (mg/kg) (mean±SD)			
		Lead	Natural abundance value	Copper	Natural abundance value
N1	*M. parviflora*	1.966±0.035355[a]	0.3	0.6425±0.077075[a]	0.2
	Soil	2.425±0.033941[b]	1.08	5.074±0.060811[c]	23.13
N2	*R. communis*	2.3225±0.006364[b]	0.3	1.365±0.062225[a]	0.2
	Soil	2.5995±0.023335[b]	1.08	5.158±0.079903[c]	23.13
N3	*E. camaldulensis*	2.413±0.008485[b]	0.3	1.017±0.106066[a]	0.2
	Soil	1.264±0.035355[a]	1.08	5.226±0.078489[c]	23.13
N4	*D. viscosa*	2.4335±0.062933[b]	0.3	1.124±0.017678[a]	0.2
	Soil	1.6285±0.053033[a]	1.08	6.906±0.052326[c]	23.13

* Different letters vertically mean statistically significant differences ($p<0.05$).

3.1.1 Bioaccumulation factor in north sites

The highest value of lead bioaccumulation (1.62) was in *E. camaldulensis* at site north 1000, followed by *D. viscosa* at site north 2000 by 1.10, then *R. communis* at site north 500 by 0.89, and *M. parviflora* with the lowest BAF value of 0.81 (Figure 2). The highest BAF value for copper was in *R. communis* at site north 500 (BAF=0.26), *E. camaldulensis* at site north 1000 (BAF=0.20), then *D. viscosa* at site north 2000 with BAF of 0.18, and *M. parviflora* at site north 100 (BAF=0.12).

The results indicate that *E. camaldulensis* was the best in removing lead from industrial areas, which is consistent with the study of Mahmood and Rathi (2024), a study conducted in Diyala Province, where the value of the bioaccumulation factor for lead in plant leaves was estimated at 0.89. A study by Kaur et al. (2021) demonstrated that *R. communis* was most efficient in eliminating copper. The findings of the current study showed that the bioaccumulation factor changes with the change in heavy element type and plant type. Also, the physiological and anatomical factors within the plant can affect the absorption of metals because they may not accumulate in their parts if the bioaccumulation factor is less than 1 (Satpathy et al., 2014). *Eucalyptus* can adapt to different conditions and therefore it is efficient in metals absorption,especially lead (Madejon et al., 2017). In addition, *R. communis* can tolerate high levels of heavy metals due to its strong root system and tissue characteristics (Yeboah et al., 2021). The ability of plants to absorb and accumulate heavy metals varies across species, which in turn affects the levels of these elements in the ecosystem. Heavy metals are continuously absorbed by plants throughout their growth and accumulate in plant tissues, so some plants are used to absorb and accumulate heavy metals from contaminated soil (Gani et al., 2024).

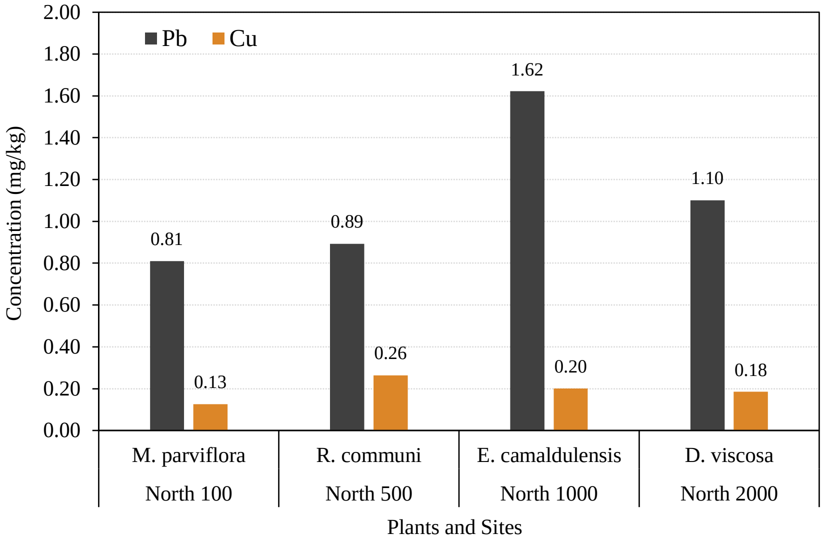

Figure 2. Plant BAF at four locations in north of Diyala State Company

3.2 Levels of lead and copper in plant leaves and soil in the southern part

The results showed that all soils and plant leaves were polluted with lead and copper in close proportions with the same plant, *E. camaldulensis*, present at three sites (S1, S3, and S4). In addition, *E. camaldulensis* tolerate high levels of heavy metals in soil and leaves than other species growing in the same environment (Madejon et al., 2017). The highest concentration of lead in the S4 region was 2.07 mg/kg in leaves of *E. camaldulensis*, and the lowest concentration (1.21 mg/kg) was revealed in *D. viscosa* leaves insite S2. Compared with the approved standard values, all leaves in the plants in all the studied areas were polluted with lead. The result was statistically significant ($p<0.05$) between *E. camaldulensis* and other plants. As for the plant soil, the highest concentration of lead was in *D. viscosa*, which was 2.73 mg/kg in site S2, followed by *E. camaldulensis* (2.68 mg/kg, 1.70 mg/kg) in sites S4 and S3, respectively. Also, *E. camaldulensis*, which had the lowest concentration (1.26 mg/kg) in site S1, with significant differences ($p<0.05$) between soil of *E. camaldulensis* and *D. viscosa*, in comparison with the natural abundance as shown in Table 3.

The highest concentration of copper was in the leaves of *E. camaldulensis* at site S4, at a concentration of 1.14 mg/kg, and the lowest level was in *E. camaldulensis* at site S3, at 0.90 mg/kg. It was found that all the leaves were polluted with copper. In plant soil, the highest concentration of copper was in *D. viscosa*, reaching 7.39 mg/kg at site S2, followed by *E. camaldulensis* (7.11, 6.40, 6.03 mg/kg) at sites S1, S4 and S3, respectively. The result was statistically significant ($p<0.05$) between soils of all plants, and the concentrations obtained with the natural abundance of the element indicate that it was not polluted with copper in large quantities compared to its natural abundance (Abd Al-wahab, 2020). Acidity and the ketone exchange capacity are the two most significant physical and chemical characteristics that may contribute to the buildup of heavy metals in soil and plants. These are the main elements influencing how metals migrate through the soil and how bioavailable they are. Elevated acidity makes these metals more soluble, which promotes their uptake by plants and soil. Element penetration into the soil is facilitated by poor exchange capacity, therefore, cation exchange capability is essential to stabilize these metals (Ikhajiagbe et al., 2019).

The findings of the study contradicted a study conducted by Jabara (2024) in Diyala, where the study showed that all soil in all studied areas was polluted with lead and copper, 61.2 and 22.1 mg/kg respectively. The results also conflicted with the results of a study conducted in Baghdad by Amer and Abdulhussein (2022), in which they showed that lead levels in the soil of an industrial area reached 19.50 mg/kg. Another study conducted in China by Yuan et al. (2021) conflicted with the current study, which had very high lead levels in soil, its level reached 30.74 mg/kg. The findings of the current study disagree with a study by Alberto et al. (2023), which showed that copper exceeded the permissible limit in agricultural soils up to 36 mg/kg. The results of previous studies show higher levels than those of the current study. This may be explained by the fact that the environment in this location is less polluted than other regions, especially big cities, such as the capital, due to the large number of industrial areas and the population movement. Rapid industrial growth and human activities all play a role in increasing pollution (Vuong et al., 2025).

Table 3. Levels of lead and copper concentrations of soil and leaves in south of Diyala State Company for four sites

Site	Sample	Metals concentration (mg/kg) (mean±SD)			
		Lead	Natural abundance value	Copper	Natural abundance value
S1	*E. camaldulensis*	1.5495±0.060104[a]	0.3	1.081±0.057276[a]	0.2
	Soil	1.26±0.049497[a]	1.08	7.1155±0.057983[c]	23.13
S2	*D. viscosa*	1.215±0.06364[a]	0.3	1.0825±0.044548[a]	0.2
	Soil	2.735±0.02192[b]	1.08	7.399±0.071418[c]	23.13
S3	*E. camaldulensis*	1.643±0.06364[a]	0.3	0.9005±0.006364[a]	0.2
	Soil	2.687±0.02687[b]	1.08	6.035±0.065054[c]	23.13
S4	*E. camaldulensis*	2.0765±0.062933[b]	0.3	1.1485±0.06364[a]	0.2
	Soil	1.702±0.049497[a]	1.08	6.403±0.072125[c]	23.13

* Different letters vertically mean statistically significant differences ($p<0.05$).

3.2.1 Bioaccumulation factor in south site

The highest value of lead bioaccumulation was in *E. camaldulensis* at site south 2000 with 2.07, followed by the sites south 1000 and south 100 with the same plant, where it reached 1.64 and 1.54 respectively, then *D. viscosa* at site south 500 by 0.44, which is the lowest value of the bioaccumulation factor (Figure 3). The highest BAF value for copper was recorded in *E. camaldulensis* at sites south 2000, south 1000, and south 100 by 0.179, 0.15, and 0.14, respectively, and the lowest BAF value was recorded in *D. viscosa* at site south 100. The findings in Figure 3 indicate that *E. camaldulensis* has the potential to remove lead and copper from the areas surrounding the company. These outcomes are similar to a study conducted in Basra in Al-Haritha by Azeez (2021), where the study showed that the BAF values for copper in plants were less than 1. It also aligns with another study conducted by Luo et al. (2016), which found that eucalyptus trees were efficient in removing lead and copper. Choosing the right plants is crucial in the phytoremediation process. The capacity of plants to absorb, withstand, and collect pollutants is taken into consideration when choosing them. The solubility, transport, and subsequent uptake of metals are also significantly influenced by the region surrounding plant roots (rhizosphere) (Zhao and Wang, 2020).

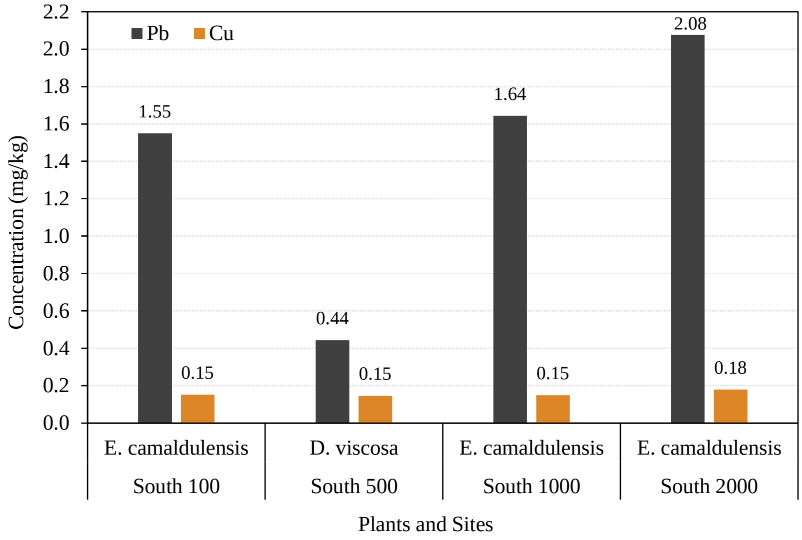

Figure 3. Plant BAF at four sites in south of Diyala State Company

3.3 Level of lead and copper in leaves and soil in the eastern part

In this study, heavy metal levels were measured at the company's eastern site. The highest lead concentration in site E3 reached 3.00 mg/kg in the leaves of *E. camaldulensis*, and the lowest concentration in the same plant reached 1.99 mg/kg in site E2. Compared with the approved standard value (0.3 mg/kg), all the leaves in plants in all areas were polluted with lead, with significant differences between *E. camaldulensis*, *D. viscosa*, and *R. communis* ($p<0.05$). As for the plant soil, the highest concentration of lead revealed in *E. camaldulensis* soil by 3.318 mg/kg in site E2 and 1.75 mg/kg in site E3, followed by *D. viscosa* by 1.46 mg/kg in site E4, and the lowest concentration was in *R. communis* in site E1 1.40 mg/kg The result was statistically significant ($p<0.05$) between soil of *E. camaldulensis*, *D. viscosa*, and *R. communis* compare with the natural abundance (Table 4).

Regarding copper, *D. viscosa* leaves at site E4 had the highest content (1.20 mg/kg), while *E. camaldulensis* leaves at site E3 had the lowest value (0.78 mg/kg). It was found that all the leaves were polluted with copper (0.2 mg/kg), with no significant differences between them and other samples. Regarding the soil for plants, the highest concentration of copper was in the soil of *E. camaldulensis* (7.09 mg/kg) in site E3, followed by *R. communis* in site E1 (6.91 mg/kg) and *E. camaldulensis* in site E2 (6.66 mg/kg). The lowest level in *D. viscosa* in site E4 reached up to 5.90 mg/kg. The result was not statistically significant ($p\geq0.05$) between soils of all plants, and the natural abundance of copper (Abd Al-wahab, 2020). By forming stable organic complexes, the amount of organic matter in the soil may help to decrease the mobility of these elements. The acidity of the soil can make heavy metals more bioavailable. Soil deterioration, a worldwide issue that presents a serious danger to environmental sustainability, can result from increased bioavailability of heavy metals in the soil-plant system (Núñez-Delgado et al., 2020).

The findings of the current study conflict with a study conducted in Kirkuk Province, Iraq, by Khurshid et al. (2022), in which they found a high level of lead and copper contamination in soil and some plants, with lead levels in soil and plants reaching 2.2 and 67 mg/kg, respectively. Copper levels in soil reached 55 mg/kg and in plants, 11 mg/kg. Another study conducted in Basra and Maysan Provinces by Mahdi et al. (2020) revealed concentrations of lead exceeding the internationally permissible limit in soil. Lead levels in Basra Province soil reached 37.32 mg/kg, and in Maysan Province, 24.13 mg/kg. This study conflict with a study conducted by Yang et al. (2022), which showed that copper exceeded the natural abundance by 33.43 mg/kg. However, the findings of this study are consistent with the outcomes of Briffa et al. (2020), which revealed the lead levels exceeded the normal background values and reached a level of 9.6 mg/kg.

Table 4. Lead and copper concentrations of soil and leaves for plants at four sites in east of Diyala State Company

Site	Sample	Metals concentration (mg/kg) (mean±SD)			
		Lead	Natural abundance value	Copper	Natural abundance
E1	*R. communis*	2.1105±0.00495[b]	0.3	1.1035±0.072832[a]	0.2
	Soil	1.4005±0.07566[a]	1.08	6.9155±0.057276[d]	23.13
E2	*E camaldulensis*	1.998±0.009899[a]	0.3	1.1605±0.068589[a]	0.2
	Soil	3.3185±0.052326[c]	1.08	6.6625±0.007778[d]	23.13
E3	*E. camaldulensis*	3.0045±0.00495[c]	0.3	0.789±0.039598[a]	0.2
	Soil	1.7505±0.049497[a]	1.08	7.0905±0.04879[d]	23.13
E4	*D. viscosa*	2.896±0.007071[b]	0.3	1.208±0.074953[a]	0.2
	Soil	1.462±0.072832[a]	1.08	5.9025±0.048083[d]	23.13

* Different letters vertically mean statistically significant differences (p<0.05).

3.3.1 Bioaccumulation factor in east sites

Figure 4 shows that the highest value of lead bioaccumulation was in *D. viscosa* at site east 2000, which amounted to 1.98, followed by *E. camaldulensis* at site east 1000 with 1.71, then *R. communis* at site east 100, which amounted to 1.50, and finally, *E. camaldulensis* at site east 500 with lowest value BAF by 0.60. The highest BAF value (0.20) for copper was recorded in *D. viscosa* at site east 2000, followed by *E. camaldulensis* at site east 500 with 0.17, then 0.15 for *R. communis* at site east 100. The lowest BAF value was recorded in *E. camaldulensis* at site east 1000. The findings represented in Figure (4) display that *D. viscosa* was the best in removing lead and copper from the areas surrounding the company. This may elucidate that *D. viscosa*, a perennial plant, is exposed to pollutants for a long period, accumulating pollution in its leaves and other parts (Goyal et al., 2020). The results of the current study conflict with a study conducted by Abed et al. (2022) in Diyala Province which exhibited that the BAF level reached 2.45 times higher than our outcomes. The findings show a decrease in pollution levels in this area over three years, which could be attributed to differences in plant species, climate change, or changes in soil properties (Chen et al., 2022).

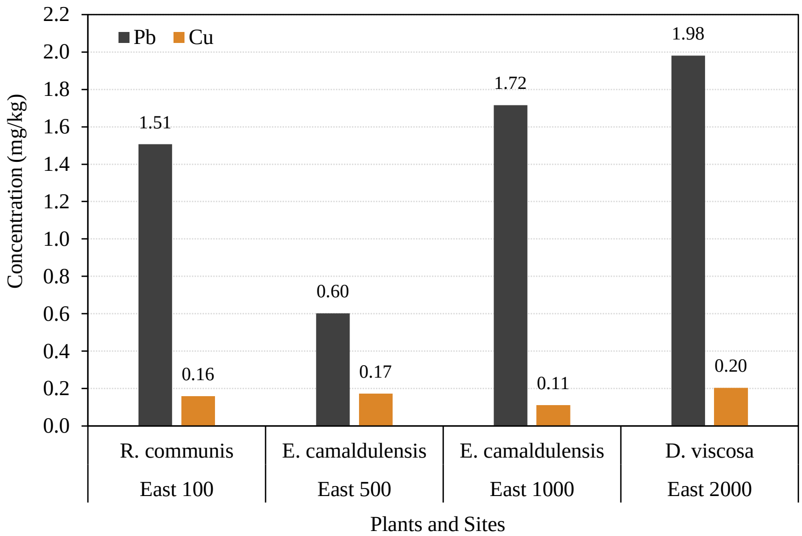

Figure 4. Plant BAF at four sites in east of Diyala State Company

3.4 Level of lead and copper in plant leaves and soil in the western part

The leaves of *R. communis* had the maximum concentration of lead in site W2, up to 1.79 mg/kg, as indicated in Table 5, while the leaves of *D. viscosa* had the lowest concentration, 1.39 mg/kg, in site W3. All plant leaves in every location under study had lead contamination when compared to the authorised standard values. The result was not statistically significant (p≥0.05) for the plant soil, the highest concentration of lead was in *E. camaldulensis*, reaching 3.73 mg/kg at site W4, followed by

M. parviflora, 2.48 mg/kg at site W1, then *D. viscosa*, reaching 2.17 mg/kg at site W3, and the lowest concentration was in *R. communis*, site W2, 2.12 mg/kg, with statistically significant ($p<0.05$) between *M. parviflora* and *R. communis*, *D. viscosa*, *E. camaldulensis*, and not statistically significant ($p\geq0.05$) between *R. communis* and *D. viscosa* compared with the natural abundance.

The highest concentration of copper was noticed in the leaves of *R. communis* at site W2, at a concentration of 1.24 mg/kg, and the lowest level was in *E. camaldulensis* at site W4, at a concentration of 0.89 mg/kg. We found that all plant leaves were polluted with copper, with no significant differences between them and other plants. As for the plant soil, the highest concentration of copper was also in *E. camaldulensis,* where its level reached 8.521 mg/kg in site W4, followed by *D. viscosa* in site W3, 7.74 mg/kg, then *R. communis* in site W2 with concentration of 6.03 mg/kg, and the lowest level in *M. parviflora* in site W1 (5.96 mg/kg), with no significant differences ($p<0.05$) between soils of all plants. The concentrations obtained from the plant indicate that it was not polluted with copper in large quantities compared to its natural abundance (Abd Al-wahab, 2022). The results of the current study were consistent with a study conducted in Diyala Province by Mahmood and Rathi (2024), which showed high levels in lead in the earth's crust. It contradicted another study in Diyala conducted by Abd Al-wahab (2020), the concentration of lead ranged between 43.10-112.30 mg/kg and ranged between 21.40-58.60 mg/kg for copper. In Kurdistan province, lead and copper contamination levels in soil increased, with lead levels reaching 16.22 mg/kg and copper levels reaching 63.33 mg/kg (Hamad et al., 2019). And also consistent with another study conducted by Zhao et al. (2022) in China high level of copper 63.73 mg/kg was shown in farmland in Anxin County.

Table 5. Copper and lead concentrations in soil and plant leaves at four sites in west of Diyala State Company

Site	Sample	Metals concentration (mg/kg) (mean±SD)			
		Lead	Natural abundance value	Copper	Natural abundance value
W1	*M. parviflora*	1.585±0.003536[a]	0.3	1.2385±0.076368[a]	0.2
	Soil	2.4825±0.096167[a]	1.08	5.9635±0.091924[d]	23.13
W2	*R. communis*	1.7915±0.00495[a]	0.3	1.2465±0.061518[a]	0.2
	Soil	2.1235±0.044548[b]	1.08	6.032±0.054447[d]	23.13
W3	*D. viscosa*	1.399±0.008485[a]	0.3	1.0565±0.067175[a]	0.2
	Soil	2.179±0.094045[b]	1.08	7.7495±0.062933[d]	23.13
W4	*E. camaldulensis*	1.425±0.002828[a]	0.3	0.898±0.007071[a]	0.2
	Soil	3.736±0.064347[c]	1.08	8.521±0.046669[d]	23.13

* Different letters vertically mean statistically significant differences ($p<0.05$).

3.4.1 Bioaccumulation factor in west sites

Figure 5 shows *R. communis* at site west 500 had the greatest RAF value (0.84), followed by *D. viscosa* at site west 1000 (0.64) and *M. parviflora* at site west 100 (0.63). The BAF of *E. camaldulensis* at site west 2000 is (0.38), the lowest value in the western area of the company. Regarding copper, *M. parviflora* at site west 100 had the highest BAF value (0.20), followed by *R. communis* at site west 500 (0.20), *E. camaldulensis* at site west 2000 (0.27), and *D. viscosa* at site west 1000 (0.13). According to our findings, *M. parviflora* was the most effective in removing copper from the vicinity of the company, while *R. communis* was the greatest at removing lead. As mentioned previously, the castor plant can tolerate high levels of heavy metals due to its strong root system and their tissue characteristics. The baker's plant has been shown to have an average ability to absorb pollutants (Yeboah et al., 2021). In 2023, Hassan and Umer found BAF value of copper greater than the one in Dohuk soil which is conflicted with our study. The results are also in a disagreement with a study undertook by Azeez (2021) in Basra, where the BAF value for lead was less than one. The difference in findings between previous studies and the current study may be due to differences in soil properties, plant type, as they differ in their ability to absorb, or due to differences in climatic conditions (Vuong et al., 2025).

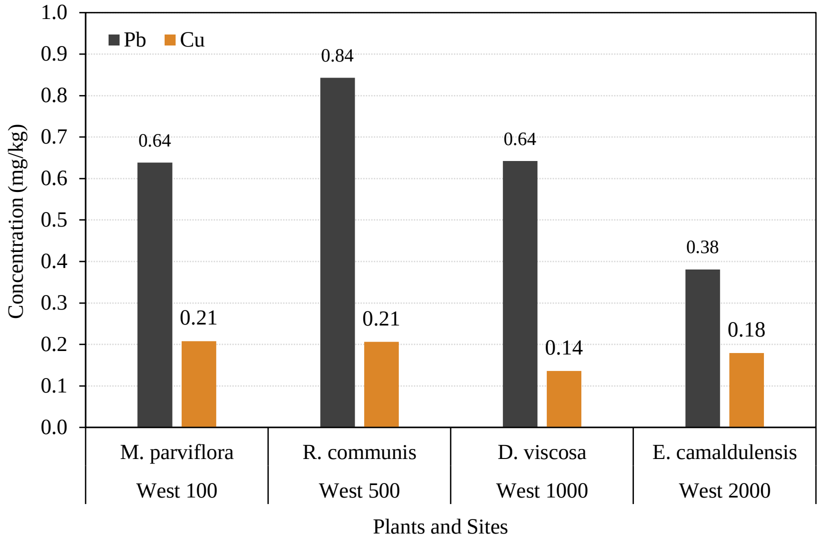

Figure 5. Plant BAF at four sites in west of Diyala State Company

4. CONCLUSION

The findings clearly showed environmental pollution with lead and copper in some areas surrounding the Diyala State Company. Lead concentrations were higher than those of copper, making lead the dominant pollutant in the studied areas. The highest concentration (3.00 mg/kg) was recorded in the eastern part of the company, at site E3. The selected plants demonstrated a high capacity to absorb and accumulate both lead and copper in their leaves. *E. camaldulensis* was highly efficient at absorbing lead, particularly at sites N3 and S4, while *R. communis* showed the highest capacity for absorbing copper at site N2. Based on the results, the studied plants can be ranked according to their ability to bioaccumulate lead and copper as follows: *E. camaldulensis* (highest accumulating capacity, especially for lead), *R. communis* (highest accumulating capacity for copper), *D. viscosa* and *M. parviflora* (lowest accumulating capacity). Therefore, these plants could be included in phytoremediation programs to reduce heavy metal pollution in the region. These results underscore the importance of incorporating the studied plant species into phytoremediation programs in contaminated industrial areas. *E. camaldulensis* can be recommended for treating lead pollution, and *R. communis* for treating copper pollution, especially in locations with high concentrations. By applying this strategy in areas surrounding factories, the accumulation of heavy metals in the soil will reduced and limit the risk of their transfer to plants, crops, and food chain. It is also an environmentally sustainable and less costly method compared to traditional chemical or physical methods for remediating pollution.

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AUTHOR CONTRIBUTIONS

The research idea was conceived by Rathi MH and Hummadi EH. The methodology, data collection, and analysis of the results were implemented by Mohammed DA. Mohammed DA wrote the first draft of the research. Rathi MH and Hummadi EH reviewed, edited and corrected the final draft. Rathi MH and Hummadi EH supervised the project.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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