Assessment of Pb and Mn Accumulation in *Marrubium vulgare* L. as a Bioindicator and Phytoremediation Candidate in Industrial and Urban Environments of Sétif (Algeria)

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INTRODUCTION & AIM

Heavy metal contamination is a major global environmental concern threatening ecosystem stability, soil functionality, and human health **(Hembrom et al., 2020)**. Lead (Pb) and manganese (Mn) are particularly hazardous due to their persistence, toxicity, and strong bioaccumulation in plant tissues **(Varma, 2021; Raza et al., 2022)**. Anthropogenic activities such as industrial emissions, urban expansion, and traffic significantly increase metal loads in soils, especially in semi-arid regions where natural attenuation is limited **(Dehkordi et al., 2024)**. Conventional remediation methods are costly and environmentally disruptive, highlighting the urgent need for sustainable solutions. Phytoremediation, based on the use of tolerant plant species to extract or stabilize contaminants, has emerged as an effective and eco-friendly approach **(Kuppan et al., 2024; Sangeetha & Jagtap, 2024)**.

Therefore, this study evaluates the accumulation of Pb and Mn in aerial tissues of *Marrubium vulgare* collected from industrial and urban sites in Sétif (Algeria) to assess its potential as a bioindicator of pollution and a candidate for phytoremediation.

METHOD

Sampling was carried out at ten industrial and urban sites in Sétif (northeastern Algeria), representing different levels of anthropogenic pressure. Aerial parts of *Marrubium vulgare (Fig.1),* were collected during the peak vegetative stage. Samples were washed with distilled water to remove surface contaminants, air-dried, oven-dried at 60 °C to constant weight, and ground into fine powder. Approximately 0.5 g of dried material was digested using a nitric acid–perchloric acid mixture following standard wet digestion procedures for plant tissues (Allen et al., 1989; Jones & Case, 1990). Concentrations of lead (Pb) and manganese (Mn) were determined by Flame Atomic Absorption Spectroscopy (FAAS) according to established analytical protocols (Skoog et al., 2014). Statistical analyses were performed to assess spatial variability among sites, and hierarchical clustering using the UPGMA method was applied to identify patterns of metal contamination.

Figure1 . Marrubium vulgare Across from Setif Region, Algeria

RESULTS & DISCUSSION

Lead (Pb) and manganese (Mn) concentrations in aerial parts of Marrubium vulgare collected from ten sites in the Sétif region were extremely high compared with natural background values and WHO limits for medicinal plants.

Pb ranged from 138.82 to 582.54 mg kg^{-1}(Fig.2), while Mn ranged from 3402.94 to 4402.55 mg kg^{-1} dry weight (Fig3). The highest Pb level occurred at Hadad Unit (El Eulma), indicating intense industrial contamination. In contrast, Mn peaked at Bazer Sakhra and the Industrial Zone of Sétif, suggesting combined anthropogenic and geogenic sources **(Dehkordi et al., 2024)**.

All sites exceeded permissible limits, confirming severe environmental pollution. Multivariate analyses (UPGMA and PCA) separated stations into distinct clusters reflecting different contamination intensities(Fig4, Fig5). Industrial and urban sites were clearly distinguished from relatively less impacted areas, demonstrating strong spatial heterogeneity **(Ullah et al., 2025)**.
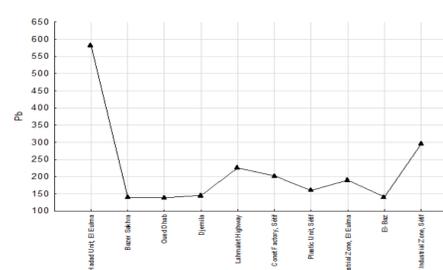

Figure 2. Lead (Pb) concentrations (mg kg^{-1} dry weight).
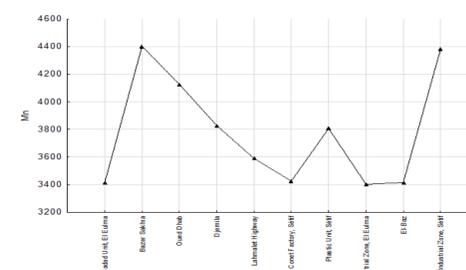
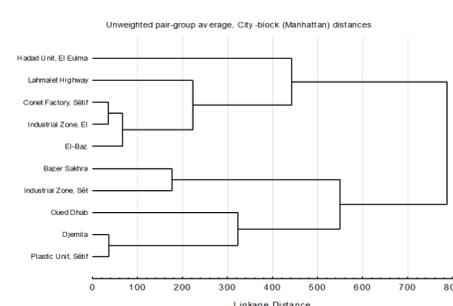

Figure 3. Mn concentrations (mg kg^{-1} dry weight).

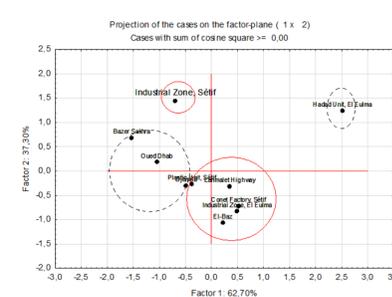Figure3.4UPGMA Analysis of Heavy Metal Accumulation in Marrubium vulgare Across Setif Region Sites

Figure 5. Principal Component Analysis (PCA) of Pb and Mn concentrations in *Marrubium vulgare* across different sampling sites in the Setif region (Algeria).

CONCLUSION

Marrubium vulgare shows a remarkable capacity to accumulate Pb and Mn in industrial and urban sites of Sétif, far exceeding international safety limits. The spatial patterns confirm the strong impact of anthropogenic activities, particularly industrial emissions and traffic. Its high tolerance highlights its value as both a reliable bioindicator and a promising phytoremediation species in semi-arid environments. However, the elevated metal levels pose potential health risks due to its medicinal use, emphasizing the need for monitoring and controlled harvesting.

FUTURE WORK / REFERENCES

Future research should investigate the mechanisms of metal uptake, translocation, and tolerance in *Marrubium vulgare* at physiological and molecular levels. Long-term field studies are needed to evaluate its efficiency in large-scale phytoremediation programs.

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