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Phytoremediation potential of *Suaeda vera* for some heavy metals in roadside soil in Benghazi, Libya

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ABSTRACT

The increased concentrations of heavy metals in soil pose a threat to human life through the food chain. Soil and plant samples from the coastal area of Benghazi city were collected and analyzed using flame atomic absorption spectroscopy (FAAS) for their heavy metal contents. The metal content of Cu, Cr, Ni, Zn, and Pb has been determined in the soil in the vicinity of plant roots, plant roots, and leaves. Biological absorption coefficient (BAC), bioconcentration factor (BCF), and translocation factor (TF) have been calculated to evaluate the ability of *Suaeda vera* to extract the metals from soil. The results showed that *Suaeda vera* Forssk. Ex J.F. Gmel is more suitable for phytoextraction than the phytostabilisation. Phytoremediation as a green technology has many advantages over the other methods of heavy metals removal from soils.

Graphical Abstract



Introduction

Over the past decades, the release of inorganic and organic anthropogenic pollutants has been increased into the surroundings. More than 50% of the heavy metal loads have been accounted to the anthropogenic activities. The heavy metal contaminants can find their way to water and food and thus affect human and livestock health through food chain [1].

Soils along highways or high traffic roads normally contain high amounts of heavy metals because of the contaminations resulted from the vehicle exhaust and wear of vehicle parts. Heavy metals do not degrade naturally and accumulate in high concentrations in soils. The use of plant species used for cleaning the contaminated soils is known as phytoremediation. It has gained increasing attention as a cheap, clean, and effective technology. The ability of many plant species to accumulate heavy metals from soil has been studied for phytoremediation purpose [2]. Phytoremediation has the advantage of being inexpensive and not disturbing or destructing the physical, chemical, and biological structure of soils [3]. There are several categories of phytoremediation mechanisms including, phytofiltration, phytoextraction, phytodegradation, phytostabilization, and phytovolatization [4, 5].

The absorption of pollutants from the soil by the plant is called phytoextraction. After accumulation of metal ions in the roots, stems, and leaves, the plants can be removed or burnt, and, then, the metals can be recovered. The accumulation of heavy metals in plants correlates with the total concentration of metals in soil, soil properties, soil content, and soil acidity. There are certain levels of metal accumulation before the metal concentration affects the plant and its bioaccumulation capacity [6]. Hyperaccumulators are characterized by a translocation factor (TF) (Shoot/root metal concentration ratio) higher than 1. $TF > 1$ which means that the heavy metals are actively transported into green parts of the plant [7]. Although it can be useful for early detection of plants that can be potentially useful as phytoremediation tools, it is not the single measure of hyperaccumulation [8, 9].

Halophytes are plants that can tolerate high levels of salts, playing an important role in protection and remediation of the areas affected by soil salinity or chemical pollution. *Suaeda* species are widely distributed in seashore and saline soils, and also most of the species are halophytes. *Suaeda vera* is a coastal species of flowering plant in the family of amaranthaceae [10], found at the coastal area of Benghazi city. Halophytic communities of Libya are still poorly known, [11] and the use of halophytes in phytoremediation is still under investigation.

This study aimed at assessing the metal accumulation ability of *Suaeda vera* Forssk. ex J.F.Gmel (*Suaeda vera*) growing in roadside soils at the coastal area of Benghazi city in Libya and also knowing the ability of *Suaeda vera* to accumulate metals in its parts against the soil metal concentration of the respective metal at the sampling point.

Experimental

Materials and methods

Suaeda vera samples have been collected from roadside positions with the soil surrounding the roots at the coastal area of Benghazi city. The plant samples were transferred to the laboratory, washed with distilled water, and then dried at room temperature in a clean area to a constant weight. Dry weight was taken using an analytical balance. Dried plant samples were ground using a grinder and sieved by using 1 mm mesh sieve. The soil samples have been collected in plastic bags and then, dried to a constant weight at room temperature, ground using a mortar and a pestle, and sieved using a 1 mm mesh sieve.

Soil analyses

pH which was measured in 1:1 (Soil/ water) suspension was estimated by McKeague procedure as described by Wayne et al. [12] using 3150 Jenway pH meter. The electrical conductivity and total dissolved solids in 1:1 (Soil/ water) suspension were measured using the electrical conductivity method [13] as described in USDA Handbook 60 by an InLap 73 conductivity meter. Potassium, sodium, magnesium, and calcium were measured in 1:1 (Soil/ water) extract using PFP 7 JENWAY flame photometer [14].

Assay of heavy metals concentration

Soil and plant samples were analyzed by flame atomic absorption spectroscopy (FAAS) to evaluate Zn, Cu, Cr, Pb, and Ni in soil, roots, and shoots. All chemicals used in the study were in analytical grade. The EPA protocol [15] that was adopted for the acid digestion of the soil and plant samples can be described as follows: A 1.00–2.00 g of the homogenous representative sample was obtained and placed in conical beakers. Sample slurries were prepared by adding 10 mL of 1:1 nitric acid (HNO_3). The slurries were then covered with watch glasses, heated to near boiling, and refluxed for 15 min. After refluxing, the slurries were cooled, and then 5 mL of the concentrated HNO_3 was added, and, finally, the solution was again allowed to reflux for an additional 30 min. This last step was repeated to ensure complete oxidation of the metals. After the third refluxing period, the sample was cooled to room temperature, and, then, 2 mL of deionized water and up to 10 mL of 30% hydrogen peroxide were added. The samples were then filtered to remove any particulates which might interfere with FAAS analysis. The filtrates were collected in 100 mL volumetric flask and were diluted with deionized water to the final volume. The metals concentration has been determined using Shimadzu 6800 flame atomic absorption spectrometer.

Results and discussion

Table 1 shows the analysis results for soil quality parameters. The quality of soil can be assessed by calculating the Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR).

Exchangeable sodium percentage (ESP)

The presence of excessive amounts of exchangeable sodium reverses the process of aggregation and causes soil aggregates to be dispersed into their constituent individual soil particles, this is known as deflocculation and occurs in sodic soil [16]. A sodic soil, by definition, contains a high level of sodium relative to the other exchangeable cations (Such as, calcium, magnesium, and potassium). Soil is considered "sodic" when the exchangeable sodium percentage (ESP) is 6% or greater (**Table 2**). The Exchangeable Sodium Percentage (ESP) is calculated as follows:

$$\text{ESP \%} = \text{exchangeable } \left[\frac{\text{Na}}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}} \right] \times 100$$

In this study, ESP % value was 88.26% which can be considered as very strongly sodic.

Sodium adsorption ratio (SAR)

A widely accepted index for characterizing soil sodicity describes the proportion of sodium to calcium and magnesium in soil solution. The formula to calculate SAR is given below, with concentrations expressed in milliequivalents per liter (meq/L) and analyzed from a saturated paste soil extract.

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{[\text{Ca}^{2+}] + [\text{Mg}^{2+}]}{2}}}$$

Table 1. Soil analyses parameters

pH	9.79
Electrical conductivity (EC), mS/cm	1.52
Total dissolved solids (TDS), ppm	998
Na, ppm	296.8
K, ppm	27.43
Ca, ppm	12.812
Mg, ppm	4.514

Table 2. Soil classes according to Exchangeable Sodium Percentage

Percentage	Classification
<6	Non-sodic
6-10	Sodic
10-15	Moderately sodic
15-25	Strongly Sodic
>25	Very strongly Sodic

When SAR value is greater than 13, the soil is considered as sodic soil, (If SAR lies between 0–10 the soil is excellent, 10–18 the soil is good, 18–26 is doubtful, and >26 is unsuitable). Excess sodium in sodic soils causes soil particles to repel each other, preventing the formation of soil aggregates and making the soil structure very tight, which affect root growth [17, 18]. SAR value was 18.156 which classified the soil as having a good quality for irrigation.

The results obtained from FAAS analysis for Zn, Cu, Cr, Pb, and Ni in soil, roots, and shoots are shown in [Figure 1](#). The metal content was in the following order Zn>Cu>Cr>Ni. Pb was not detected in soil or plant.

In the studied heavy metal ions, Zn is more mobile and available for plant uptake. The mobility of metal ions in soil mainly depends on the pH of soil and presence of chelating agents. Many other factors such as root size, external metal concentrations, temperature, metal interaction, the addition of nutrients, and salinity also seem to play a minor role to influence the metal ions mobility in soil. In some cases, the solubility of metal ions in water is very low as they have a strong affinity toward soil particles and many other organic contaminants present in soil [19].

Biological absorption coefficient (BAC), bioconcentration factor (BCF), and translocation factor (TF)

BAC has been calculated on the base of the ratio of heavy metals content in the plant and soils [20, 21] using the following formula:

$$\text{BAC} = \text{C}_{\text{Plant}} / \text{C}_{\text{Soil}}$$

C=Metal concentration

According to biological absorption coefficient (BAC) range, the plants can be classified to four levels, 1.0–10 is high accumulator plant, 0.1–1.0 is moderate accumulator plant, between 0.01–0.1 is known as low accumulator plant and BAC<0.01 is not accumulator plant [22]. According to this

classification, *Suaeda vera* is the moderate accumulator plant for the metals according to the following order Cu>Zn>Ni>Cr.

Translocation factor is the ratio of metal concentration in the shoot to the root. If the translocation factors are ≥ 1 it means that the plant is a hyperaccumulator plant which can perform phytoextraction [23].

Bioconcentration factor is the metal concentration ratio of plant roots to soil. Plants with a high BAC value ($BAC > 1$) are suitable for phytoextraction, while plants with a high bioconcentration factor, BCF ($BCF > 1$) and low translocation factor, ($TF < 1$) are more suitable for phytostabilisation [24, 25].

The translocation factor values for the studied metals are listed in [Table 3](#). The higher translocation factor was in case of Ni, and the lowest was for Zn.

$TF > 1$ means that *Suaeda vera* can take up Ni in the roots and ready to be accumulated in the shoots. In this sense, it can be used in phytoextraction [26]. From the obtained results, *Suaeda vera* is more suitable for phytoextraction than phytostabilisation.

Figure 1. The concentration of the metals in soil and the parts of *Suaeda vera* ($\mu\text{g/g}$)

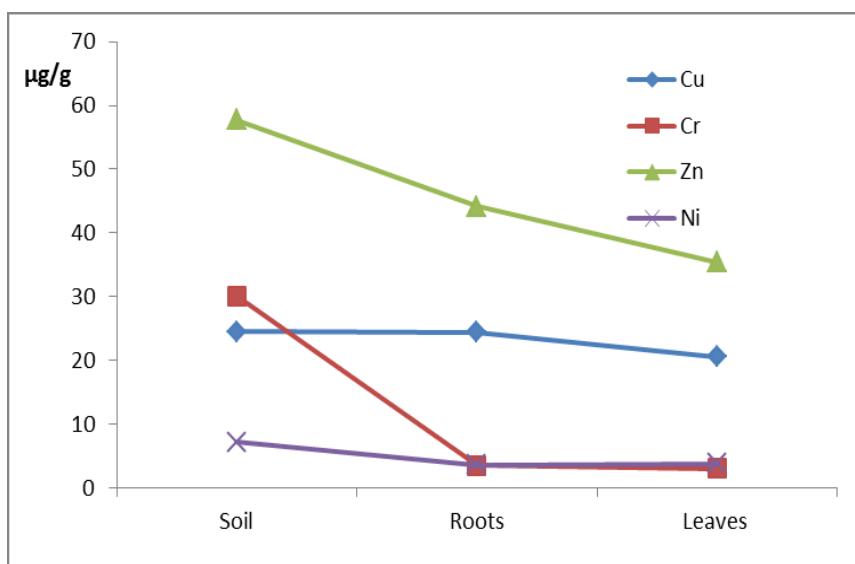


Table 3. The calculated values of BAC, BCF, and TF

Metal	BAC	BCF	TF
Cu	0.84	1.00	0.84
Cr	0.10	0.12	0.86
Zn	0.61	0.77	0.80
Ni	0.54	0.50	1.08
Pb	N. D.	N. D.	N.D.

N.D. = Not detected

However, that results are less than 1 for the other metals, they are close to each other and they are approaching 1. Translocation factor less than 1 does not mean that *Suaeda vera* is unable to absorb heavy metal but at that concentration, translocation will run more slowly and the metal not yet reached in stems or in leaves. The highest metal content was in the soil followed by roots and finally the leaves of *Suaeda vera* as in Figure 1. This is in harmony with many previous studies where the metal content was accumulated more in the root than the shoots and leaves because the roots were the first part of the plant to utilize nutrient uptake and the available metal content. Roots of the plants act as a barrier against heavy metal translocation, and it causes the higher concentration in the roots [27]. Figure 2 shows the soil and plant transfer percent.

The bioavailable fraction of metals in the soil is generally considered to be the free metal ion in the soil solution and available to plants [27]. Metals accumulation into plant roots is a complex process. It depends on the nature of the roots, the bioavailable fraction of metals, soil composition, and soil pH. Plants can change the solubility and speciation of metals in the rhizosphere using different strategies including, chelators exuding and manipulating rhizosphere pH [28]. Metal translocation to shoots is through mass flow and diffusion. The rate of metal translocation to the shoot may depend on metal concentration in the root [29].

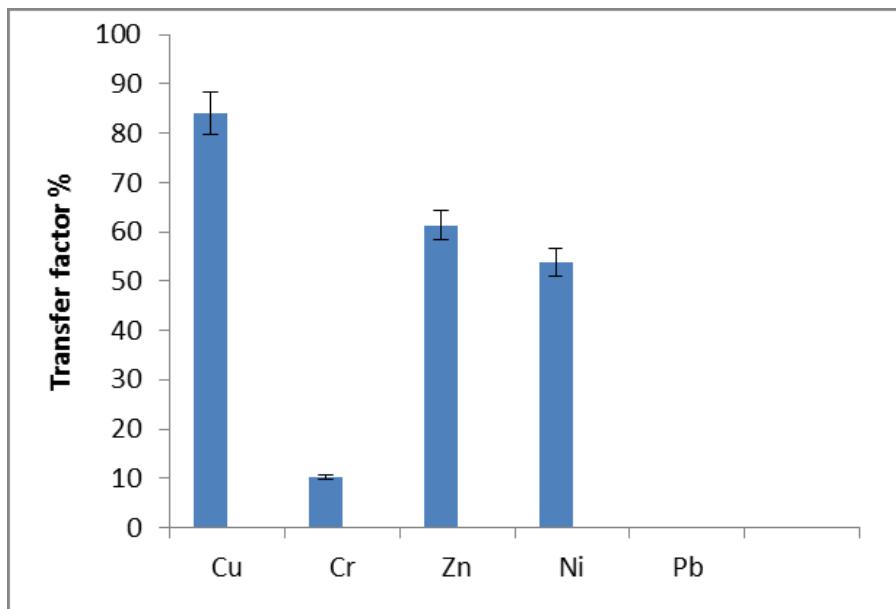


Figure 2. Soil to plant transfer percent

Conclusion

The results showed that the *Suaeda vera* is a moderate accumulator plant for the metals in following order Cu>Zn>Ni>Cr. *Suaeda vera* is also more suitable for phytoextraction than

phytostabilisation. In addition, *Suaeda vera* can be effectively used as a bioindicator for soil contamination monitoring.

Disclosure statement

No potential conflict of interest was reported by the authors.

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