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Biogeochemical Exploration for Gold Mineralization Using Wild Plants

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Abstract: *Lotus hebranicus* and *Zilla spinosa* were selected for gold biogeochemical exploration in Wadi El-Missikat. Their soil associations were examined using Inductively Coupled Plasma, Emission&Mass spectrometry, ICPES spectrometry, and Mass Spectrometry. The significant levels of gold in plants and soil, along with the consistent link between gold and its markers, plus the relationship between gold in plants and soil, suggest the presence of gold mineralization in nearby rocks in the area under investigation. *Lotus hebranicus* has a greater ability to accumulate Au compared to *Zilla spinosa*. Both of these species can be utilized for exploring and phytoremediating silver. Additionally, *Lotus hebranicus* is more effective in uptaking and storing Sb than *Zilla spinosa*, making it valuable for treating Sb contamination. *Lotus hebranicus* and *Zilla spinosa* are beneficial for both exploration and remediation tasks.

Keywords: Biogeochemical exploration; Phytoremediation; Gold, Silver; Antimony, Arsenic.

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1. INTRODUCTION

Exploration and processing of minerals are significant parts of the global industry. Several plants can absorb gold from the soil and store it within their tissues. Progress has been achieved in comprehending these mechanisms, making the use of plants in gold prospecting a viable option (1). The initial study on gold accumulation in vegetation dates back to 1900 (2) and has since been followed by research on its biogeochemistry and the utilization of plants as a tool for exploring gold-rich ore deposits (1-11).

The presence of trace elements in plants is a result of their transfer from rocks and soil to plants (12). In their natural environment, trace elements are found in low concentrations without causing any significant harm to biodiversity (13,14). Plants show a variety of behaviors when it comes to absorbing trace elements. Biogeochemical prospecting is a cost-effective method for exploration (15,16). Three main uptake patterns are accumulation, indication, and exclusion, which vary among plant species due to their unique abilities (17). Research on the absorption of gold is abundant, with a focus on how gold is transported from soil to plants (1, 17-24). Plants tend to absorb chemicals from the soil, making them useful for metal exploration and soil remediation purposes (25).

Gold levels in wild plants typically stay below 10 $\mu g.kg^{-1}$ dry weight, even when found near gold deposits (26). Higher reported values may result from wind-carried substrate contamination. Gold, Au, is commonly found in plants like *Phacelia sericea* near gold mines, aiding in the detection of soil gold deposits by geologists (15). Geologists have utilized these plants to find gold in the soil. *Brassica juncea*, a quick-growing member of the mustard family, is a hyperaccumulator of gold and has been grown in soil with small amounts of gold to yield almost 1 milligram of gold per gram of dry plant tissue. Researchers aim to improve this gold yield for potential gold mining purposes.

Studies have shown that plants can be used to explore gold in its biogeochemistry. Various plant species, such as *Pseudotsuga menziesii, Pinus banksiana, Picea mariana, Hordeum vulgare, and Phacelia sericea*, have the ability to accumulate detectable amounts of gold (27). Gold can be absorbed by plants in soluble form and easily transported to different parts of the plant through the root vascular systems (23).

Aljahdali and Alhassan (28) defined the biological absorption coefficient (*BAC*) as the measure of absorption intensity of chemical elements by plants from their substrate, which can be calculated using the provided equation.

$$\text{BAC} = \frac{Concentration\ of\ Elements\ in\ Plants: Cp}{Concentration\ of\ Elements\ in\ Soil: Cs} \qquad \text{(Eq. 1)}$$

where *Cp* is the concentration of an element in a plant and *Cs* is the concentration of the same element in soil. *BAC* tells if a plant species is an accumulator or hyperaccumulator of trace elements or a specific trace element from the soil into the plants (12,13,28).

BAC levels differ greatly based on weight, with most elements below one. Plants were grouped into five categories based on *BAC* values: 1) Intensive; 10-100, 2) Strong; 1.0-10, 3) Intermediate; 0.1-1.0, 4) Weak; 0.01-0.1, 5) Very weak; 0.001-0.01 (29,30).

Numerous wild plants found in the Eastern Desert of Egypt include *Glinus lotoides, Aerva javanica, Astragalus vogelli, Tamarix nilotica, Zygophyllum coccineum, Zilla spinosa, Fagonia boveana, Moringa peregrina, Trichodesma africanum, Lotus hebranicus, Pergularia tomentosa,* and *Citrullus colocynthis* (31, 32). Most of these plants are considered short-lived compared to grazing plants (33). The perennial plants *Zilla spinosa* and *Lotus hebranicus* were selected for this study. Perennial plant cover serves as a lasting element of the desert vegetation, reflecting the habitat conditions. The locations of soil and plant samples in Wadi El-Missikat, Eastern Desert, Egypt, are indicated on a Landsat image of the area (Figure 1).

The present study briefs the ability of the gold uptake by plants, *Lotus hebranicus* and *Zilla spinosa,* for further exploration of gold.

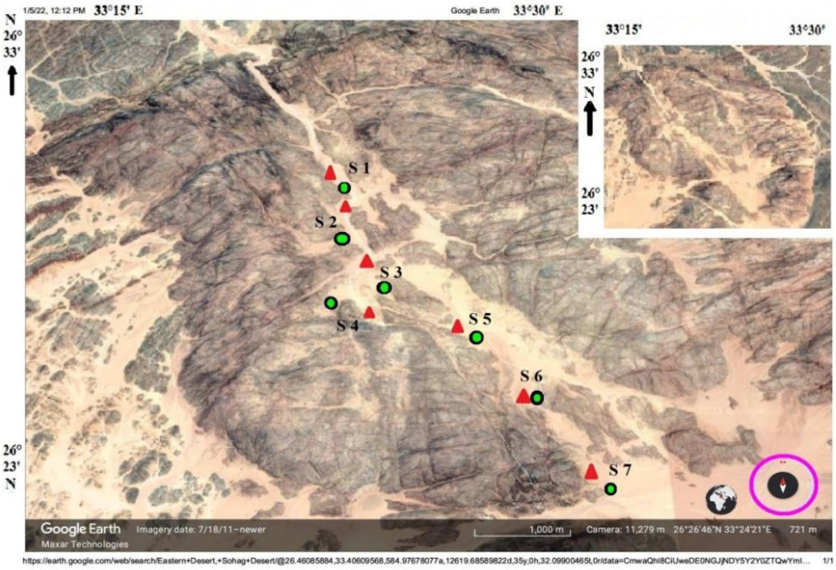

Figure 1: Landsat image showing samples location of the studied soil and plants in Wadi El-Missikat area.

2. MATERIAL AND METHODS

2.1 Plant Samples Collection

The plant species studied are *Lotus hebranicus*, *Lotus* sp., (Figure 2), and *Zilla spinoza*, *Zilla* sp., (Figure 3) from the Fabaceae and Zygophyllaceae families, respectively. These plants are highly prevalent in the research location and are thus ideal for this investigation. The collection of these species was done manually, with a minimum of 140 g of plant material prepared for each sample. Samples were promptly sent for analysis to prevent degradation of the collection bags, which can disintegrate if stored for long periods.

Every time, healthy plants were carefully selected for sampling, free of soil deposits. They were cleansed with tap and distilled water, then deionized water, and finally dried in an electric furnace at 105 °C for 12 hours. Afterward, the whole herba was blended and powdered using stainless-steel and mechanical agate mortar, respectively. The resulting powder was stored in clean polyethylene bottles.

Figure 2: *Lotus hebranicus* plant.

Figure 3: *Zilla spinoza* plant.

2.2. Plant Analysis

1.0 g of dried plant samples were for analysis by digestion in HNO_3 then in modified aqua regia (hot 1:1:1 HCl, HNO_3, H_2O) with an ICP-AES or ICP-MS finish (Acme Labs, Vancouver, Method 1VE) for 37 elements. Quality control (blanks, duplicates, and CRMs) constituted 10.8% of the samples analyzed. Many of the elements reported by this method were at or below detection.

2.3. Soil Samples Collection

Composite soil samples were gathered from the top 30 cm of soil depth, often in conjunction with plant samples. The soil samples were placed in bags and quartered before being crushed and pulverized with a mechanical agate mortar. Next, they were dried in an oven at 100 °C for 5 hours and stored in polyethylene bags for analysis.

2.4. Soil Analysis

0.5 g of finely powdered soil was precisely weighed and sent for analysis (Acme Labs, Vancouver) by ICP-AES and ICP-MS following a multiacid digestion involving heating in HNO_3–$HClO_4$– HF to fuming and taken to dryness, with the residue dissolved in HCl (Acme Method 1EX). For soil samples' concentrations above the upper detection levels for some elements, Acme's assay method STD DST6 was used.

Chemical analysis of plant and soil samples was carried out at ACME Analytical Laboratories in Vancouver, Canada. Detection limits for trace elements were 0.01–0.5 ppm. The analytical precision, as calculated from replicate analyses, varied from 2% to 20% for trace elements.

3. RESULTS

Gold, silver, antimony, and arsenic found in plants can identify areas with gold deposits based on the plant's capacity to absorb and store these elements. Plants unable to absorb gold will be disregarded. Silver, antimony, arsenic, bismuth, copper, lead, selenium, tellurium, and zinc are key elements linked to gold (34, 35). Among these, silver, antimony, and arsenic were chosen due to their strong connection with gold.

3.1. Distribution of Gold, Silver, Antimony and Arsenic in The Studied Soil Samples

The primary origin of the soil samples is closely linked to the predominant granitic rocks in the surveyed region. Exploration typically focuses on indicators of gold mineralization such as Te, Bi, As, Ag, Cu, and Sb, among others (36-42). Tables 1 and 2 displayed the concentration mean of Au and its pathfinder in the studied plants and its associating soil. Firstly, these elemental distributions will be discussed in El-Missikat soil.

3.2. Gold and Its Pathfinders in Soil

The amount of gold in soil samples beneath the wild plants studied varies from 91.0 to 160.0 μg.kg^{-1}, averaging 106.0 μg.kg^{-1}. This is greater than the levels found in granitic rocks as reported by Kabata-Pendias and Pendias (17), which ranged from 1.2 to 1.8 μg.kg^{-1}. The soil analyzed contains gold levels approximately 100 times greater than those documented by Kabata-Pendias and Pendias (17). Abyan (18) found that the gold concentration in comparable soil, such as that in Gebel Qattar in the North Eastern Desert of Egypt, ranged from 1 to 3 μg.kg^{-1}, revealing a presence of gold enrichment in El-Missikat soil.

Williams et al. (21) observed that soil in an Au mining area in New Zealand has gold levels ranging from 3-48 μg.kg^{-1}. The average gold concentration in the soil studied was 106.0 μg.kg^{-1}, which is double the previously recorded values. This implies the possibility of gold mineralization in the studied area or nearby locations.

Table 1: Concentration of elements; Au, Ag, Sb, and As μg.kg^{-1} in dry weight of *Lotus* sp*.* and soil samples and the biological absorption coefficients; *BAC*.

	Au			**Ag**			**Sb**			**As**		
Samples	***Lotus* sp**	**Soil**	***BAC***	***Lotus* sp**	**Soil**	***BAC***	***Lotus* sp**	**Soil**	***BAC***	***Lotus* sp**	**Soil**	***BAC***
1	10.5	94	0.11	59	164	0.36	66	198	0.33	1050	2070	0.51
2	9.98	91	0.11	57	180	0.32	65	202	0.32	1000	2005	0.50
3	10.7	100	0.11	62	173	0.36	69	205	0.34	985	2000	0.49
4	10.3	100	0.10	62	200	0.31	70	209	0.33	1030	1960	0.52
5	10.9	110	0.10	64	223	0.29	71	211	0.34	1100	1980	0.55
6	11.2	130	0.10	65	230	0.28	73	225	0.32	970	2040	0.48
7	11.5	160	0.10	68	236	0.29	76	240	0.31	940	1990	0.47
Average	10.71	112	0.10	62	201	0.32	70	213	0.33	1011	2006	0.50

Table 2: Concentration of elements; Au, Ag, Sb, and As μg.kg^{-1} in dry weight of *Zilla* sp*.* and soil samples and the biological absorption coefficients; BAC.

	Au			**Ag**			**Sb**			**As**		
Samples	***Zilla* sp**	**Soil**	***BAC***	***Zilla* sp**	**Soil**	***BAC***	***Zilla* sp**	**Soil**	***BAC***	***Zilla* sp**	**Soil**	***BAC***
1	1.12	99	0.01	90	193	0.46	28	195	0.14	590	2000	0.30
2	1.19	91	0.01	95	199	0.47	27	196	0.14	610	2013	0.30
3	1.15	93	0.01	96	195	0.49	31	198	0.16	640	2030	0.32
4	1.35	101	0.01	98	203	0.48	31	201	0.15	600	2008	0.30
5	1.26	104	0.01	97	201	0.48	30	205	0.15	575	1980	0.29
6	1.54	101	0.02	102	210	0.51	33	200	0.17	560	1970	0.28
7	1.48	108	0.01	98	200	0.46	32	208	0.15	630	2018	0.31
Average	1.30	100	0.01	97	200	0.48	30	200	0.15	601	2003	0.30

Silver concentrations in the soil samples fell between 164 and 236 μg.kg^{-1} on average, at 200.1 μg.kg^{-1} (Tables 1 and 2). These levels were notably higher than those reported by Jones et al. (43), who found that typical soil silver concentrations were under 100 μg.kg^{-1}, but aligned with Mukherjee (44), who noted that typical silver concentrations in soil ranged from 30 to 400 μg.kg^{-1}.

Antimony; Sb, like arsenic; As, is considered a priority pollutant (19,45,46). On average, Sb concentration in the Earth's crust is 200-300 μg.kg^{-1} (47) while uncontaminated soils have around 1000 μg.kg^{-1} (48,49). Soil samples showed Sb levels ranging from 195 to 240 μg.kg^{-1}, averaging at 206.5 μg.kg^{-1} (Tables 1 and 2), which is double Ebyan's finding of 100 μg.kg^{-1} (18) but aligns with Rish's (50) statement that Sb's presence in the Earth's crust is between 200 and 300 μg.kg^{-1}. Kabata-Pendias and Pendias (17) noted that Sb in surface soil ranges from 50 to 4000 μg.kg^{-1}. Smith and Huyck (51) mentioned that the average Sb abundance in the crust is 200 μg.kg^{-1}, in line with our results.

Depending on the soil's parent material, background concentrations of arsenic can differ among soils. Typically, soil contains around 5000 μg.kg^{-1}; 5 mg.kg^{-1} of arsenic (52). The average As concentration in European topsoil is around 7000 μg.kg^{-1} (53, 54). Arsenic and gold are often found together in gold deposits, as they are both hosted in Fe-sulfide minerals like pyrite, marcasite, and arsenopyrite, with As geochemistry influencing Au accumulation (55). Many countries have exceeded the USEPA's recommended soil As concentration of 24 μg.kg^{-1} due to human activities (56, 57).

The levels of As in the soil samples varied from 1960 to 2070 μg.kg^{-1} with an average of 2004.5 μg.kg^{-1} as shown in Tables 1 and 2, exceeding the findings of Eyban (18), who documented a range of 1200 to 1400 μg.kg^{-1} for arsenic in soil. Arsenic is distributed rather uniformly in major types of rocks, and its common concentrations in most rocks ranged between 500 and 2500 μg.kg^{-1}. All values of As in the present study are in agreement with values mentioned by Kabata-Pendias and Pendias (17) and the United States Environmental Protection Agency (USEPA).

Figure 4a exhibited the same even distribution of Au and its associated elements, Ag, Sb, and As, in soil samples beneath *Lotus* sp. and *Zilla* sp., despite differing concentrations. Figures 4b and 4c displayed moderate positive links between Au-Ag and Ag-Sb, while a strong positive relationship between Au-Sb and Au-As indicated a solid correlation between gold and its indicators in Figures 4d and 4e.

3.3. Uptake of Gold, Silver, Antimony and Arsenic by The Studied Plant Samples

Lotus sp. had an average Au concentration of 10.7 μg.kg^{-1}, while *Zilla sp*. had a concentration of 1.3 μg.kg^{-1} (Tables 1 and 2). The highest uptake levels for *Lotus* sp. were 11.5 μg.kg^{-1} and 1.54 μg.kg^{-1} for *Zilla* sp., with the lowest at 9.98 μg.kg^{-1} and 1.12 μg.kg^{-1}. The average biological absorption coefficients (*BAC*) for Au were 0.1 for *Lotus* sp. and 0.01 for *Zilla* sp., suggesting they are moderate to weak hyperaccumulator plants (30).

According to Girling et al. (58), the amount of Au in plants is usually below 1.0 μg.kg^{-1}, so *Lotus* sp. may increase Au levels by eleven times and *Zilla* sp. may also increase levels by two times compared to the background level.

Oakes (59) indicated that the levels of Au in fruits and vegetables range from 0.01 to 0.4 μg.kg^{-1}, where *Lotus* sp. and *Zilla* sp. can concentrate Au by 1071 and 130 times greater than the reported values, respectively. *Helichrysum arenarium* has Au concentrations ranging from 0.4 to 5.8 μg kg^{-1}, with *Lotus* sp. capable of concentrating Au more than *Helichrysum arenarium*.

Rashed (60) discovered that *Cyamopsis tetragonolobus* in the east of Aswan, Eastern Desert, Egypt, can absorb Au elements up to 4.6 μg.kg^{-1}. Ebyan (18) found that in the Gattar area, Eastern desert, Egypt, *Zygophyllum coccineum*, *Zilla spinosa*, *Fagonia boveana*, *Aerva javanica*, and *Moringa peregrine* can accumulate Au with average amounts of 1, 3, 2, 4, and 4 μg.kg^{-1}. Furthermore, *Lotus sp*. has even higher Au concentration values.

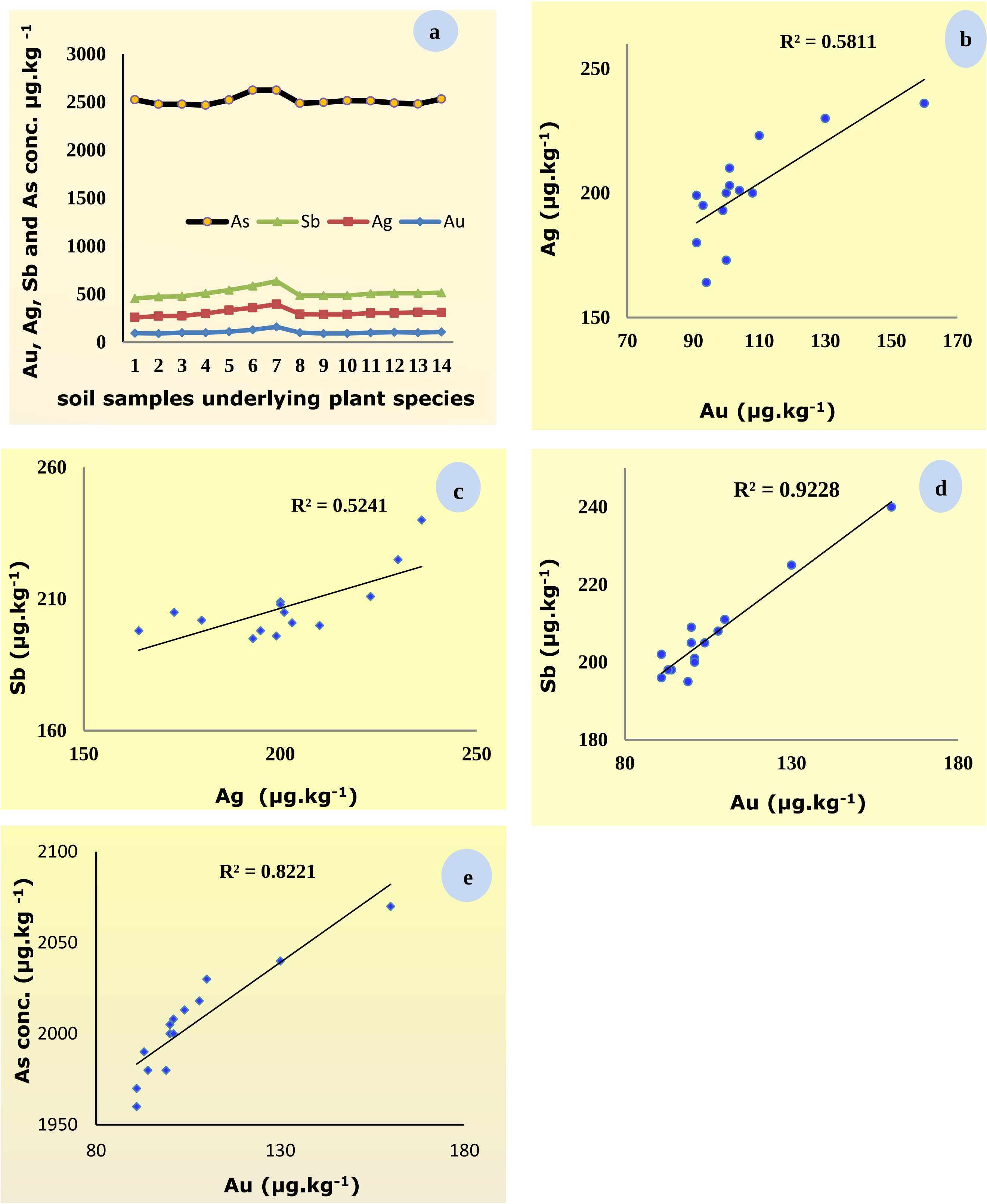

Figure 4: Correlation between Au, Ag, Sb, and As elements in soil samples underlying two plants.

Busche (9), Ebyan (18), and Rashed (60) found that the average concentration of Au in plant samples was 0.4 µg.kg^{-1}. They also suggested that Au anomalies in plants could signal the presence of gold veins in the area where the anomalies were discovered.

Hacklette et al. (61) found that *Lotus* sp. can absorb and store higher levels of Au compared to previous studies (9,18,58,61). The high Au content in plants may indicate gold mineralization in the area. Analysis of *Lotus* species and soil suggests that Au uptake in plants increases with higher soil Au levels. This is supported by a positive correlation between Au levels in plants and soil (Figure 5). *Lotus* sp. can concentrate more Au than *Zilla* sp. (Figure 6).

In the plant samples examined, Figure 7 displayed the same consistent absorption as Au. Ahmed et al.

(62) confirmed the presence of gold mineralization in El-Missikat area in Jasper and quartz veins.

The upper and lower limits of Ag absorption in *Lotus* and *Zilla* were 57-68 µg.kg^{-1} and 90-102 µg.kg^{-1}, as shown in Tables 1 and 2. On average, the uptake of Ag in these species was measured at 62 µg.kg^{-1} and 97 µg.kg^{-1}, respectively.

Vural (15) found that Ag concentration in *Helichrysum arenarium* ranged from 4-47 µg.kg^{-1}. *Lotus* and *Zilla* plants can absorb higher levels of Ag than this. Reimann et al (63) stated that *Betula pubescens* and *Pinus syluestris* in Northern Europe can absorb Ag at 7.0 and 8.0 µg.kg^{-1}. He also noted that *Hylocomium splendens* and *Pleurozium schreberi* can absorb Ag at 25 µg.kg^{-1} in dry weight. *Lotus* and *Zilla* plants can absorb more Ag than these plants, according to Reimann et al. (63).

Ebyan (18) stated that *Lotus* sp. and *Zilla* sp. plants showed greater uptake and accumulation of Ag, with levels of 26, 44, 40, and 15 µg.kg^{-1} in *Fagonia, Moringa, Aerva*, and *Zygophllum* plants, indicating their superior ability for Ag absorption and concentration compared to the other plants.

Ebyan (18) found that *Fagonia, Moringa, Aerva*, and *Zygophllum* plants accumulated 26, 44, 40, and 15 µg.kg^{-1} of Ag, indicating that *Lotus sp*. and *Zilla sp*. have a greater capacity for Ag absorption than *Fagonia* and *Moringa*. Rashed (64) reported that *Aerva javanica* in Wadi Allaqi, Egypt, can absorb 70 µg.kg^{-1} of Ag in dry samples. *Zilla* sp. had an average of 97 µg.kg^{-1} Ag, higher than the value in Wadi Allaqi, while *Lotus* sp. values were similar. Bonanno (65) stated that *Phragmites australis* sp. absorbs <50 µg.kg^{-1} Ag, whereas *Zilla* sp. and *Lotus* sp. recorded 102 and 68 µg.kg^{-1} Ag, respectively, which is relatively higher.

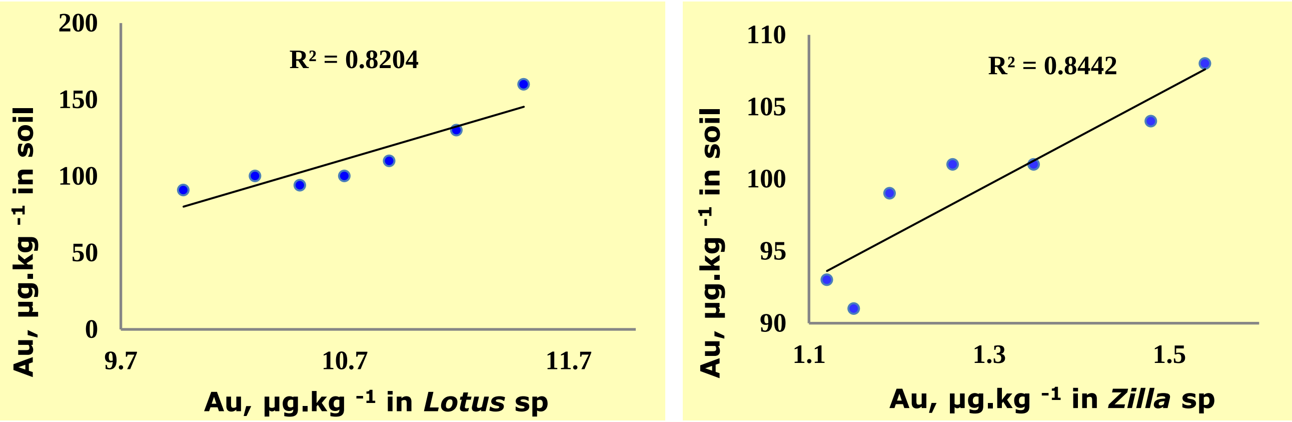

Figure 5: Correlation of Au concentration in plant species and their underlying soil.

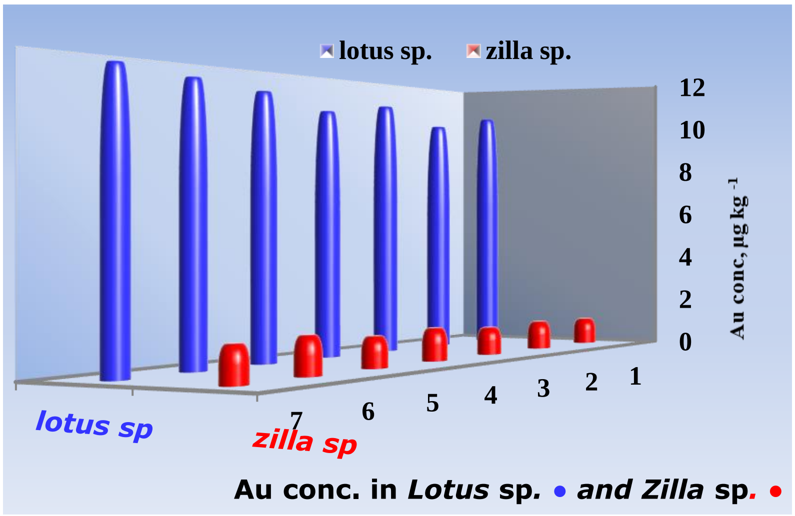

Figure 6: Histogram showing Au accumulation in *Lotus* sp. and *Zilla* sp. plant samples.

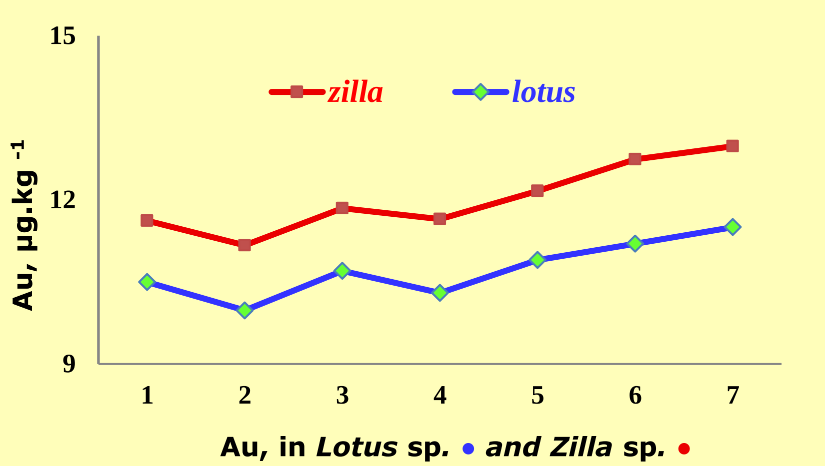

Figure 7: Histogram showing Au accumulation in *Lotus* sp. and *Zilla* sp. plant samples.

Khadija et al (66) found that *Rhazya stricta* plant can accumulate an average of nearly 70 µg.kg^{-1} of Ag. This falls within the range of 68 to 102 µg.kg^{-1} Ag in the current study. Reimann et al (63) demonstrated that *Lotus* sp. and *Zilla* sp. can uptake and retain Ag element at levels nine and thirteen times higher than the global average of 8 µg.kg^{-1} for silver in plants.

According to Chaney et al (67), hyperaccumulator plants have the ability to gather ten to 500 times the amount of an element compared to regular plants, making them ideal for phytoremediation. Therefore, *Lotus* and *Zilla* plants are ideal for studying and cleaning up silver using phytoremediation. The positive correlation between the concentration of Ag element in *Lotus* sp. and *Zilla* sp. and the soil beneath them implies that the source rocks may also contain minerals (Figure 8).

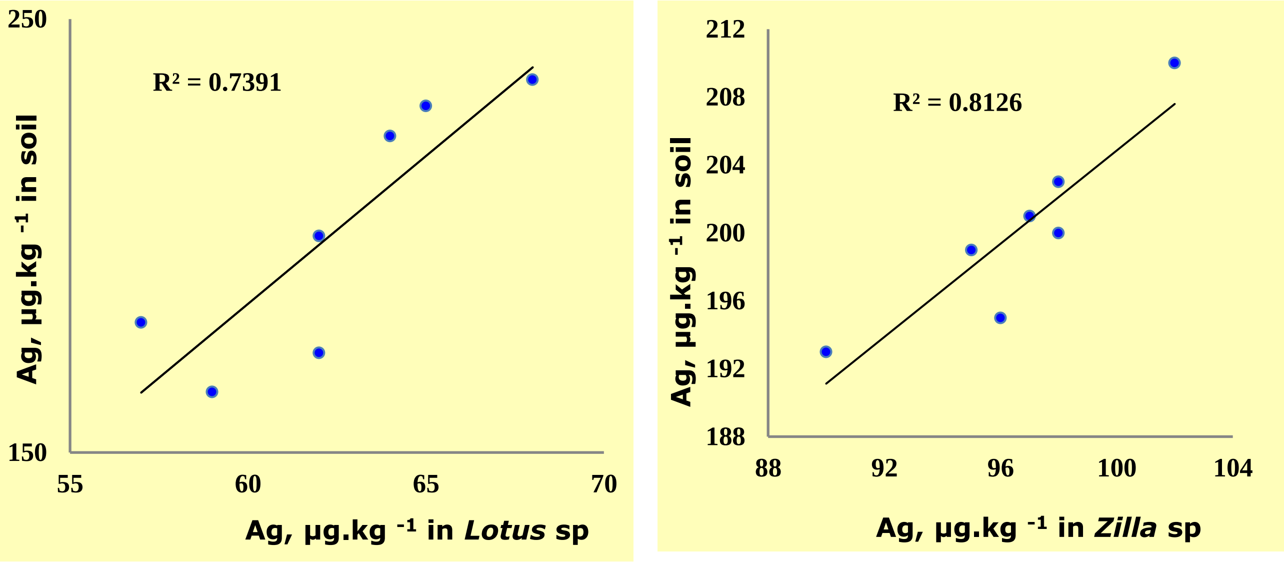

Figure 8: Correlation of Ag concentration in plants species and their underlying soil.

Figure 9 shows the concentration of Ag in two species, *Lotus* and *Zilla,* indicating that they can uptake and accumulate the silver element with nearly equal values, whereas Figure 10 shows the identical and homogenous absorption of Ag in the studied plant samples.

Several studies have investigated the transfer of Sb from soil to plants under natural or controlled conditions, finding that the absorption and retention of Sb by plants are greatly influenced by the oxidation states of Sb, type of soil, and species of plant (68-70).

Antimony is recognized as a significant toxic element by the European Union and global experts (71,72). Recent years have seen a rise in Sb pollution globally (73,74). *Lotus* sp. was found to have Sb concentrations ranging from 65 to 76 µg.kg^{-1} with an average of 70 µg.kg^{-1} (Table 1), higher than values reported in wild plants in the Eastern desert of Egypt (18). Reimann et al. (63) discovered that certain plants in Northern Europe, *Hylocomium splendens* and *Pleurozium schreberi,* can accumulate up to 0.06 µg.kg^{-1} of Sb in dry samples.

According to Bonanno (65), *Phragmites australis* can uptake Sb at a rate of 0.05 µg.kg^{-1}. *Hylocomium splendens, Pleurozium schreberi*, and *Phragmites* *australis* are able to store Sb levels ranging from 50 μg.kg^{-1} to 60 μg.kg^{-1} (63,65). Additionally, various edible plants have been detected with Sb content between 30-220 μg.kg^{-1} when grown in contaminated soils (75-79).

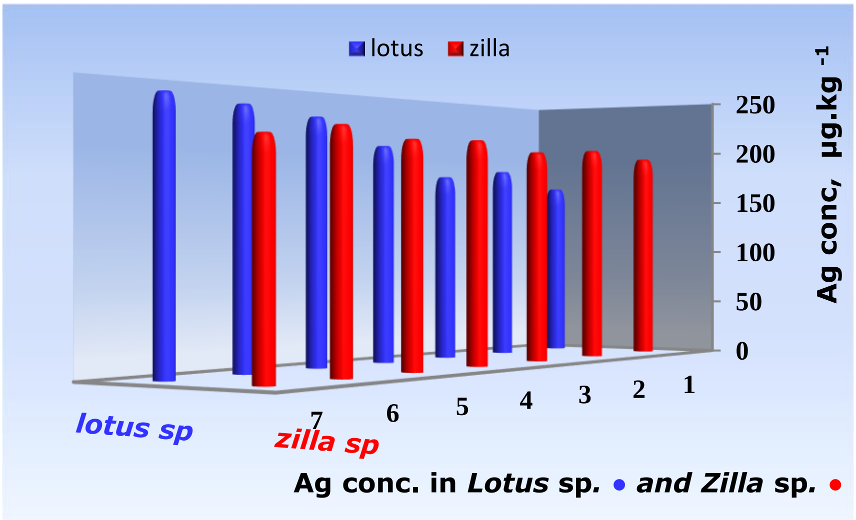

Figure 9: Histogram showing Ag accumulation in *Lotus* sp. and *Zilla* sp. plant samples.

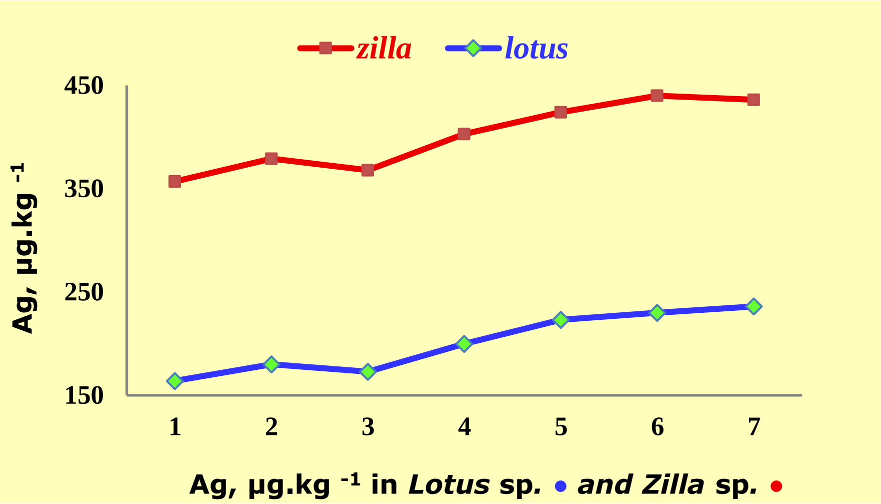

Figure 10: Histogram showing Ag accumulation in *Lotus* sp. and *Zilla* sp. plant samples.

Hockmann et al. (80) found *Lotus* sp. can accumulate Sb levels up to fifteen times higher than *L. perenne,* which had a concentration of 5 μg.kg^{-1}. Background Sb levels in plants range from 0.2 to 50 μg.kg^{-1} (47,48,82). In Losacio mine soil in Spain, various plant species had Sb concentrations: *Quercus rotundifolia* (13 μg.kg^{-1}), *Agrostis castellana* (60 μg.kg^{-1}), *Agrostis delicatula* (6 μg.kg^{-1}), *Anthoxanthum odoratum* (2 μg.kg^{-1}), *Carlina corymbosa* (30 μg.kg^{-1}), *Dactylis glomerata* (7 μg.kg^{-1}), *Daphne gnidium* (2 μg.kg^{-1}), *Daucus carota* (80 μg.kg^{-1}), *Lavandula stoechas* (46 μg.kg^{-1}), *Marrubium vulgare* (15 μg.kg^{-1}), *Rubus idaeus* (60 μg.kg^{-1}), *Santolina rosmarinifolia* (80 μg.kg^{-1}), and *Centaurea paniculata* (49 μg.kg^{-1}). These values are consistent with those reported by Casado et al. (47).

Reimann et al. (63) reported a WAP uptake of 10 μg.kg^{-1} for Sb. *Lotus* sp. can absorb and accumulate Sb seven times higher than the average uptake in plants worldwide. Both *Lotus* sp. and *Zilla* sp. have biological absorption coefficients (*BAC*) for Sb (Sbp/Sbs) of 0.33 and 0.15, respectively. Tschan et al. (83) noted that *BAC* is below 0.03. Leduc and Gardou (82) found similar *BAC* rates in plants from Sb-rich ore deposits in Vendée, France. High *BAC* values were recorded for *Lotus* sp. and *Zilla* sp. (82,83).

Behzad et al. (30) found that plant samples fall into the moderate category of hyperaccumulator plants. Their study (Figure 11) revealed a correlation for Sb between *Lotus* sp. and *Zilla* sp. and their corresponding soils. *Lotus* sp. showed a positive correlation with their underlying soil, while *Zilla* sp. exhibited a negative correlation. Casado et al. (47) noted that Sb levels in plants did not correlate with concentrations in soils. *Lotus* sp. was able to uptake and accumulate more Sb compared to *Zilla* sp. (Figure 12).

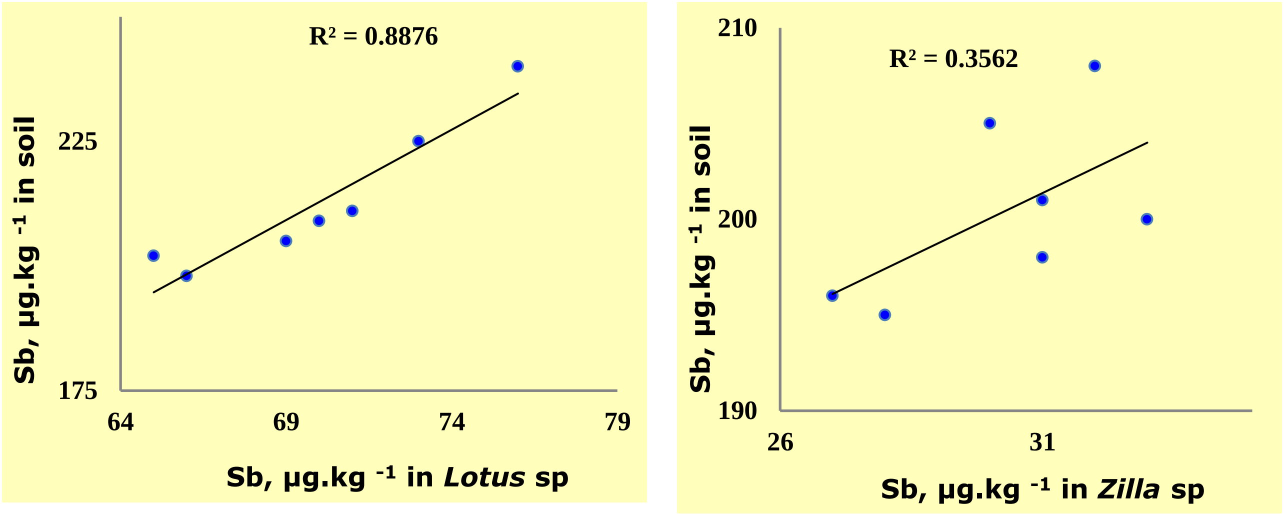

Figure 11: Correlation of Sb concentration in plant species and their underlying soils.

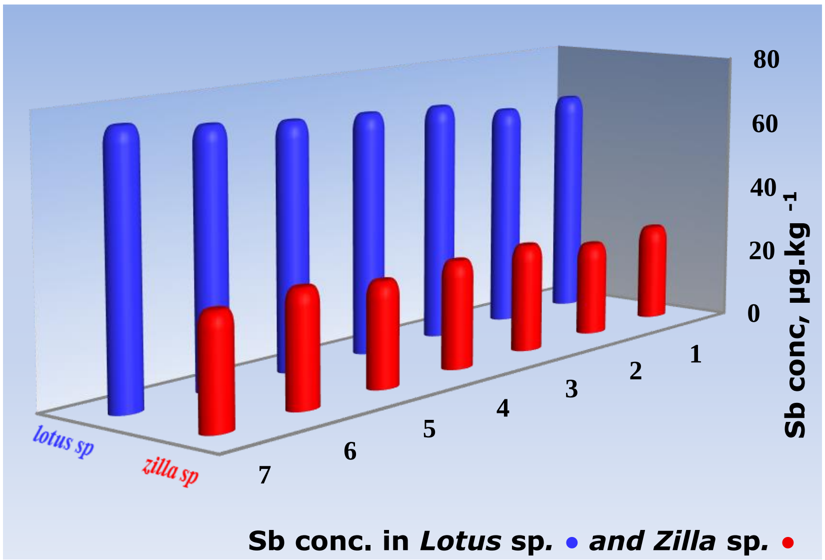

Figure 12: Histogram showing Sb accumulation in *Lotus* sp and *Zilla* sp. plant samples.

Chemical analysis of As in *Lotus* sp. showed a range of 1100-940 $\mu g.kg^{-1}$ (Table 1) with an average of 1011 $\mu g.kg^{-1}$. The As ratio (As p/As s) in *Lotus* sp. ranged from 0.55 to 0.47, with an average of 0.5. In *Zilla* sp., As contents ranged from 640 to 560 $\mu g.kg^{-1}$ with an average of 601 $\mu g.kg^{-1}$ (Table 2). The As ratio in *Zilla* sp. ranged from 0.32 to 0.28. Ebyan (18) reported a maximum As concentration of 300 $\mu g.kg^{-1}$ in *Zilla* sp. in the Gattar area, while the present study found levels twice as high. The data suggest that *Lotus* sp. absorbs and concentrates As more efficiently than *Zilla* sp. (Figure 13).

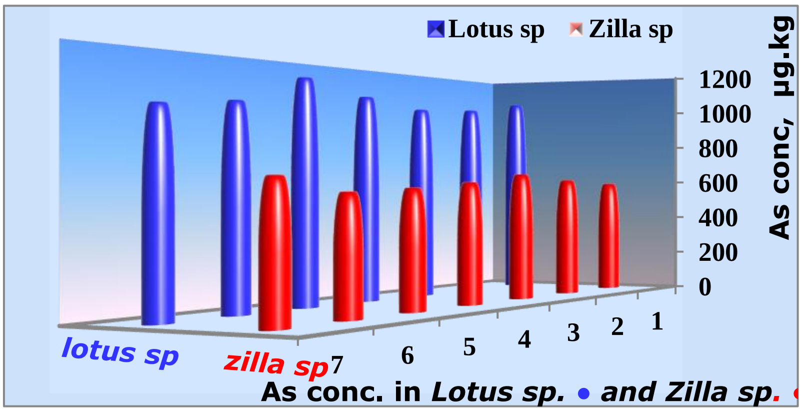

Figure 13: Histogram showing As accumulation in *Lotus* sp. and *Zilla* sp. plant samples.

Rashed (64) found that *Aerva* sp. near the gold mine at wadi Allaqi, Eastern Desert, Egypt, has the ability to absorb As at 400 µg.kg^{-1}and far from the mine with 150 µg.kg^{-1}. Both plant species in the present study showed one- and two-times higher values than those recorded by Rashed (64). The concentration of As in plants is usually lower than 1000 µg.kg^{-1} dry weight in different plant species growing on As-contaminated soil (84,85). Wild plant species that naturally inhabit arsenic-contaminated areas could likely show high potential for arsenic uptake (86). Plants can be classified for arsenic uptake into three basic groups: excluders, indicators, and accumulators (86,87). Accumulator plants for arsenic element have a threshold arsenic content above 1,000 µg.kg^{-1} (Dw). Prasad (88) mentioned that the most arsenic accumulator species were *Amaranthus bilitoides*; 800-120000 µg.kg^{-1}, *Chamaemelum fuscatum,* 7000-23000 µg.kg^{-1}, *Convolvulus arvensis*, 100-26000 µg.kg^{-1}, *Cynodon dactylon*, 200-40000 µg.kg^{-1}, and *Malva nicaensis*, 1000-28000 µg.kg^{-1}. The *Lotus* sp. in the present study is considered an accumulator plant for arsenic, according to the Prasad report.

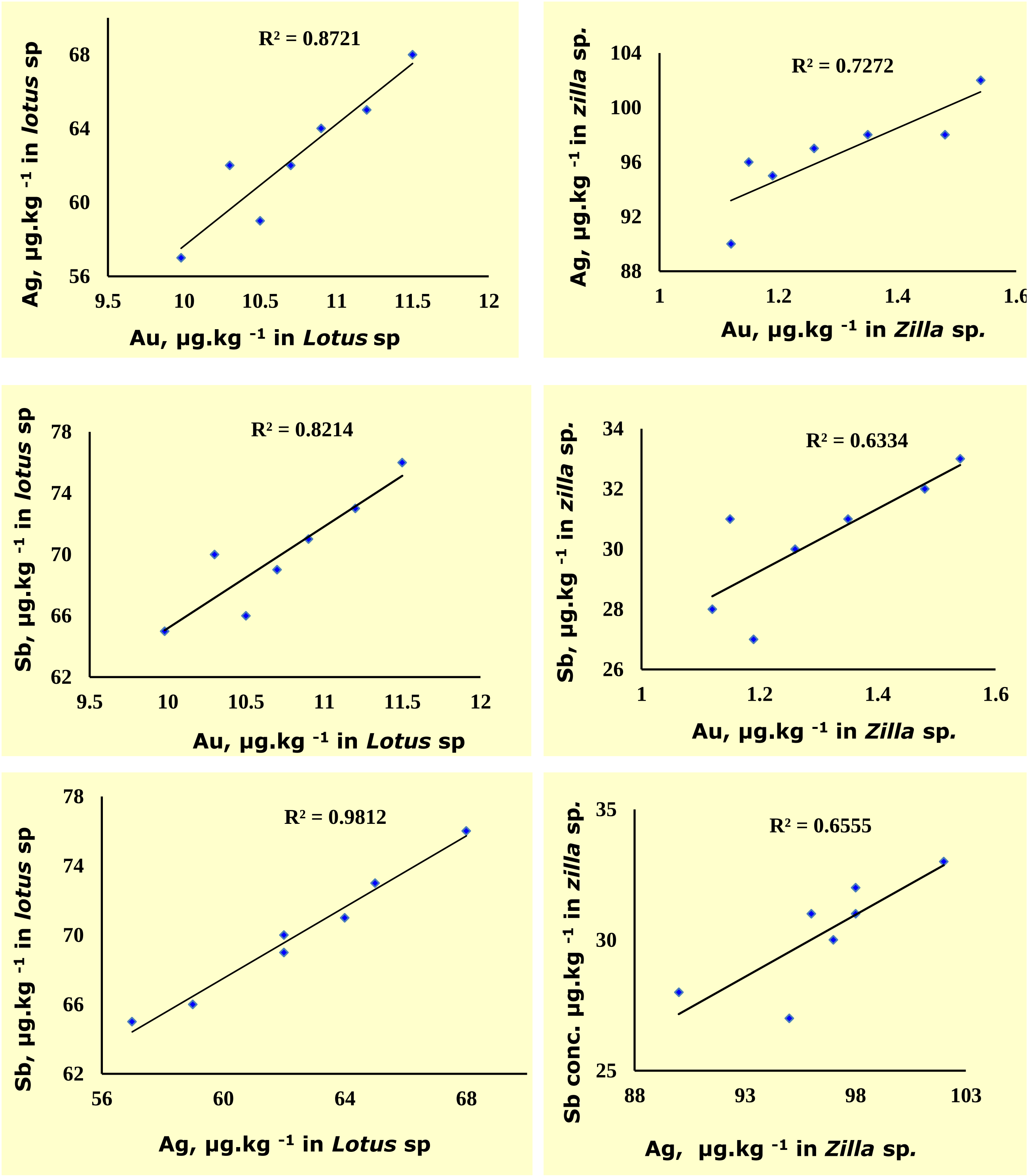

Figure 14: Strong positive and positive correlation between Au, Ag, and Sb in *Lotus* sp. and *Zilla* sp. samples.

3.4. The Relationship Between Gold and Its Pathfinder

In the present study, there is a clear correlation between Au, Ag and Sb in *Lotus* and *Zilla* species, as indicated in Figure 14. The presence of strong positive correlation between Au and Ag, Au and Sb and Ag and Sb, in *Lotus* plants. Also, there is a positive correlation between Au and Ag, Au and Sb, and Ag and Sb, in *Zilla* plant. It can be concluded from the previous discussion that *Lotus* sp. can uptake and accumulate Au, Sb and As elements higher than *Zilla* sp. On the other hand, *Zilla* sp. can uptake and accumulate Ag elements more than *Lotus* sp. (Figure 15).

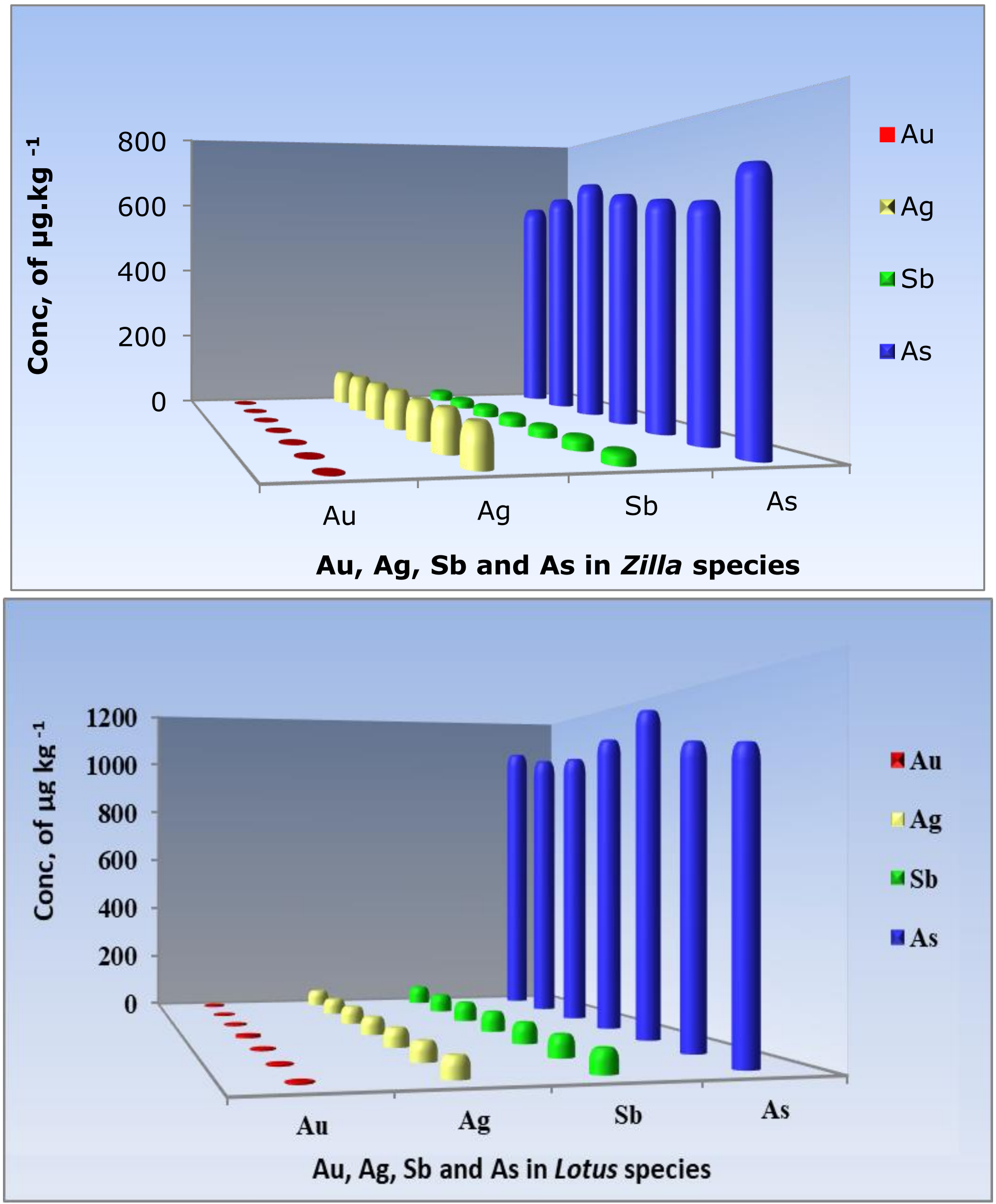

Figure 15: Frequency curves of Au, Ag, Sb, and As elements; µg.kg^{-1} in two plants species.

4. CONCLUSIONS

The high Au content in plants and its associating soil, in addition to the moderate to strong correlation between gold and its pathfinders, could be considered an indication for the presence of gold mineralization in the adjacent rocks of El-Missikat area, which may be confirmed by the positive correlation between Au in the plants and in the underlying soil. Also, Lotus sp. can concentrate Au more than Zilla sp. For silver exploration and phytoremediation, researchers can use Lotus and Zilla plants. The Lotus sp. can uptake and accumulate Sb element more than the Zilla sp., so, it is useful for remediation processes of Sb as a toxic element. We conclude that we can utilize these plants for both exploration and remediation procedures.

Availability of data and materials

I clarify the availability of data and materials after receiving the acceptance from the journal.

Consent to participate

I declare our agreement to participate in this work.

Consent to publish

I declare our agreement to publish this work.

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No potential conflict of interest was reported by the author(s).

Ethical approval statement
All authors attest to the uniqueness of this paper, its non-publication in any form or language (in part or in whole), and its simultaneous submission to multiple publications for consideration. I also assert unequivocally that I have presented the results accurately, honestly, and without any fabrication, falsification, or data modification (including image-based manipulation).

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