International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8, 2025
https://theaspd.com/index.php

Study of Lead (Pb) and Nickel (Ni) mobility in plants from the steppe region of Djelfa

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Abstract
This study investigates how lead (Pb) and nickel (Ni) move and accumulate in plants collected from two locations in the Djelfa region. The concentrations of these heavy metals were measured in both the soil and plant samples and compared to global reference levels. To understand how the metals move within plants, translocation factors (TF) were calculated, and bioconcentration factors (BCF) were used to assess how efficiently the plants absorbed metals from the soil. The analysis showed that lead levels in the soil were lower than the global natural range. Nickel concentrations, on the other hand, were within the typical global range. Notably, there were clear differences between the two locations in how the metals moved through the plants. In Ain Oussera, both Pb and Ni showed high translocation factors (Pb: 5.11, Ni: 2.75), indicating strong movement from roots to shoots. In contrast, plants from Djelfa had TF values below 1 (Pb: 0.63, Ni: 0.61), suggesting limited upward movement of these metals. When it came to accumulation, only one BCF value stood out: Pb in Djelfa had a BCF of 1.394, meaning plants there were actively taking up and storing Pb. All other BCF values were below 1, indicating lower accumulation. These results highlight how heavy metal behavior in plants can vary significantly between locations, offering important clues about environmental quality and potential risks for agriculture in these areas.

Keywords: *Heavy metals, Lead, Nickel, Translocation factor, Bioconcentration factor, Soil contamination, Plant uptake, Ain Oussera, Djelfa.*

1. INTRODUCTION

In agricultural landscapes, heavy metals in soil pose serious risks to ecosystems and human health by entering food chains through contaminated crops (Collin et al., 2022). Among these metals, lead (Pb) and nickel (Ni) are especially problematic. Lead is entirely foreign to plant metabolism; even trace amounts can impair photosynthesis, disrupt enzyme activity, and hinder nutrient uptake. Nickel, in contrast, is required in trace quantities for functions such as urease activation, but it quickly becomes toxic when concentrations exceed narrow physiological thresholds (Ahmad and Ashraf, 2011).

The fate of Pb and Ni in soil–plant systems depend on multiple interacting factors. Soil texture, organic-matter content, pH, and redox conditions all influence whether a metal remains tightly bound to particles or becomes soluble and available for root uptake. Climatic parameters (aridity, temperature) and species-specific physiological traits further determine how much metal is taken up by roots and translocated to leaves and reproductive tissues (Antonkiewicz et al., 2016). In agricultural settings, these processes are critical: metals that accumulate in edible tissues pose long-term risks to food safety and public health.

Drawing on our own research on chromium dynamics in neighboring regions, we can anticipate similar complexities for Pb and Ni in Djelfa's steppe soils. In our study (Rebhi et al., 2016) we demonstrated that Cr exhibit markedly different retention behaviors, controlled primarily by soil pH and organic-matter content. Those findings underscore how local pedological characteristics modulate metal mobility and suggest that Pb and Ni may likewise respond sensitively to Djelfa's soil parameters. Likewise, in 2019 (Rebhi et al., 2019) we showed that a native steppe-adapted species can sequester Cr in roots, limiting translocation to aerial parts even under severe chromium stress, pointing to species-specific tolerance mechanisms that might influence Pb and Ni uptake in Djelfa flora.

Yet, despite their importance, there is a paucity of data characterizing how Pb and Ni move from soils into local vegetation at these sites. To address this gap, the present study (1) quantifies soil concentrations of Pb and Ni in both locations relative to global benchmarks; (2) computes root-to-shoot translocation factors for each metal; (3) assesses soil-to-plant bioconcentration factors; and (4) compares Ni translocation and bioconcentration patterns against those of Pb across a variety of plant species and tissue types.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Plant and soil samples were collected from two locations in the steppe region: Ain Oussera and Djelfa. The study area lies in the central part of the Algerian steppe and is characterized by an arid to semi-arid climate. It is bordered to the north by the Tellian Atlas and to the south by the Saharan Atlas. All samples were properly processed and prepared for analysis according to standard protocols.

2.2 Analytical Methods

Plant species were collected from the areas surrounding Djelfa and Ain Oussera, located in the Algerian steppe region. After collection, the plants were dried, ground, crushed, and sieved to a particle size of 2 mm to obtain a fine powder suitable for heavy metal concentration analysis. Soil samples were taken from the same locations where the plants were gathered.

The concentrations of Pb and Ni in soil and plant samples were determined using appropriate analytical techniques. Quality control measures were implemented to ensure the accuracy and reliability of the analytical results.

2.3 Data Analysis

2.3.1 Comparison to Reference Values

Measured soil concentrations of Pb and Ni were compared to global reference values obtained from scientific literature. For Pb, the natural concentration range of 10-40 mg/ kg with a median of approximately 20 mg/kg was used as reference (Smith et al., 2021). For Ni, the natural concentration range of 0.2-50 mg/kg was used (Ahmad and Ashraf, 2011).

2.3.2 Translocation Factor Calculation

The translocation factor (TF) was calculated to assess the efficiency of metal movement from roots to aerial parts:

TF = Concentration in aerial part / Concentration in roots

TF values greater than 1 indicate efficient translocation of metals from roots to aerial parts, while values less than 1 indicate restricted translocation or preferential accumulation in roots.

2.3.3 Bioconcentration Factor Calculation

The bioconcentration factor (BCF) was calculated to assess the efficiency of metal uptake from soil to the plant:

BCF = Total concentration in plant / Concentration in soil

BCF values greater than 1 indicate accumulation of the metal in the plant relative to soil, while values less than 1 indicate exclusion or restricted uptake.

2.3.4 Ni/Pb Translocation and Bioconcentration Ratio Comparison

To compare the relative translocation and bioconcentration of Ni versus Pb, the ratios of their respective translocation factors and bioconcentration factors were calculated:

Ni/Pb Translocation Ratio = Ni TF / Pb TF

Ni/Pb Bioconcentration Ratio = Ni BCF / Pb BCF

Values greater than 1 indicate higher translocation or bioconcentration of Ni compared to Pb, while values less than 1 indicate higher translocation or bioconcentration of Pb compared to Ni.

2.4 Statistical Analysis and Visualization

Data analysis was performed using Python programming language with pandas. Descriptive statistics were calculated, and results were visualized using appropriate graphical representations to facilitate interpretation and comparison.

3. RESULTS

3.1 Soil Concentrations of Pb and Ni

The soil concentrations of Pb and Ni in both locations are presented in Table 1.

Table 1. Soil concentrations of Pb and Ni in Ain Oussera and Djelfa locations.

Region	Pb (mg/kg)	Ni (mg/kg)
Ain Oussera	6.5	7.6
Djelfa	6.8	10.9

Compared to global reference values, the Pb concentrations in both locations were below the natural range (10-40 mg/kg) and the median value (20 mg/kg) reported in the literature (Smith et al., 2021). The Ni concentrations in both locations fell within the natural range (0.2-50 mg/kg) as shown in Figure 1, and as reported by Ahmad and Ashraf (2011).

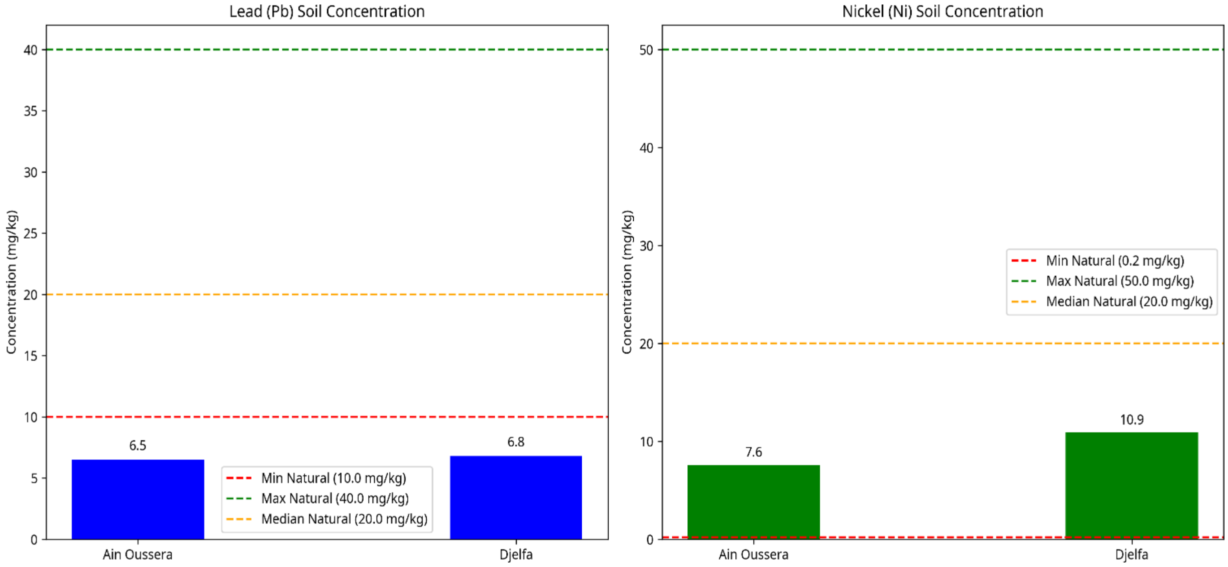

Figure 1. Comparison of soil lead (Pb) and nickel (Ni) concentrations (mg/kg) in Ain Oussera and Djelfa regions with global reference ranges.

3.2 Translocation Factors

The translocation factors (TF) for Pb and Ni in plants from Ain Oussera and Djelfa are presented in Table 2 and Figure 2.

Table 2. Translocation factors for Pb and Ni.

Region	Aerial N (mg/kg)	Root N (mg/kg)	Ni TF	Aerial P (mg/kg)	Root P (mg/kg)	Pb TF	Ni/Pb T Ratio
Ain Oussera	3.36	1.22	2.75	4.14	0.81	5.11	0.54
Djelfa	3.22	5.28	0.61	3.66	5.82	0.63	0.97

The translocation factors for both Pb and Ni in Ain Oussera were remarkably high (5.11 and 2.75, respectively), indicating efficient translocation of these metals from roots to aerial parts. In contrast, the TF values in Djelfa were below 1 for both metals (0.63 for Pb and 0.61 for Ni), suggesting restricted translocation or preferential accumulation in roots.

As for the Ni/Pb TF ratio, it was 0.54 in Ain Oussera, which indicates a more efficient translocation of Pb compared to Ni in this region. In Djelfa, the ratio was 0.97, suggesting similar translocation efficiency for both metals.

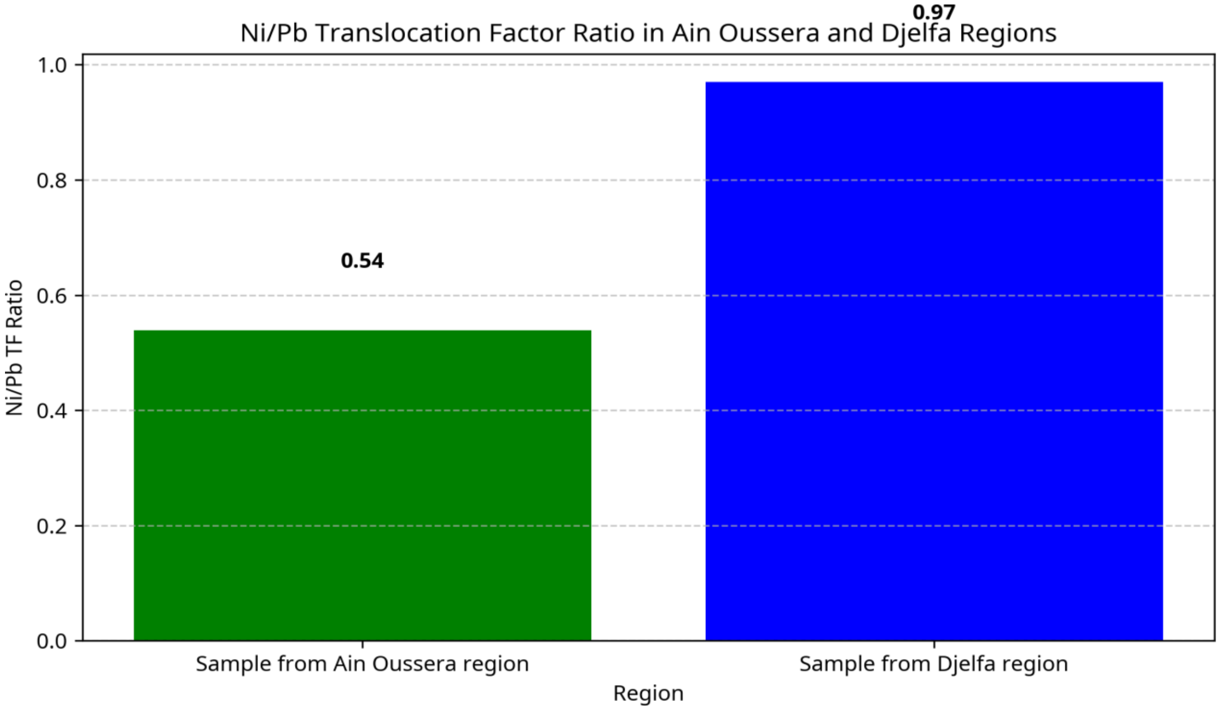

Figure 2. Ratio of nickel (Ni) translocation factor to lead (Pb) translocation factor (Ni TF / Pb TF) in plants from Ain Oussera and Djelfa locations.

3.3 Bioconcentration Factors

The bioconcentration factors (BCF) for Pb and Ni in plants from Ain Oussera and Djelfa are presented in Table 3 and Figure 3.

Table 3. Bioconcentration factors for Pb and Ni.

Region	Total Ni in Plan (mg/ kg)	Soil Ni (mg/ kg)	Ni BCF	Total Pb in Plan (mg/ kg)	Soil Pb (mg/ kg)	Pb BCF	Ni/Pb BCF Ratio
Ain Oussera	4.58	7.60	0.603	4.95	6.50	0.762	0.791
Djelfa	8.50	10.90	0.780	9.48	6.80	1.394	0.559

The BCF for Pb in Djelfa (1.394) exceeded 1, indicating that Pb accumulated in the plant at a concentration higher than that in soil. All other BCF values were less than 1, suggesting a restricted uptake of these metals. The Ni BCF was higher in Djelfa (0.780) compared to Ain Oussera (0.603), and similarly, the Pb BCF was higher in Djelfa (1.394) compared to Ain Oussera (0.762).

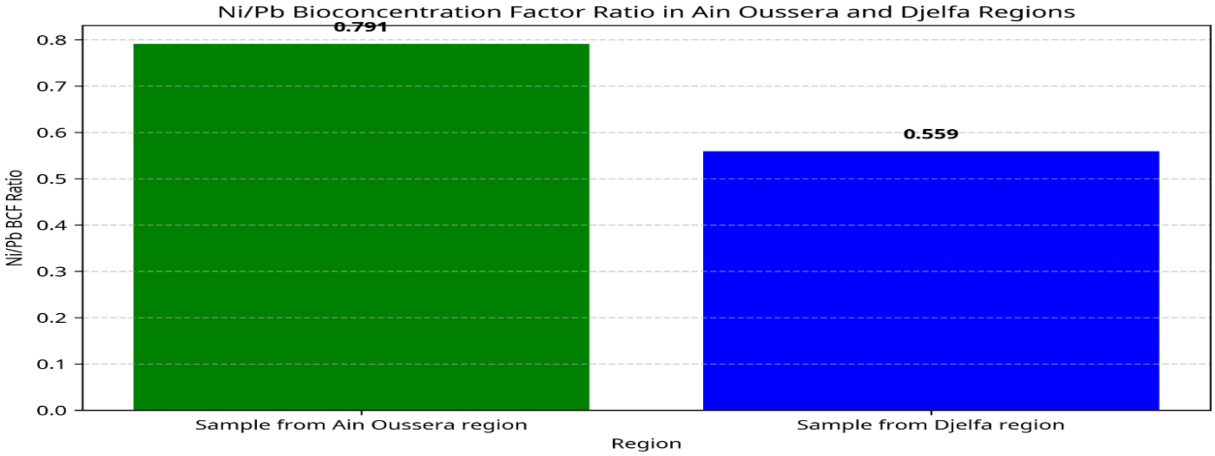

Figure 3. Ratio of nickel (Ni) bioconcentration factor to lead (Pb) bioconcentration factor (Ni BCF / Pb BCF) in plants from Ain Oussera and Djelfa.

The Ni/Pb BCF ratio was less than 1 for both locations (0.791 in Ain Oussera and 0.559 in Djelfa), indicating more efficient bioconcentration of Pb compared to Ni in both locations, with a more pronounced difference in Djelfa.

4. DISCUSSION

4.1 Soil Concentrations in Regional and Global Context

Our measurements showed that soil Pb levels in Ain Oussera (6.5 mg/kg) and Djelfa (6.8 mg/kg) fall below the 10–40 mg/kg range considered natural (Smith et al., 2021). This low concentration points to minimal lead contamination in both areas, likely because there are few industrial or other human-derived Pb sources nearby. By contrast, Ni was present at 7.6 mg/kg in Ain Oussera and 10.9 mg/kg in Djelfa, values that are within the 0.2–50 mg/kg normal range for soils (Ahmad and Ashraf, 2011).

The slightly higher Ni content in Djelfa probably reflects differences in the underlying geology, since parent-rock characteristics can drive regional variations in soil Ni (Ahmad and Ashraf, 2011). In turn, this discrepancy in baseline Ni may help explain why we observed distinct Ni uptake and translocation behaviors between the two sites.

4.2 Translocation Factors and Regional Differences

Plants from Ain Oussera showed strikingly high root-to-shoot movement for both metals: a Pb TF of 5.11 and a Ni TF of 2.75. In most reports, Pb TFs remain below 1, reflecting limited upward transport. For example, Testa et al. (2023) observed that industrial hemp retained most lead in the roots, and Baldi et al. (2021) found TFs under 1 across several herbaceous species. A Pb TF of 5.11 thus stands out as exceptional in Ain Oussera's plants.

While Ni generally moves more freely (since it is a micronutrient), a TF of 2.75 still exceeds values often seen in other studies. Buendía-González et al. (2010) measured a Ni TF of about 0.66 in mesquite seedlings, so the elevated Ni translocation in Ain Oussera implies that these plants activate particularly efficient Ni-transport mechanisms.

By contrast, Djelfa's plants displayed TFs of 0.63 for Pb and 0.61 for Ni, which fall in line with typical patterns. Those figures match closely with the TFs reported by Buendía-González et al. (2010) for mesquite (roughly 0.67 for Pb and 0.66 for Ni), suggesting standard metal-movement processes in Djelfa.

Taken together, the marked discrepancy, high TFs in Ain Oussera versus modest TFs in Djelfa, points to local factors shaping metal mobility. Soil chemistry, rhizosphere interactions, or plant adaptations to each site could all play a role. Even more unusual is that Pb moves more effectively than Ni in Ain Oussera (Ni/Pb TF ratio of 0.54), reversing the common trend where Ni usually travels more readily than a nonessential toxin like Pb. This finding underscore how unique the metal-transport dynamics are for plants in Ain Oussera.

dynamics in plants from this region.

4.3 Bioconcentration Patterns and Implications

In Djelfa, plants showed a Pb BCF of 1.394, meaning they contained more lead than the surrounding soil. This is striking, considering Djelfa's soil Pb level (6.8 mg/kg) was only marginally above Ain Oussera's (6.5 mg/kg). Such a high BCF suggests that Pb is more bioavailable in Djelfa, perhaps because of factors like lower soil pH, different clay minerals, or particular organic matter that makes lead easier for roots to absorb.

By comparison, Ni uptake was limited in both areas, with BCFs of 0.603 in Ain Oussera and 0.780 in Djelfa. Still, Djelfa's higher Ni BCF follows the same trend seen for lead, implying that its soil conditions favor metal availability and uptake in general.

When looking at the Ni/Pb BCF ratio, both sites show values under 1, plants concentrate lead more readily than nickel. This gap is wider in Djelfa (0.559) than in Ain Oussera (0.791), matching the overall higher BCFs found in Djelfa.

These findings raise food safety concerns: if local crops behave like the wild species we studied, they could accumulate lead at levels exceeding what's in the soil. Monitoring specific food crops for Pb accumulation will be important to gauge risk and guide safe agricultural practices in Djelfa.

4.4 Relationship Between Translocation and Bioconcentration

A notable finding from this work is the opposite trend between metal translocation and bioconcentration at the two sites. In Ain Oussera, plants move metals from roots to shoots very effectively but take up relatively little from the soil overall. Conversely, Djelfa plants absorb more metal from the soil but keep most of it in their roots instead of sending it upward, especially in the case of lead.

These contrasting patterns hint at different ways plants cope with metals in each area. In Ain Oussera, the emphasis seems to be on shuttling metals into above-ground tissues, even though root uptake remains modest. In Djelfa, by comparison, plants draw in a larger share of soil metals but largely immobilize them in root tissues, perhaps to protect leaves and stems from toxicity.

Such strategies likely reflect both the local soil environment and the plants' own physiological traits. Restricting movement into shoots in Djelfa could be a defense against harming photosynthetic organs, whereas Ain Oussera plants may rely on other detoxification methods in their leaves and stems or may intentionally distribute metals throughout the plant.

4.5 Environmental and Agricultural Implications

This study's results suggest several practical takeaways for managing the environment and agriculture in these areas:

1. Although soil Pb levels are low in both Ain Oussera and Djelfa, the fact that Djelfa plants can still concentrate lead (high Pb BCF) means even small amounts in soil could end up in crops, posing a potential food safety risk.
2. Since Ni levels in the soil are within normal ranges and plants aren't accumulating it heavily (BCF < 1), nickel doesn't appear to pose a significant threat under current conditions.
3. Because Pb and Ni behave so differently from one region to another, risk assessments and management plans need to be tailored to each location rather than relying on blanket assumptions.
4. In Ain Oussera, plants shuttle unusually large amounts of Pb and Ni into their stems and leaves (high TFs), so if crops there show similar patterns, the edible portions could end up with elevated metal levels.
5. In Djelfa, plants may trap significant Pb in their tissues (high BCF), meaning even if soil levels are low, crops could still accumulate lead to worrisome levels.
6. Finally, the way metals move varies by region: in Ain Oussera, the concern is metals in leaves and fruits, whereas in Djelfa, roots may hold more of the contamination, each scenario has different implications for how metals enter the food chain.

5. CONCLUSIONS

In this work, we examined how Pb and Ni move through and accumulate in plants from Ain Oussera and Djelfa. We found that soil Pb levels in both areas fell below typical global background values, and Ni was likewise within expected normal ranges, suggesting that neither site is heavily contaminated.

Interestingly, plants in Ain Oussera showed unusually high root-to-shoot movement: Pb moved with a TF of 5.11 and Ni with a TF of 2.75. In contrast, plants from Djelfa behaved more conventionally, with TFs under 1 for both metals, implying that most of the metals stayed in the roots.

When looking at bioconcentration factors, Djelfa stood out for Pb (BCF = 1.394), meaning these plants tended to accumulate lead more readily than the soil baseline. All other BCFs, (Ni in Djelfa and both Pb and Ni in Ain Oussera) were below 1, indicating limited uptake relative to soil levels.

Putting these observations together, we see an inverse pattern: Ain Oussera plants shuttle more metal up into their shoots but don't concentrate as much overall (BCF < 1), whereas Djelfa plants hold metals in their roots yet accumulate Pb more strongly in the roots relative to soil (BCF > 1). Moreover, the ratio of Ni to Pb BCF was under 1 at both sites. This tells us that, compared to Ni, Pb is more readily bioconcentrated, and this tendency is especially clear in Djelfa.

These regional differences point to underlying soil properties and plant responses that modulate metal transport and storage. Future work should delve into specific factors, such as soil pH, organic content, and species-specific uptake mechanisms, that drive these contrasting behaviors in Ain Oussera versus Djelfa.

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