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Benefits of *Louts hebranicus* in Exploration an Phytoremediation of some Radioactive, Trace, and Toxic Elements

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Abstract: The studied area is located within the North Abu Rusheid region, Southeastern Desert, Egypt, specifically between latitudes 24° 36' 30" N and 24° 37' 15" N, and longitudes 34° 46' 15" E and 34° 46' 45" E. The soil and plant samples were chemically analyzed for radioactive and trace elements determination by using ICP-AES or ICP-MS techniques. The study focuses on the concentration and accumulation of certain radioactive and some trace elements, including U, Th, Ni, Cd, Mo, Co, Pb, and Zn in *Louts hebranicus*, assessing the potential of this species for identifying new locations. The U, Th, Ni, Mo, Cd, and Zn concentrations observed in the soil samples fall below or within the permissible threshold for soil, while the lead concentrations exceed the levels suggested by the World Health Organization (WHO). Bioconcentration factor (*BCF*) values indicate that *Lotus hebranicus sp*. can absorb and accumulate uranium at a rate 115 times and thorium at a rate 154 times greater than the global average for desert plants indicating that *Lotus hebranicus* could be classified as a hyperaccumulator of uranium and thorium. The findings suggest that *Lotus hebranicus* is capable of absorbing and storing thorium in greater quantities than uranium. *Lotus hebranicus* can concentrate Pb, Ni, and Cd with elevated rates, thus this plant should be avoided in cattle forage. Zn, Co, and Mo uptake levels exhibit that *Lotus hebranicus* is a viable candidate for exploration and phytoremediation of these elements. *Lotus hebranicus* can concentrate certain elements more effectively than others, in the following order: Ni > Pb > Co > Th > Mo > U > Cd.

Keywords: *Louts hebranicus*, radioactive, toxic elements.

1 Introduction

Radioactive and trace elements represent significant sources of environmental contaminants that can lead to detrimental changes within ecosystems [1]. These contaminants adversely impact soil, vegetation, groundwater, and ultimately human health [2, 3]. The extent of contamination is influenced by three primary factors: the chemical characteristics of the contaminant, its concentration, and the degree of accumulation [4]. These radioactive and trace elements are naturally present in the soil crust as a result of the weathering of geological materials [5]. They persist in the soil without undergoing biodegradation and can be absorbed by plant roots, leading to bioaccumulation. This process poses significant risks to the environment, particularly in grazing areas. When concentrations of these elements exceed permissible thresholds, they can precipitate severe ecological crises [6-9].

The toxicity of trace elements is influenced by several factors, including their concentrations, chemical characteristics, bioavailability, and the developmental stage of the plants. Upon exposure to these toxic elements, plants activate their tolerance mechanisms, which help them mitigate the effects of toxicity. Nevertheless, at elevated concentrations, these elements can impair the plant's defense systems [10-16].

Plants primarily acquire elements from the soil during their growth and developmental stages. This process involves the uptake of essential nutrients, as well as trace amounts of radioactive and toxic elements present in the environment [17-19]. The degree of concentration and accumulation of these elements within plants is affected by various factors, including plant species, geographical location, and specific environmental conditions [17, 19-20-22]. Consequently, investigating the concentration and translocation of elements from soil to plants is crucial for understanding the tolerance thresholds of different plant species regarding

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each element. The presence of radioactive and toxic elements in plants is significant for identifying species that can effectively absorb these contaminants, thereby contributing to environmental remediation efforts. While plants typically contain only minimal levels of radioactive and trace elements under standard conditions, it remains essential to study the concentration and accumulation of these elements to address issues related to soil contamination and to explore their presence in various locations [19, 23-27].

The examination of plants' capacity to absorb and concentrate radioactive and toxic elements is crucial for identifying the most suitable species for remediation and exploration of these contaminants. Recently, numerous studies have quantified the concentration and transfer factors of trace and radioactive elements from soil to plants [17,19,28,29], as well as their environmental impacts [30,31].

Phytoremediation is recognized as one of the more cost-effective and impactful techniques for environmental remediation, particularly in the context of mitigating potentially toxic elements (PTEs). This method primarily utilizes green plants to diminish the concentration of contaminants in the environment, leveraging the remarkable capacity of plants to absorb pollutants from the soil and subsequently detoxify them through various biological processes [32, 33].

In the Eastern desert of Egypt, numerous plant species have been documented; however, many of these are classified as ephemeral plants, characterized by their short life cycles and adaptations that allow them to thrive during brief wet periods typical of arid climates [34, 35]. These ephemeral species are primarily grazing plants and are therefore unsuitable for the objectives of this study. In contrast, *Lotus hebranicus* (*Lotus sp.*), a perennial species, has been selected for investigation. Perennial plant cover constitutes the enduring framework of desert vegetation and serves as a reliable indicator of habitat conditions [36].

This research examines *Louts hebranicus*, a perennial species belonging to the Fabaceae family, which persists for over two years and exhibits regrowth each spring, noted for its prolific spread and density [37]. The study focuses on the concentration and accumulation of certain radioactive and some trace elements, including U, Th, Ni, Cd, Mo, Co, Pb, and Zn, in *Louts hebranicus*, assessing the potential of this species for identifying new locations.

Achieving these objectives would facilitate the assessment of the concentrations of radioactive and heavy metals in plants, thereby enabling the formulation of an appropriate strategy for identifying suitable plant species for the detection of these elements in alternative locations.

Soil and plant samples were collected from Wadi Abu Rusheid in the southeastern Desert of Egypt and clarified on the Landsat image of the area (Figure 1).

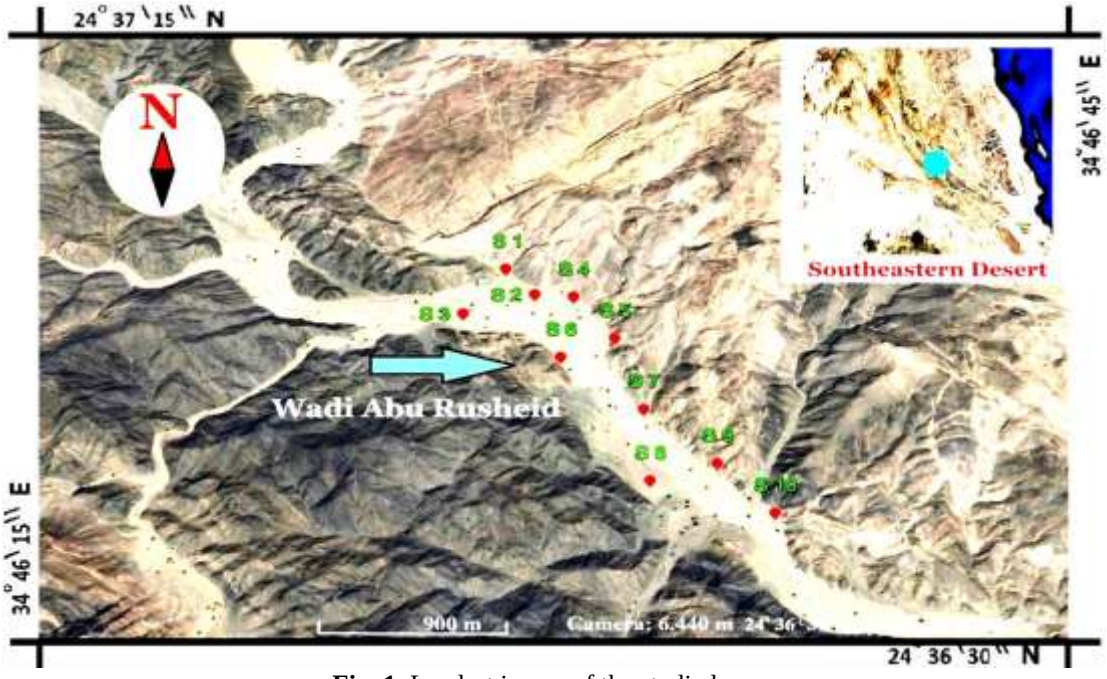

Fig. 1. Landsat image of the studied area.

2 Bioconcentration factor *(BCF)*

Bioconcentration factor (*BCF*) is calculated to assess the concentration of trace elements that were transferred from the soil to the plant. It was calculated according to the following formula 1 **[**17,19**]**.

$$BCF = \frac{\textit{Concentration elements in plant}}{\textit{Concentration elements in soil}}$$

3 Materials and Methods

3.1 Study area

The research site is located within the North Abu Rusheid region, positioned in the Southeastern Desert (SED) of Egypt, specifically between latitudes 24° 36' 30" N and 24° 37' 15" N, and longitudes 34° 46' 15" E and 34° 46' 45" E. The area is characterized by a topography that ranges from low to moderate elevation. The focus of the study was on the native plant species *Lotus hebranicus* (*Lotus sp*.), which is recognized as the most prevalent herbaceous perennial in the entire Eastern Desert of Egypt. A total of ten sites for vegetation and soil sampling were selected to assess the concentration and accumulation of radioactive and trace elements. The chemical analysis of both plant and soil samples was conducted at ACME Analytical Laboratories located in Vancouver, Canada.

3.2 Plant samples collection

The plant specimens were gathered from designated sampling locations, with around five samples collected from each site. Intact specimens were chosen and subsequently combined to create a composite sample representative of each location. Each composite sample included various plant parts, such as seeds, leaves, stems, and roots (Figure 2). The collection of plant samples occurred after the spring season, coinciding with the flowering period, during which the specimens were identified by their scientific names. The samples were cataloged as herbarium specimens within the Botany Department at the Faculty of Science, Cairo University. Upon collection, all plant samples were stored in paper bags until they arrived at the laboratory.

3.3 Plant samples analysis

In the laboratory, plant samples underwent a gentle washing process with deionized distilled water for 2 minutes to eliminate any adhering soil particles. Subsequently, the samples were dried in an oven at 60°C for 48 hours to achieve dry weight (DW). Following this initial drying phase, the samples were subjected to a further drying process at 105°C for 12 hours. Once dried, the samples were ground into a fine powder using a non-metallic rotor grinder and stored in clean, dry plastic bags until the analytical procedures were conducted. For analysis, 2 mL of concentrated nitric acid was added to the dried plant samples and allowed to react for one hour. This was followed by the addition of a solution comprising 2 mL of hydrochloric acid, 2 mL of nitric acid, and 2 mL of hydrogen peroxide, which was heated to 90°C for an additional hour. The resulting solution was then diluted to a final volume of 20 mL and analyzed using either ICP-AES or ICP-MS techniques (Acme Labs, Vancouver, and Method 1VE) for the determination of 37 elements. Quality control measures, including blanks, duplicates, and certified reference materials (CRMs), accounted for 10.8% of the total samples analyzed. The ICP techniques were employed to assess radioactive and trace elements, [38].

3.4 Soil samples collection

Before the sampling process, a 3 cm layer of topsoil was removed to eliminate the collection of turf. Soil samples were obtained as a composite from the root zone, extending to a depth of 30 cm, by excavating profiles around each selected plant. Each sample weighed approximately 2 kg and was stored in plastic bags to prevent cross-contamination before being transported to the laboratory for further preparation. The collected soil samples were subsequently quartered. Representative samples were then ground into a fine powder using a mechanical agate mortar to achieve a particle size of 100 mesh. Following this, the powdered samples were dried in an oven at 100°C for 5 hours. The resulting powdered soil samples were kept in clean polyethylene bags until they were ready for analysis.

3.5 Soil samples analysis

0.5 gm. of finely powdered soil was precisely weighed and sent for analysis (Acme Labs, Vancouver) by ICP-AES and ICP-MS following a multi-acid digestion involving heated in HNO_3–$HClO_4$– HF to fuming and taken to dryness, with the residue dissolved in HCl (Acme Method 1EX). For soil sample concentrations above the upper detection levels for some elements, Acme's assay method STD DST6 was used. The analytical precision, as calculated from replicate analyses varied from 2% to 20% for trace elements

4 Results

Plants possess a significant capacity to absorb trace elements from the soil through their roots and subsequently distribute these elements to various parts of the organism [39-41]. This research focuses on the absorption and accumulation of eight trace elements within the examined plants and the corresponding soil samples collected from ten locations within the study area. Numerous trace elements from polluted soils are taken up by plants [42, 43], subsequently being translocated to the aerial portions of the plants [44-46] and stored in various sections of the shoot [47-49]. The trace elements under investigation include

radioelements (U, Th), toxic elements (Pb, Cd), and other trace elements (Mo, Zn, Co, and Ni). Their concentrations are quantitatively assessed in both plant and soil samples, expressed in parts per million (Table 1). The concentration of these elements in native plants may serve as a valuable tool for identifying new mineralized areas and for phytoremediation efforts in contaminated soils, particularly in regions affected by mining and milling activities.

4.1 Radioactive and Trace elements in soil samples

The origins of trace elements in soil and the environment can be attributed to both natural and human-induced factors. Natural contributors encompass volcanic eruptions, rock weathering, and erosion processes [50].

Fig.2. *Lotus hebranicus* plant.

In the area under investigation, the predominant source of the soil samples is closely associated with the nearby granitic rock formations, which are the primary geological types present. Table 1 presents the concentrations of uranium (U), thorium (Th), cobalt (Co), lead (Pb), molybdenum (Mo), zinc (Zn), cadmium (Cd), and nickel (Ni) across ten soil samples.

4.1.1 Uranium and Thorium

The mean concentrations of uranium (U) and thorium (Th) in the analyzed soil samples are recorded at 4.22 mg kg^{-1} for U and 10.33 mg kg^{-1} for Th, as presented in Table 1. According to [51], the global average concentration of U in non-contaminated soils typically ranges from 0.4 to 6.0 mg kg^{-1}. The U concentrations observed in the soil samples fall within this established range. Furthermore, the global concentration of Th in soils is reported to be between 2 and 12 mg kg^{-1}, with an average of 6 mg kg^{-1} [52]. In the current study, U concentrations vary from 3.86 to 4.52 mg kg^{-1}, while Th concentrations range from 10.16 to 10.49 mg kg^{-1}, [51,52] (Table 1). The correlation coefficient between U and Th in the soil samples indicates a weak positive correlation (R^2 = 0.12), implying that the mobilization of these radionuclides occurs independently due to their differing chemical properties in the oxidation zone (Figure 3-A). The mineralogical composition of the El-Missikat stream sediments includes thorite, uranothorite, uranophane, zircon, allanite, and fluorite [53].

4.1.2 Lead

The maximum concentration of lead observed in the analyzed soil samples is 16.38 mg kg^{-1}, while the minimum concentration is recorded at 15.89 mg kg^{-1}, resulting in an average lead concentration of 16.21 mg kg^{-1} (Table 1). International benchmarks for lead concentrations in various soil types range from 10 to 67 mg kg^{-1}, with an average of 32 mg kg^{-1}, [52]. According to Davies, 1977[54], the threshold for lead content in typical soil is suggested to be 70 mg kg^{-1}. WHO (1995)[55] indicates that the average lead concentration in natural soils typically falls between 0.5 and 10 mg kg^{-1}. The lead concentrations found in the soil samples align with the values reported by [52,54], yet they exceed the levels suggested by the WHO. Additionally, Figure 3-B illustrates a weak positive correlation (R^2 = 0.12) between uranium and lead, suggesting that both elements are present in distinct mineral forms.

4.1.3 Molybdenum

Molybdenum (Mo) is recognized as a vital trace element for humans, animals, and plants. This transition metal is found in the environment in relatively low concentrations, specifically at 2.4 mg kg^{-1} in the lithosphere and ranging from 0.2 to 36 mg kg^{-1} in soil [56]. The maximum recorded concentration of molybdenum is 1.48 mg kg^{-1}, while the minimum is 1.15 mg kg^{-1} (Table 1). The global average

concentration of molybdenum in soils has been established at 1.8 mg kg^{-1} [57], which aligns with the findings of [57 op.cit]. Numerous studies have indicated that elevated levels of Mo are frequently associated with uranium ore [58-60], attributable to the similar geochemical characteristics of uranium and molybdenum as redox-sensitive elements. However, a weak correlation between molybdenum and uranium has been observed, potentially due to the migration of uranium (Figure 3-C).

4.1.4 Zinc

The analysis of zinc (Zn) distribution within the examined soil reveals a limited range of variation, with the maximum concentration recorded at 34.1 mg kg^{-1} and the minimum at 28.7 mg kg^{-1} (Table 1). Ebyan, 2005[61] reported a Zn concentration of 29.00 mg kg^{-1} in comparable soil from the Gattar region in the Northern desert of Egypt. In the United States, surface soil Zn levels vary between 17 and 125 mg kg^{-1}, which are generally regarded as baseline concentrations of Zn [52]. The Zn concentrations observed in this study align closely with the findings of both [52, 61]. Additionally, Figure 3-D illustrates a positive correlation between uranium and zinc, suggesting a potential association due to their presence in similar mineral forms.

4.1.5 Cobalt

The maximum concentration of cobalt (Co) recorded is 2.35 mg kg-1, whereas the minimum is 2.13 mg kg-1, as presented in Table 1. According to Kabata-Pendias, 2001[52], the typical cobalt content in surface soils generally varies from 0.1 to 70 mg kg-1, with a global average concentration of 7.9 mg kg-1 and a mean of 8.2 mg kg-1 for soils in the United States. In contrast, the average cobalt concentrations in Egyptian soils range from 16.5 to 26.8 mg kg-1 [62]. The values obtained in this study are lower than those reported by [62 op.cit]. Furthermore, the distribution of cobalt in the stream sediments of the examined area shows a very weak correlation (R2 = 0.016) with uranium, likely due to cobalt's enrichment in basic rocks, which typically contain lower levels of uranium, as illustrated in Figure 4-E.

4.1.6 Nickel

The concentration of nickel (Ni) in the analyzed soil samples varies from 5.01 to 6.92 mg kg^{-1}, with a mean value of 6.02 mg kg^{-1}, as presented in Table 1. According to Kabata-Pendias, 2001[52], nickel concentrations tend to diminish with increasing rock acidity, typically ranging from 5 to 15 mg kg^{-1} in granitic formations. The nickel content in soils is significantly influenced by the nickel levels in the underlying parent rocks. The soil in the research area, which has developed from the weathering of El-Missikat granite, reflects these findings, aligning with the observations made by [52]. Furthermore, the measured nickel concentrations fall below the permissible threshold for soil, which Antoniadis et al. (2017)[63] have established at 35 mg kg^{-1}. Additionally, Figure 3-H illustrates a weak positive correlation (R^2 = 0.123) between uranium (U) and nickel, attributed to their occurrence in distinct environmental contexts.

4.1.7 Cadmium

Trace elements, including cadmium (Cd), are naturally found in geological formations such as rocks and soil, primarily as a result of weathering processes [64]. The concentration of cadmium in the three studied locations (QI, QII, and Wadi El Abde) is less than 0.1 mg kg^{-1}, while in location Q V, it reaches 0.1 mg kg^{-1} (Table 6).

These measurements align with the typical background concentration of cadmium in soil, which is approximately 0.06 mg kg^{-1} [65]. According to Kabata-Pendias (2001) [52], the chemical composition of the parent rock significantly influences the cadmium levels in the soil. She noted that the average cadmium concentrations in soils typically range from 0.06 to 1.1 mg kg^{-1}. Mnasri et al. (2015)[66] further reported that cadmium levels in reference soils can vary from 0.06 to 4.3 mg kg^{-1}. The cadmium concentrations observed in the study area are generally consistent with the findings of [52]. Additionally, Figure 3-F illustrates a positive correlation with uranium, suggesting that both elements may be hosted within the same mineral structures.

4.2 Radioactive and Trace elements in plant samples

4.2.1 Uranium and thorium

Uranium is recognized as a toxic and radioactive element, exhibiting significant carcinogenic properties [67]. Plants can absorb trace amounts of uranium and thorium from their surrounding soil and water. However, this absorption is typically minimal, and these elements are not considered essential for plant development [68-70]. The extent of uptake is influenced by various factors, including (1) specific plant species, such as ferns and mosses, which are known to accumulate higher levels of uranium and thorium compared to other species; (2) soil characteristics, including pH, organic matter content, and the presence of competing minerals, which can affect the absorption process; and (3) the availability of water, as plants tend to absorb more elements when water is abundant [71-75]. Establishing a global standard for uranium and thorium uptake in natural plants is complex due to the extensive variety of plant species, soil conditions, and environmental influences.

Research on the uptake of uranium and thorium by plants often concentrates on particular species or ecological contexts [76-79]. The International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) provide valuable insights regarding environmental radioactivity and its associated health implications.

Table 1. The concentration of radio and trace elements mg.kg^{-1} in dry weight of *Lotus sp.* and soil samples and the biological absorption coefficients; *BAC.*

	U										**Av.**
Plants	1.11	1.09	1.18	1.10	1.14	1.25	1.06	1.19	1.21	1.20	1.15
Soils	4.10	3.94	4.32	4.15	4.20	4.52	3.86	4.28	4.45	4.38	4.22
BCF	0.27	0.28	0.27	0.27	0.27	0.28	0.27	0.29	0.27	0.27	0.27
					Th						**Av.**
Plants	3.05	3.11	3.09	2.98	3.07	3.01	3.16	3.10	3.13	3.04	3.07
Soils	10.27	10.42	10.36	10.16	10.30	10.22	10.49	10.39	10.46	10.25	10.33
BCF	0.30	0.30	0.30	0.30	0.30	0.29	0.30	0.30	0.30	0.29	0.30
					Co						**Av**.
Plants	3.48	3.62	3.58	3.46	3.71	3.51	3.78	3.68	3.87	3.93	3.66
Soils	2.13	2.18	2.17	2.20	2.26	2.15	2.28	2.24	2.31	2.35	2.23
BCF	1.63	1.66	1.65	1.57	1.64	1.63	1.66	1.64	1.68	1.67	1.64
					Pb						**Av.**
Plants	5.23	5.28	5.31	5.33	5.35	5.48	5.53	5.46	5.38	5.45	5.38
Soils	15.89	16.12	16.17	16.19	16.21	16.33	16.38	16.28	16.25	16.25	16.21
BCF	0.33	0.33	0.33	0.33	0.33	0.34	0.34	0.34	0.33	0.34	0.33
					Mo						**Av**.
Plants	1.88	1.93	1.96	1.89	2.04	2.00	2.11	2.15	2.18	2.21	2.04
Soils	1.15	1.25	1.29	1.21	1.32	1.30	1.35	1.37	1.42	1.48	1.31
BCF	1.63	1.54	1.52	1.56	1.55	1.54	1.56	1.57	1.54	1.49	1.55
					Zn						**Av**.
Plants	273.8	274.8	275.3	274.5	275.2	276.5	276.3	275.6	276.8	277.8	275.66
Soils	28.7	29.6	30.8	29.3	30.5	33.4	32.4	31.1	33.5	34.1	31.34
BCF	9.54	9.28	8.94	9.37	9.02	8.28	8.53	8.86	8.26	8.15	8.82
					Cd						**Av**.
Plants	0.92	0.88	0.98	1.01	0.95	1.03	1.05	1.09	1.10	1.12	1.01
Soils	0.088	0.084	0.093	0.10	0.091	0.13	0.11	0.14	0.15	0.17	0.12
BCF	10.45	10.48	10.54	10.01	10.44	7.92	9.55	7.79	7.33	6.59	9.12
					Ni						**Av.**
Plants	19.8	20.10	21.20	20.3	20.7	21.8	21.9	22.3	21.5	22.5	21.21
Soils	5.01	5.30	5.80	5.50	5.60	6.50	6.70	6.73	6.11	6.92	6.02
BCF	3.95	3.79	3.66	3.69	3.70	3.35	3.27	3.31	3.52	3.25	3.55

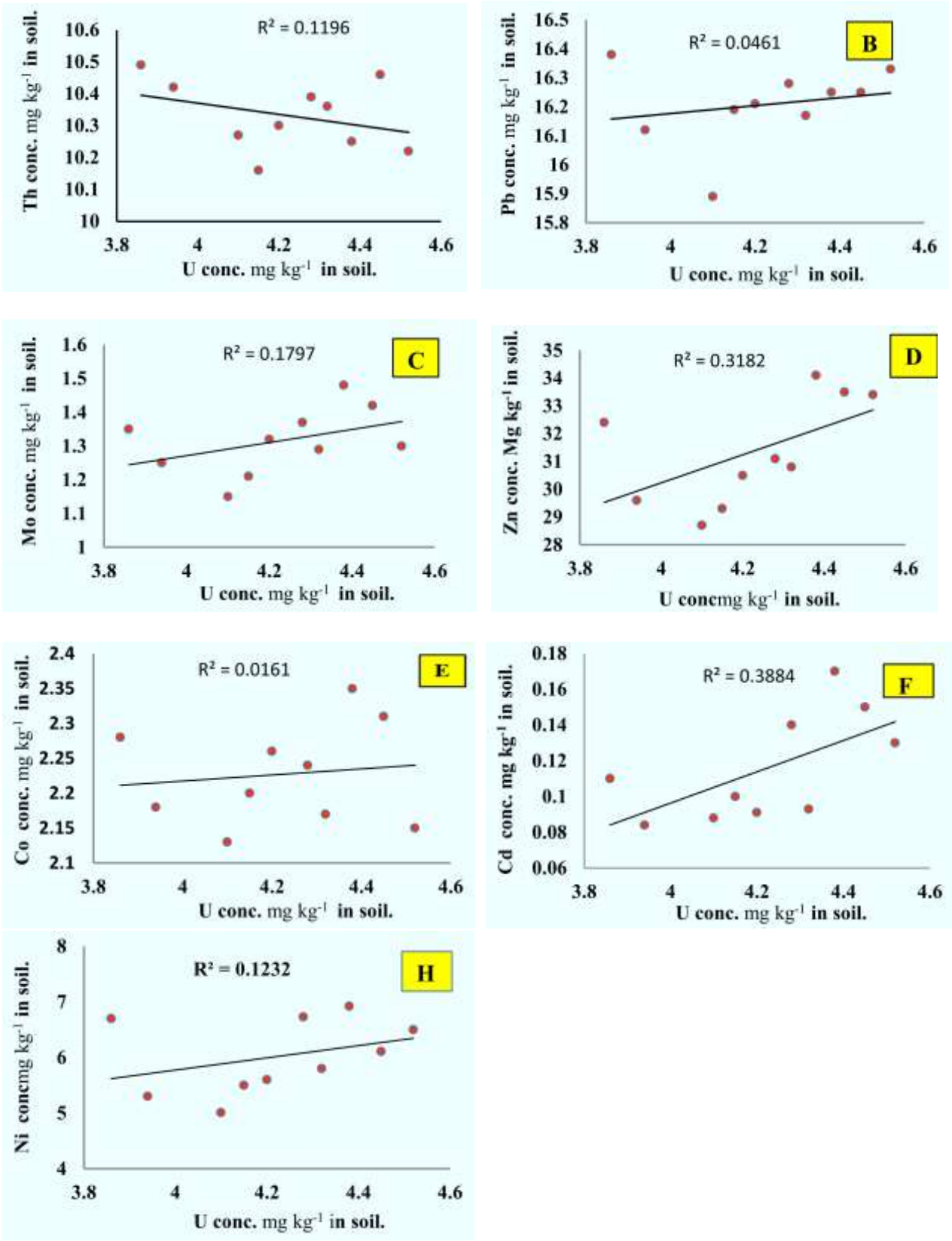

Fig.3. Correlation between U and other trace elements in soil samples.

The mean concentration of uranium in the analyzed plant samples was determined to be 1.15 mg kg^{-1}. The maximum recorded uptake was 1.25 mg kg^{-1}, while the minimum was 1.06 mg kg^{-1} (Table 1). Ebyan, 2014[80] noted that the average uranium uptake in *Fagonia sp*. from the Gattar region, which is in proximity to the current study area, was 0.84 mg kg^{-1}. This finding suggests that the species under investigation exhibits a greater capacity for uranium absorption compared to the values reported for *Fagonia sp*. Other studies, including those by [81] and [82,83], have indicated uranium concentrations in various aerial plant species, such as 0.24 mg kg^{-1} in *broad bean*, 0.21 mg kg^{-1} in *sunflower*, and 1.82 mg kg^{-1} in *mustard*, with an additional value of 1.23 mg kg^{-1} noted. Favas et al., 2016[84] reported uranium concentrations of 0.4 mg kg^{-1} in *Zebrina* and 1.1 mg kg^{-1} in *Antirrhinum majus*. The uranium concentrations observed in the current study are comparable to those reported for other plant species. Watel et al. (2020) [85] documented bioconcentration factor (*BCF*) values for desert plants ranging from 0.051 to 0.234, while the BCF observed in this study exceeds those values. Reimann et al. (2001)[86] indicated that the world average uptake of uranium in plants is 0.01 mg kg^{-1}, implying that *Lotus hebranicus* sp. can absorb and accumulate uranium at a rate 115 times greater than the global average for desert plants. Chaney et al. (1997) [87] suggested that hyperaccumulator plants can sequester uranium at levels 10 to 500 times higher than typical plants. Consequently, *Lotus hebranicus sp*. may be a viable candidate for phytoremediation and uranium exploration.

Thorium concentrations in *Lotus hebranicus* exhibit variability, with the maximum recorded level reaching 3.16 mg kg^{-1} and the minimum at 2.98 mg kg^{-1} (Table 1). The mean concentration was determined to be 3.07 mg kg^{-1}. In the Gattar region, thorium levels are comparable to those found in the study area. Ebyan, 2014 [80] reported an average thorium concentration of 3.13 mg kg^{-1} in *Fagonia* species. In contrast, the global average for thorium uptake is significantly lower, at 0.02 mg kg^{-1} [86]. The species under investigation demonstrates a capacity to accumulate thorium at a rate 154 times greater than the global average. Consequently, *Lotus hebranicus* can be classified as a hyperaccumulator of thorium, as per the criteria established by [87]. The findings suggest that *Lotus hebranicus* is capable of absorbing and storing thorium in greater quantities than uranium (Figure 4). It is well-established that uranium exhibits greater mobility in soil compared to thorium, rendering it more bioavailable [88]. Despite the geological occurrence of uranium and thorium in similar mineral matrices [89], their interactions within biological systems appear to differ significantly. Uranium can form complex compounds that can be readily absorbed by plants [90].

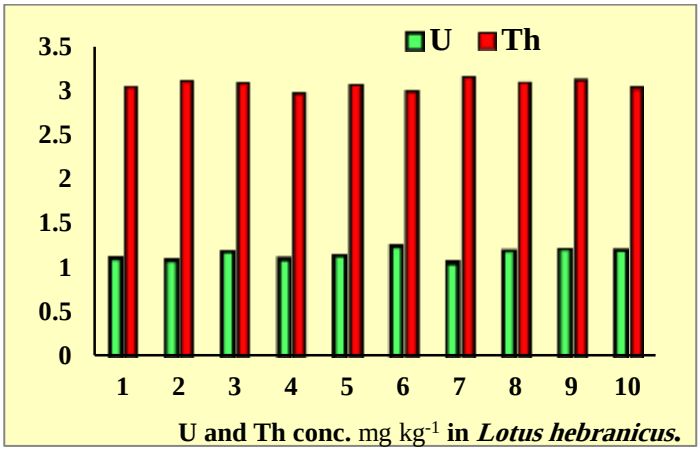

Fig. 4. Histogram showing U and Th accumulation in 10 *Lotus hebranicus* plant samples.

4.2.2 Lead

The maximum recorded concentration of lead (Pb) was 5.53 mg kg^{-1}, while the minimum was 5.23 mg kg^{-1}, as presented in Table 1. The mean uptake of this toxic element was determined to be 5.38 mg kg^{-1}. Rashed (2002)[91] indicated that *Aerva javanica*, a wild plant located near a gold mine in Wadi Allaqi, Eastern Desert, Egypt, demonstrated an ability to absorb and accumulate Pb at a concentration of 0.23 mg kg^{-1}, which is significantly higher than the 0.03 mg kg^{-1} found in plants situated farther from the mine. This suggests that *Lotus hebranicus* can concentrate Pb at a rate 24 times greater than the value reported by [91]. Furthermore, Ebyan (2005)[61] reported that the average Pb concentrations in five wild plant species (*Zilla spinosa*, *Zygophyllum coccineum*, *Fagonia boveana*, *Aerva javanica*, *and Moringa peregrina*) from the Gattar area in the northeastern desert of Egypt, with values of 0.07, 0.30, 1.32, 0.75, and 0.37 mg kg^{-1}, respectively. In the current study, *Lotus hebranicus* was found to absorb and accumulate Pb at levels twice that of the highest values recorded by Ebyan. The average bioconcentration factor (*BCF*) for lead absorption from soil in *Lotus hebranicus* is 0.33, indicating a noteworthy ratio. Consequently, this plant should be avoided in cattle forage, despite the Zn concentrations in this study not exceeding the World Plant Average (WPA) for Pb, which is 15.60 mg kg^{-1} [86, 92]. Figure 5 illustrates a strong positive correlation between Pb levels in the plant and the soil (R^2 = 0.82). Vasileios et al. (2021)[63] reported Pb concentrations in four native plant species (*Holcus lanatus*, *Bromus inermis*, *Stellaria holostea*, *and Poa angustifolia*) along the Elbe River in Germany, with values of 1.94, 2.87, 2.83, and 2.30 mg kg^{-1}, respectively; the Pb levels in this study exceed those reported by [63].

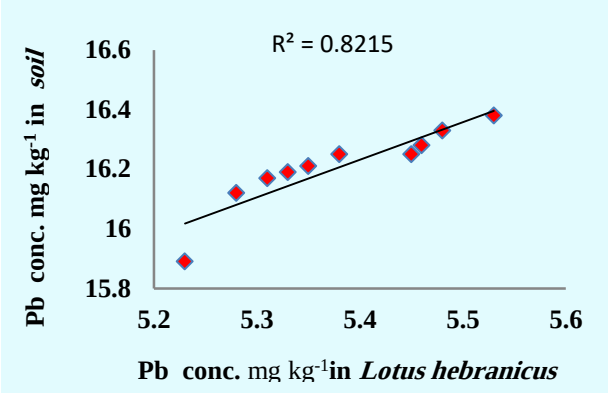

Fig. 5. Strong positive correlation between Pb in plants and soil.

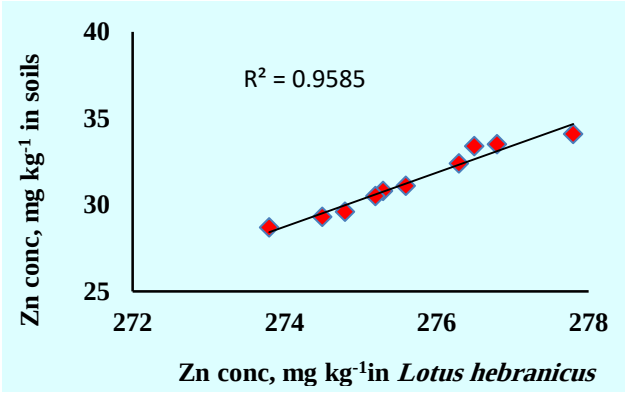

Fig. 6. Very strong positive correlation for Zn between plant and soil.

4.2.3 Zinc

The mean concentration of zinc (Zn) recorded was 275.66 mg kg^{-1}, with the maximum and minimum values being 277.8 and 273.8 mg kg^{-1}, respectively. Vasileios et al. (2021)[63] reported higher concentrations of Zn in two Indigenous plant species, *Alopecurus pratensis*, and *Elytrigia repens*, at 503.1 and 528.8 mg kg^{-1}, indicating that the values presented in this study are lower than those found by [63 opcit]. Rashed (2002) [91]observed that *Aerva sp.* located near a gold mine exhibited a Zn absorption capacity of 7.8 mg kg^{-1}, while those situated further away recorded a lower concentration of 3.0 mg kg^{-1} in Wadi Allaqi, Egypt. Ebyan (2005) [61]documented the average Zn concentrations in various wild plants, including *Zilla spinosa, Zygophyllum coccineum, Fagonia boveana, Aerva javanica, and Moringa peregrina*, in the Eastern Desert of Egypt, which were 24.1, 11.7, 23.4, 18.7, and 19.6 mg kg^{-1}, respectively. Additionally, Subramanian et al. (2012)[93] found that the Zn uptake in the wild plants *Syzygium caryophyllatum and Syzygium densiflorum* was 99.3 and 93.8 mg kg^{-1}, respectively. Obinna et al. (2019) reported an average Zn concentration of 161.5 mg kg^{-1} across 27 different plant species. In comparison, the global average Zn uptake in plants is reported to be 32.0 mg kg^{-1} (Reimanna et al., 2001)[86], suggesting that the species examined in this study exhibit Zn uptake levels that are nine times higher than this average. Consequently, *Lotus hebranicus* is a viable candidate for the exploration and phytoremediation of Zn. Figure 6 illustrates a very strong positive correlation between Zn levels in plants and soil, with an R^2 value of 0.958.

4.2.4 Cobalt

Chemical analysis of cobalt in *Lotus hebranicus* indicates that the maximum uptake value is 3.93 mg kg^{-1} (Table 1), while the minimum uptake value is recorded at 3.46 mg kg^{-1}. The mean absorption of cobalt in this species is calculated to be 3.66 mg kg^{-1}. In comparison, cobalt concentrations in various wild plants across different regions of the Eastern Desert of Egypt have been documented to range from 0.15 to 0.24 mg kg^{-1} [91] and from 0.18 to 0.61 mg kg^{-1} [61]. Although cobalt is not categorized as an essential element for plant growth, it is recognized as a beneficial element, with typical concentrations in the dry matter of plants varying between 0.1 and 10.0 mg kg^{-1} [94]. Reimann et al. (2001)[86] noted that the World Health Organization's permissible level for cobalt uptake is 0.17 mg kg^{-1}, while *Lotus hebranicus* can absorb cobalt at a rate 23 times greater than this threshold. Furthermore, Chaney et al. (1997) [87] classified *Lotus hebranicus* as a hyperaccumulator of cobalt. Consequently, this species holds potential for applications in cobalt exploration and phytoremediation. Figure 7 illustrates a robust positive correlation between cobalt levels in the plant and the soil, with an R^2 value of 0.8814.

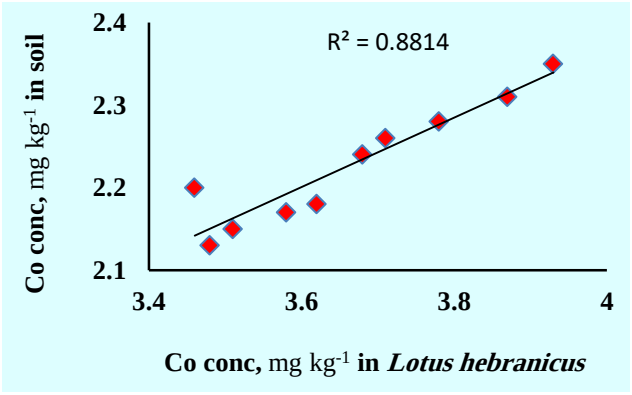

Fig. 7. Very strong positive correlation between Co (R^2 = 0.8814) in plants and soil.

4.2.5 Molybdenum

The average for Mo absorption in *Lotus hebranicus sp.* was 2.04 mg kg^{-1}, the highest and lowest values were 2.21 and 1.88 mg kg^{-1}, respectively (table 1). Małgorzata Stojek (2013)[95] found that the average Mo uptake in three plant species (*Plantago major L., Plantago lanceolata L., and Trifolium hybridum L.)* were 1.31, 1.58 and 0.80 mg kg^{-1}, respectively. Harada and Hatanaka (1998) [96] reported that the Median value of Mo elemental concentrations in

wild plants in the central and eastern parts of Japan was 0.329 mg kg^{-1}. Also, Ebyan 2005[61] mentioned that the average concentration of Mo in some wild plants in Gabal Gattar in the Central Eastern Desert of Egypt (similar to the study area) were 0.65, 0.29, 0.91, 1.12, and 0.60 mg kg^{-1}.

The obtained results for Mo uptake in the present study are higher than the results of the aforementioned research. The world plant average (WPA) for Mo is 0.05 mg kg^{-1} [86]. *Lotus hebranicus* can uptake Mo with 41 times more than WPA. According to Chaney et al. (1997) [87], the *Lotus hebranicus* is a hyperaccumulator plant for Mo. Thus, *Lotus hebranicus sp*. can be used for the exploration and phytoremediation of Molybdenum. Figure 8 shows a very strong positive correlation between Mo (R^2 = 0.9273) in plants and soil.

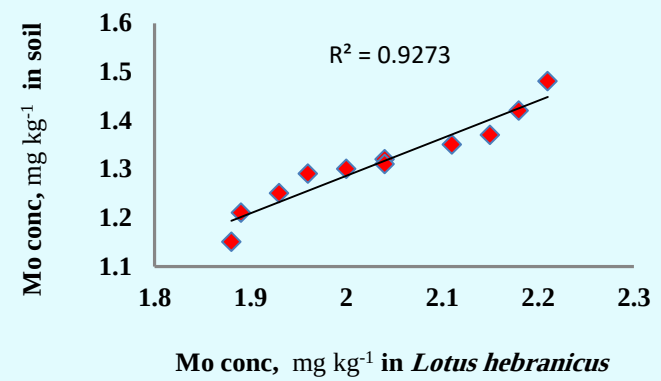

Fig. 8. Very strong positive correlation between Mo (R^2 = 0.9273) in plants and soil.

4.2.6 Cadmium

The maximum concentration of cadmium (Cd) recorded is 1.12 mg kg^{-1}, while the minimum is 0.88 mg kg^{-1}, as presented in Table 1. The average uptake across the samples is 1.01 mg kg^{-1}. Nabulo (2011)[97] indicates that the species *Brassica oleracea Acephala, Brassica oleracea Capitata, and Allium ampeloprasum var. porrum Musselburgh* can accumulate Cd levels of 0.39, 0.52, and 0.27 mg kg^{-1}, respectively. Additionally, various plant species, including *Patrinia intermediates, Rhazya stricta, Aerva javanica, Zygophyllum coccineum, Zilla spinosa, Fagonia boveana, and Moringa peregrina,* have been shown to concentrate Cd at levels of 0.39, 0.16, 0.3, 0.28, 0.47, 0.26, and 0.03 mg kg^{-1}, respectively [80,98-100]. In this study, the average concentration of Cd in *Lotus hebranicus* is 1.01 mg kg^{-1}, indicating that this species has a greater capacity for Cd accumulation compared to the aforementioned plants. Reimann et al. (2001)[86] noted that the permissible concentration for Cd is 0.08 mg kg^{-1}, and *Lotus hebranicus* can uptake and concentrate Cd at levels 14 times higher than this threshold. Chaney et al. 1997[87] classified *Lotus hebranicus* as a hyperaccumulator of Cd. Cadmium is recognized as one of the most toxic elements and is deemed non-essential for living organisms [101]. Exposure to elevated Cd concentrations typically results in stunted growth in plants [102]. Therefore, it is advisable to minimize the presence of *Lotus hebranicus* in cattle forage.

Conversely, this plant may serve beneficially in exploratory studies and phytoremediation efforts for Cd. Figure 9 illustrates a strong positive correlation between Cd levels in plants and soil, with an R^2 value of 0.8383.

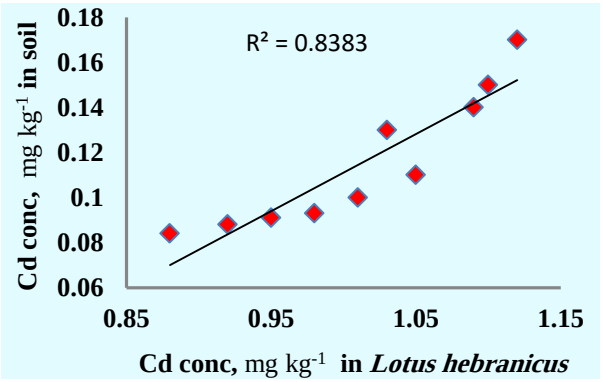

Fig.9. Very strong positive correlation between Cd (R^2 = 0.8383) in plants and soil.

4.2.7 Nickel

The maximum concentration of nickel (Ni) identified as a toxic element in *Lotus hebranicus* is 22.5 mg kg^{-1}, whereas the minimum concentration recorded is 19.8 mg kg^{-1} (Table 1). The mean concentration of Ni in this species is 21.21 mg kg^{-1}. In various desert plants located in different regions of the Eastern Desert of Egypt, Ni concentrations have been reported as follows: 0.038, 0.053, 0.056, 0.035, 0.028, 0.039, and 0.063 mg kg^{-1} [103]; 6.5, 15.2, 1.10, and 2.0 mg kg^{-1} (Rashed, 2010)[99]; and 1.26, 2.54, 8.5, 2.5, and 3.55 mg kg^{-1} [61]. Antoniadis et al. (2021)[63] indicated that the Ni concentrations in certain plants (*Elytrigia repens, Poa angustifolia, Stellaria holostea, and Galium mollugo*) along the Elbe River in Germany were 4.82, 11.08, 13.6, and 15.71 mg kg^{-1}, respectively. In Southwest Poland, four species (*Sparganium erectum, Glyceria maxima, and Phalaris*) exhibited Ni concentrations of 6.81, 4.41, 4.36, and 1.66 mg kg^{-1}, respectively [104]. Brooks and Robinson (1998)[105] reported that the natural Ni content in plants is approximately 0.32 mg kg^{-1}. The World Health Organization's permissible level for Ni is 1.97 mg kg^{-1}, indicating that *Lotus hebranicus* can absorb and accumulate Ni at a rate 11 times greater than this threshold. According to Chaney et al. (1997)[87], *Lotus hebranicus* is classified as a hyperaccumulator of Ni. Figure 10 illustrates a strong positive correlation (R^2 = 0.969) between the Ni concentrations in the plant and the soil. Additionally, Figure 10 demonstrates that *Lotus hebranicus* can concentrate certain elements more effectively than others, in the following order: Ni > Pb > Co > Th > Mo > U > Cd.

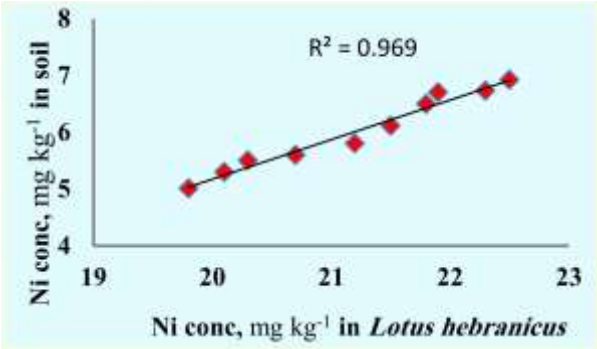

Fig.10. Very strong positive correlation between Ni in plants and soil.

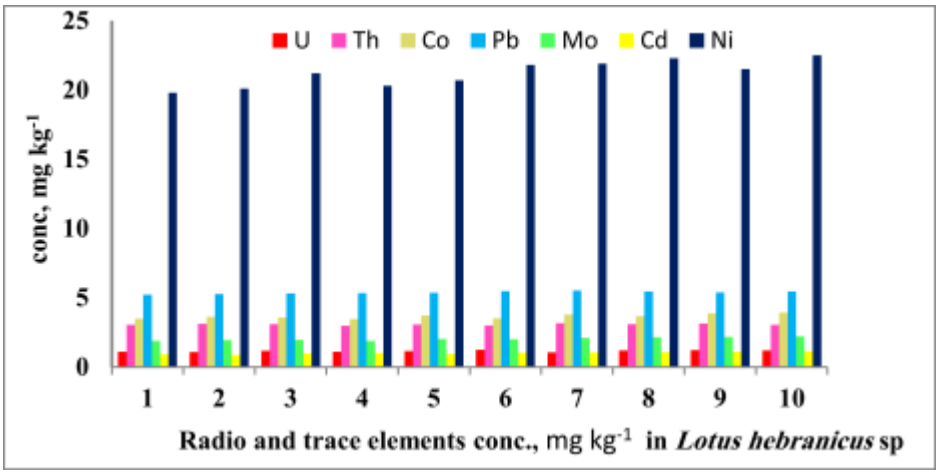

Fig.11. Histogram showing radio and trace elements concentration in 10 *Lotus hebranicus* plant samples.

5 Conclusion

The studied area is located within the North Abu Rusheid region, southeastern Desert, Egypt, specifically between latitudes 24° 36' 30" N and 24° 37' 15" N, and longitudes 34° 46' 15" E and 34° 46' 45" E. U, Th, Ni, Mo, Cd and Zn concentrations in the soil samples fall within or below the permissible threshold for soil, while the lead concentrations exceed these levels. The findings suggest that *Lotus hebranicus* is capable of absorbing and storing thorium in greater quantities than uranium. *Lotus hebranicus* can concentrate Pb, Ni, and Cd with elevated rates, thus this plant should be avoided in cattle forage. Zn, Co, and Mo uptake levels exhibit that *Lotus hebranicus* is a viable candidate for exploration and phytoremediation of these elements. *Lotus hebranicus* can concentrate certain elements more effectively than others, in the following order: Ni > Pb > Co > Th > Mo > U > Cd.

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