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Biogeochemical Studies in Zinc Deposit Areas of Zawar Mines, Rajasthan, India

Y D TIAGI and N C AERY
Department of Botany, SBSH, University of Udaipur, Udaipur 313001

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Several plant species in the study area accumulated metallic elements in a reproducible manner and deserve the rank of metal accumulators. Plant species with comparatively higher relative accumulation (concentration in plant ash/ concentration in the soil) for the metal zinc were *Impatiens balsamina*, *Acanthospermum hispidum*, *Melhania futteyporensis* and *Triumfetta pentandra* with relative accumulation values of 5.08, 4.38, 4.17, 4.52, respectively.
Herbs accumulated higher concentrations of the elements than the shrubs and trees. Different plant parts varied in their capacity to accumulate different elements. Leaves accumulated much more of zinc while stems accumulated more of lead, copper and cadmium. Certain plant species showed very high positive correlations for zinc content in the plant body and the soil in which they grew. This points to a striking regularity of metal uptake by the plants depending upon the soil concentrations. *Impatiens balsamina* which is restricted in its distribution exclusive'y to metal-rich deposits in the mining area and is the "Characteristic species" acumulates appreciable quantities of the metals, especially zinc as high as 12141 ppm and hence, could be regarded as a local indicator for a zinc deposit.

Key Words: Biogeochemistry, Metal accumulators, Zinc accumulators, Plant soil relationship

Introduction

Botanical methods of prospecting for minerals include geobotanical and biogeochemical techniques. Though, geobotany and biogeochemistry are considered as two separate disciplines, they are, in fact closely linked as the type of vegetation and its elemental contents are influenced both by the chemical composition of the soil and the physical features of the environment. Biogeochemical methods of metal prospecting are based on the fact that an element in the underlying substratum will be accumulated by the plant in a reproducible manner and consequently will indicate anomalies in the former. Biogeochemical methods of mineral exploration have been successfully employed in various countries (Warren & Delavault 1949, Warren et al. 1952, 1955, Cannon 1957, 1960, 1963, 1964, Thaler 1962, Nicolls et al. 1964, Brooks & Lyon 1966, Brooks 1968, Yates et al. 1974, Nicolas & Brooks 1969, Brooks et al. 1977, Brooks & Wither 1977, Wither & Brooks

1977, Brooks & Radford 1978, Lee et al. 1977 and Malyuga 1964).

In view of the definite success of the above techniques in metal prospecting, a systematic application of biogeochemical and geobotanical methods in mineral exploration is all the more pertinent in India (cf. Tiagi & Singh 1973, Aery 1977, 1978, Venkatesh 1964, 1966, Gandhi & Aswathanarayana 1975).

Study Area

The metalliferous Zawar area (about 67 sq. km) is situated between the latitudes 24°18′ 48″ and 24°22′48″ N, and longitudes 73°40′ and 73°45′24″ E, at a distance of about 43 km to the south of Udaipur township. The general elevation of the area is 377.7 m above MSL. It is a rugged terrain characterised by steep-sided ridges that rise from about 90–300 m above the intervening hilly lowlands and narrow valleys.

The various hills of this area which contain zinc and lead deposits are Mochia, Balaria, Zawar Mala, Baroi and Bawa of which the first two have been intensively studied by us (figure 1). The geology and distribution of old workings were already described by Stretzek and Srikantan (1965). The rocks are a part of the Aravalli system of Middle Pre-Cambrian age—a thick series of phyllites and slates with sub-ordinate intercalated dolomites, quartzites and conglomerates, or their further metamorphosed equivalents (Heron 1953). Dolomite is intruded by dolorite dikes.

The ore mineralization is mainly confined to siliceous dolomites. The metallic minerals identified in the order of abundance are: Sphalerite (zinc sulfide), Galena (lead sulfide), Pyrite (ferrous sulfide), Arsenopyrite (FeS_2 $FeAS_2$), Chalcopyrite ($CuFeS_2$) and Pyrrhotite (Fe_5S_6 to $Fe_{16}S_{17}$).

The area has a tropical monsoon continental type of climate. During the study period (1975–1978), the average temperatures were 42°C (maximum) and 3.5°C (minimum), and average annual rainfall was 563.72 mm. There is little soil cover and the rocks are well exposed. The vegetation is typical of those growing under tropical semi-arid conditions. The hills are scantily forested. The trees are small and generally less than 30.48 cm in diameter.

Samples and Methods

Plants and soil samples were collected from the mineralized, halo- and non-mineralized zones and from the old mine workings and mine dumps. The area was thoroughly studied to determine the abundance and distribution of most prominent plant species. Determination of the abundance of the plants was of great importance since it is essential that those selected for the survey should be obtainable at all the sampling sites throughout the whole area; otherwise, there would be gaps in the sampling network. Several species were selected on the basis of abundance in order to ensure that there would be at least one of the species at each sampling point.

Sampling was carried out along a transect laid at right angles to the strike of the ore deposits. Plants were sampled for leaves and young twigs, at the time of blooming. Care was taken that the material be young enough to have gone through the main process of mineral accumulation and yet, be not so old that it reached a stage of senescence, when the bulk of plant material comprises nearly dead cells which have lost varying portions of their mineral constituents.

About 100 g of fresh material (leaves and twigs) was collected which was sufficient to provide about 10–30 g of dry material. Plant samples were collected at various points around the shrubs and trees on the transect. Soil samples were collected around the base of plants collected for investigation.

Plant and soil samples were digested according to the routine methods (Jackson 1967,

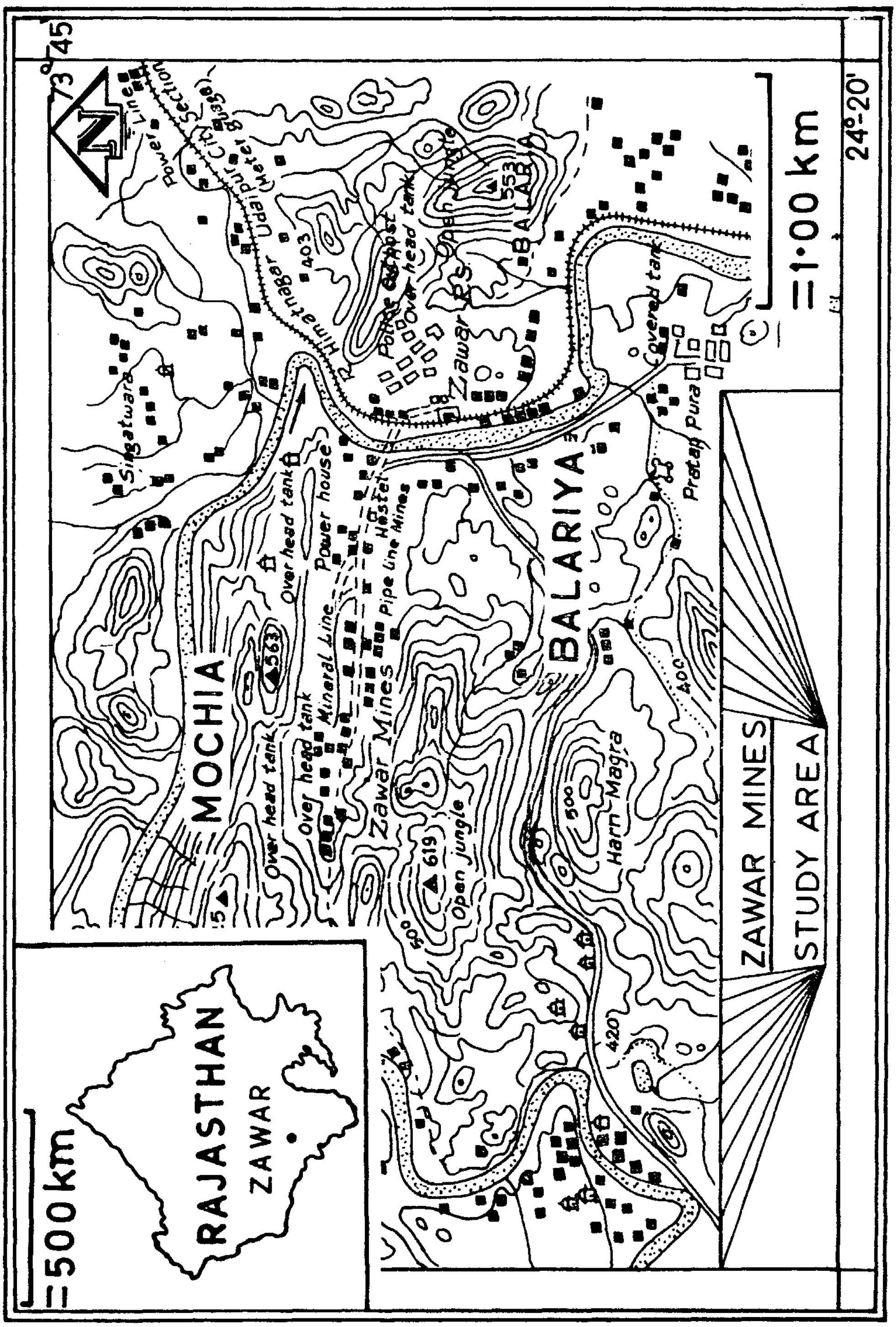

Figure 1 Topographical Map of the study area; a map of Rajasthan, showing the location of Zawar is inserted. Symbols used in the map are the standard ones used by the Survey of India. Study sites, the Mochia and Balaria hills which respectively extend to about 4 km and 1.8 km in east-west direction, are indicated

Table 1 *Zinc concentrations in the soils and the ash of certain plant species of Zawar mines*

S. No.	Name of the plant	Organ	% Ash	Concentration in the plant ash (ppm)				Concentration in soils (ppm)			
				Median	AM	GM	Range	Median	AM	GM	Range
1	2	3	4	5	6	7	8	9	10	11	12
1.	*Acanthospermum hispidum*	L	11.87	4064	4760	4493	3277– 8129	915	1083	1025	746–1815
		S	7.52	2923	3338	3190	2393– 5353				
2.	*Aegle marmelos*	L	12.89	1237	1452	1299	737– 2482	1006	1231	1148	770–1900
		S	8.45	889	1015	903	474– 1657				
3.	*Celosia argentea*	L+Fl	13.31	2456	3478	3120	2066– 7550	1100	1298	1174	750–2700
		S	9.25	1845	2507	2258	1513– 5191				
4.	*Crotalaria linifolia*	L	9.35	3689	4034	3918	2941– 5914	1220	1350	1311	975–1980
		S	5.80	2275	2569	2515	2056– 3706				
5.	*Dyerophytum indicum*	L	9.58	4175	4294	4236	3549– 5970	1180	1174	1158	979–1635
		S	5.32	2631	2590	2557	2161– 3571				
6.	*Grewia flavescens*	L	12.81	3207	3656	3544	2731– 5446	1250	1430	1389	1003–2100
		S	7.31	2602	2825	2743	2053– 4102				
7.	*Hemigraphis latebrosa*	L	19.74	2051	2489	2329	1644– 4599	800	948	893	600–1700
		S	6.25	1445	1745	1638	1211– 3240				
		R	8.39	1121	1393	1291	836– 2623				
8.	*Impatiens balsamina*	L	13.59	6201	6648	6482	5149–12141	1227	1308	1274	1000–2402
		S	8.93	5362	5742	5591	4480–10531				
		R	11.55	3425	3644	3467	2951– 6549				
		Fl+Fr	6.21	5652	6032	5879	4754–10958				

9. *Lannea coromandelica*	L	7.30	1871	1924	1945	1464–2669	1271	1320	1298	970–1811
	S	5.61	839	848	834	641–1168				
10. *Lepidagathis trinervis*	L	13.92	3070	3191	3131	2320–4166	1369	1413	1388	1050–1850
	S	3.37	2121	2189	2149	1543–2804				
11. *Lindenbergia muraria*	L	6.89	6966	8138	7732	5515–15384	1839	2059	1958	1396–3885
	S	4.06	6157	6826	6534	4802–12341				
12. *Melhania futteyporensis*	L	8.27	5274	5367	5301	4038–6444	1212	1288	1270	978–1565
	S	4.55	1406	1484	1468	1142–1835				
	Fl+Fr	10.20	3381	3419	3375	2519–4075				
13. *Nyctanthes arbor-tristis*	L	8.53	1313	1831	1594	876–3536	987	1234	1136	700–2115
	S	6.82	1015	1296	1163	722–2429				
14. *Triumfetta pentandra*	L	5.51	6669	7108	6817	4537–11796	1471	1572	1508	1000–2625
15. *Wrightia tinctoria*	L	10.17	1381	1864	1591	830–5339	744	1000	859	464–2795
	S	5.12	930	1232	1047	488–3427				

L = Leaf; *S* = Stem; *AM* = Arithmetic mean; *GM* = Geometric mean; *R* = Root

Table 2 *Lead concentration in the soil and the ash of certain plant species of Zawar mines*

S. No.	Name of the plant	Organ	% Ash	Concentration in the plant ash (ppm)				Concentration in soils (ppm)			
				Median	AM	GM	Range	Median	AM	GM	Range
1	2	3	4	5	6	7	8	9	10	11	12
1.	*Acanthospermum hispidum*	L	11.87	136	162	151	104– 304	175.25	190.14	183.5	145.16–345.75
		S	7.52	332	373	346	211– 640				
2.	*Aegle marmelos*	L	12.89	129	154	144	77– 233	108.17	126.36	117.7	65.70–190.50
		S	8.45	232	281	258	132– 453				
3.	*Celosia argentea*	L+Fl	13.31	150	210	190	127– 457	125.00	168.81	153.6	100.75–350.60
		S	9.25	258	383	340	210– 893				
4.	*Crotalaria linifolia*	L	9.35	207	215	210	149– 302	140.45	149.11	145.3	102.75–218.00
		S	5.80	361	399	389	274– 558				
5.	*Dyerophytum indicum*	L	9.58	313	318	314	250– 433	328.75	335.59	330.7	248.43–450.38
		S	5.32	1033	1030	1020	812–1353				
6.	*Grewia flavescens*	L	12.81	175	202	195	156– 314	140.95	161.77	158.1	135.00–250.90
		S	7.31	324	376	365	311– 560				
7.	*Hemigraphis latebrosa*	L	19.74	204	249	238	181– 463				
		S	6.25	523	662	618	460–1282	85.15	106.95	99.5	70.60–205.35
		R	8.39	572	726	675	500–1374				
8.	*Impatiens balsamina*	L	13.59	385	436	421	311– 852	230.15	262.20	252.6	185.00–525.50
		S	8.93	1042	1184	1143	842–2354				
		R	11.55	954	1076	1036	778–2168				
		Fl+Fr	6.21	307	352	333	221– 774				

9.	*Lannea coromandelica*	L	7.30	222	230	226	181– 366	206.69	218.65	213.4	169.80–360.65
		S	5.61	434	455	445	356– 735				
10.	*Lepidagathis trinervis*	L	13.92	225	235	230	179– 313	186.15	199.78	197.2	154.75–245.30
		S	3.37	585	622	615	489– 756				
11.	*Lindenbergia muraria*	L	6.89	968	1094	1014	584–2121	255.86	295.03	273.1	156.77–572.40
		S	4.06	3974	4454	4169	2527–8004				
12.	*Melhania futteyporensis*	L	8.27	534	512	493	241– 677				
		S	4.55	1112	1093	1026	351–1587	267.49	260.22	244.2	85.97–376.17
		Fl+Fr	10.20	261	250	240	107– 325				
13.	*Nyctanthes arbor-tristis*	L	8.53	213	275	255	166– 471	166.12	207.41	192.6	130.25–365.15
		S	6.82	359	431	404	274– 711				
14.	*Triumfetta pentandra*	L	5.51	509	538	516	349– 910	317.68	337.63	324.4	225.10–568.19
15.	*Wrightia tinctoria*	L	10.17	315	433	387	231–1007	122.46	163.37	147.8	90.85–350.88
		S	5.12	971	1328	1177	664–3140				

L=Leaf; *S*=Stem; *R*=Root; *Fl*=Flower; *Fr*=Fruit; *AM*=Arithmetic mean; *GM*=Geometric mean

Table 3 *Cadmium concentrations in the soils and ash of certain plant species of Zawar mines*

S. No.	Name of the plant	Organ	% Ash	Concentration in the plant ash (ppm)				Concentration in soils (ppm)			
				Median	AM	GM	Range	Median	AM	GM	Range
1	2	3	4	5	6	7	8	9	10	11	12
1.	*Acanthospermum hispidum*	L	11.87	27.37	33.39	30.98	21.90– 61.07	27.40	32.14	30.03	20.65–60.60
		S	7.52	91.17	105.14	95.81	57.12–197.95				
2.	*Aegle marmelos*	L	—	—	—	—	— —	—	—	—	— —
		S	—	—	—	—	— —				
3.	*Celosia argentea*	L+Fl	13.31	52.59	77.10	66.42	30.05–187.82	17.50	27.47	23.63	10.95–61.95
		S	9.25	91.89	141.31	121.20	55.13–360.54				
4.	*Crotalaria linifolia*	L	9.35	218.18	252.57	246.67	202.67–371.65	56.25	64.90	63.39	52.25–95.20
		S	5.80	365.51	420.76	411.90	344.82–603.44				
5.	*Dyerophytum indicum*	L	9.58	106.99	108.10	106.40	88.72–151.35	30.95	30.97	30.56	25.34–42.50
		S	5.32	263.15	282.88	277.60	201.12–375.93				
6.	*Grewia flavescens*	L	12.81	21.45	22.31	21.61	15.60– 33.94	10.75	11.26	10.86	7.50–17.05
		S	7.31	40.34	43.68	42.54	30.77– 67.69				
7.	*Hemigraphis latebrosa*	L	19.74	6.92	7.67	7.14	3.85– 12.83	9.25	10.62	9.53	4.90–20.05
		S	6.25	42.42	47.68	43.79	24.00– 84.00				
		R	8.39	55.12	56.89	53.80	30.98–106.07				
8.	*Impatiens balsamina*	L	13.59	139.58	159.78	154.1	121.41–309.04	24.34	28.02	26.81	20–57
		S	8.93	320.54	365.16	350.5	256.43–732.36				
		R	11.55	343.07	380.19	365.6	277.92–735.93				
		Fl+Fr	6.21	150.96	162.50	157.4	112.72–289.85				
9.	*Lannea coromandelica*	L	—	—	—	—	— —	—	—	—	— —
		S	—	—	—	—	— —	—	—	—	— —

10.	*Lepidagathis trinervis*	L	13.92	—	—	—	— —	—	—	—	— —
		S	—	—	—	—	— —	—	—	—	— —
11.	*Lindenbergia muraria*	L	6.89	30.83	38.72	34.22	23.22–101.59	8.36	10.94	9.64	6 – 29
		S	4.06	139.28	172.59	154.2	108.37–443.34				
12.	*Melhania futteyporensis*	L	8.27	97.94	108.55	93.07	30.22–302.29	19.00	22.10	19.32	8 – 60
		S	4.55	228.57	246.27	214.1	65.93–626.37				
		Fl+Fr	10.20	123.77	131.66	114.8	39.21–343.13				
13.	*Nyctanthes arbor-tristis*	L	—	—	—	—	— —	—	—	—	— —
		S	—	—	—	—	— —				
14.	*Triumfetta pentandra*	L	5.51	148.81	164.02	156.50	107.98–276.76	31.87	35.75	33.93	22–61
15.	*Wrightia tinctoria*	L	10.17	44.24	60.74	28.26	4.91–196.65	7.50	9.46	6.15	0.55–30.01
		S	5.12	156.24	163.08	75.61	14.64–205.07				

L=Leaf; *S*=Stem; *R*=Root; *Fl*=Flower; *Fr*=Fruit; *AM*=Arithmetic mean; *GM*=Geometric mean;

Table 4 *Copper concentrations in the soils and the ash of certain plant species of Zawar mines*

S. No.	Name of the plant	Organ	% Ash	Concentration in the plant ash (ppm)				Concentration in soils (ppm)			
				Median	AM	GM	Range	Median	AM	GM	Range
1	2	3	4	5	6	7	8	9	10	11	12
1.	*Acanthospermum hispidum*	L	11.87	98.18	121.24	113.2	78.68– 231.42	32.82	39.95	37.89	25.21– 75.60
		S	7.52	378.90	448.50	420.6	285.37– 798.45				
2.	*Aegle marmelos*	L	12.89	61.86	72.68	64.10	31.03– 130.33	44.52	49.53	45.35	25.95– 80.15
		S	8.45	178.33	218.50	191.5	106.46– 377.96				
3.	*Celosia argentea*	L+Fl	13.31	112.69	158.90	143.4	90.15– 328.69	22.45	29.69	26.85	16.75– 60.50
		S	9.25	302.70	402.27	363.5	242.16– 821.08				
4.	*Crotalaria linifolia*	L	9.35	96.25	101.22	98.70	69.51– 141.71	25.25	26.78	26.23	17.05– 36.0
		S	5.80	157.75	166.11	164.4	137.93– 211.20				
5.	*Dyerophytum indicum*	L	9.58	113.08	117.10	117.0	83 – 167	34.65	35.91	35.28	26.12– 50.22
		S	5.32	559.20	594.28	578.4	406 – 902				
6.	*Grewia flavsecens*	L	12.81	81.93	92.08	89.5	71.01– 137.18	39.75	40.42	39.62	32.0 – 55.35
		S	7.31	222.23	231.61	229.1	191.46– 304.29				
7.	*Hemigraphis latebrosa*	L	19.74	56.47	75.74	68.85	50.06– 155.32	20.92	27.31	24.88	17.10– 55.40
		S	6.25	375.00	502.72	362.3	321.60–1046.40				
		R	8.39	758.63	980.62	895.4	640.64–2029.19				
8.	*Impatiens balsamina*	L	13.59	97.49	106.99	103.20	77.26– 206.03	32.25	36.28	34.89	25.30– 72.50
		S	8.93	327.54	353.00	340.2	263.15– 682.53				
		R	11.55	1861.47	2040.75	1971.00	1476.62–3956.70				
		Fl+Fr	6.21	257.08	282.66	272.6	209.33– 563.60				
9.	*Lannea coromandelica*	L	7.30	41.07	70.34	29.89	3.42– 260.11	40.52	70.35	38.56	20.10– 75.11
		S	5·61	124.74	197.26	124.5	10.33– 721.71				

10.	*Lepidagathis trinervis*	L	13.92	150.85	157.63	154.50	118.53– 215.51	31.45	34 23	33.44	27.43– 49.45
		S	3.37	1318.17	1329.55	1317.0	1016.0 –1810.0				
11.	*Lindenbergia muraria*	L	6.89	232.21	239.43	231.10	134.25– 348.32	59.82	61.33	59.61	35.66– 88.43
		S	4.06	432.26	445.12	428.70	246.30– 652.70				
12.	*Melhania futteyporensis*	L	8.27	255.36	258.50	242.1	108.82– 362.75	30.59	34.68	27.10	16.54– 47.18
		S	4.55	1221.97	1330.00	1243.0	558.24–1876.92				
		Fl+Fr	10.20	262.69	285.80	271.0	127.45– 396.07				
13.	*Nyctanthes arbor-tristis*	L	8.53	74.43	106.03	92.87	49.23– 203.98	24.61	35.96	31.75	18.20– 70.15
		S	6.82	170.42	253.18	223.0	139.27– 498.46				
14.	*Triumfetta pentandra*	L	5.51	415.06	446.19	425.4	276.76– 748.63	54.86	60.12	57.35	39.50–100.9
15.	*Wrightia tinctoria*	L	10.17	78.65	108.16	89.39	49.16– 349.06	65.65	83.36	72.36	40.01–250.7
		S	5.12	535.15	668.74	549.60	253.90–1962.66				

L=Leaf; *S*=Stem; *R*=Root; *Fl*=Flower; *Fr*=Fruit; *AM*=Arithmetic mean; *GM*=Geometric mean

Brooks 1972). The metal contents of the digested samples were determined on Atomic Absorption Spectrophotometer (Varian Techtron 1200, Digital Readout; CZ AAS-1).

Results and Discussion

Elemental Concentrations in Soils and Vegetation (tables 1-4) : In a preliminary survey, a number of plant species were tested for their elemental concentrations. It was found that the species having high constancy and fidelity values, i.e., the "Characteristic species" also showed higher concentrations of the sought for elements and were selected for further analytical work. Consequently the results of only those species have been discussed which showed high accumulation for metals studied.

It was also revealed that the concentrations of all the elements studied were log-normally distributed in soils and vegetation as suggested by Ahrens (1954) and Tipton and Cook (1963). The only exceptions were, *Lannea coromandelica* and *Dyerophytum indicum* for zinc. Liebscher and Smith (1968) have suggested that essential elements were normally distributed and that non-essential elements had a log-normal distribution. Since copper and zinc are essential elements, the above assumption apparently does not apply at least to the plants investigated in the present work. Considering the above, log-transformations of the original data were done which normalised the original data and all further calculations were done with these log-transformed values.

The concentration of a particular element varies in different organs of the same plant species as reported by several earlier workers (Warren et al. 1952, Carlisle & Cleveland 1958, Nicolas & Brooks 1969, Keith 1968, Lounamaa 1956, and Yates et al. 1974). Warren et al. (1952) proposed that only those organs of a plant species should be sampled which can (i) most readily be collected, (ii) most easily be analysed, and (iii) which respond most readily to anomalous conditions. We observed that leaves and twigs of trees and herbs are the most readily collected organs and can be most easily analysed. Although leaves are easier to pulverize, their ash contents are higher in comparison to those of twigs (tables 1-4).

Our studies also show that different plant organs show varying elemental content. While twigs concentrated more of copper, lead and cadmium, leaves contained more of zinc (tables 1-4).

The concentration of zinc, lead, cadmium and copper in stems and leaves of certain plant species show strong positive correlation (table 5). These data indicate that the amount of most elements in stems and leaves are strongly interdependent and that in searching

Table 5 *Results of correlations between the amounts of elements in stems and leaves of certain plant species of Zawar mines*

S. No.	Name of the plant	Zn	Pb	Cd	Cu
1.	*Acanthospermum hispidum*	S**	S**	S**	S**
2.	*Aegle marmelos*	S**	S**	—	S**
3.	*Celosia argentea*	S**	S**	S**	S**
4.	*Crotalaria linifolia*	S*	S**	S**	S
5.	*Dyerophytum indicum*	S*	S*	S*	S**
6.	*Grewia flavescens*	S**	S**	S**	S*
7.	*Hemigraphis latebrosa*	S*	S**	S**	NS
8.	*Impatiens balsamina*	S**	S**	S**	S**
9.	*Lannea coromandelica*	S*	S**	—	PS
10.	*Lepidagathis trinervis*	S*	S**	—	S**
11.	*Lindenbergia muraria*	S**	S**	S**	S**
12.	*Melhania futteyporensis*	S**	S**	NS	S**
13.	*Nyctanthes abror-tristis*	S**	S**	—	S*
14.	*Wrightia tinctoria*	S*	S**	S**	S**

NS = Not significant; *PS* = Probably significant; *S* = Significant; *S** = Highly significant; *S*** = Very highly significant; — = Element not detected

Table 6 *Relative accumulation of different elements in certain plant species of Zawar mines*

S. No.	Name of the plant	Organ	Relative accumulation (Mean plant ash concentration/Mean soil concentration)				
			Zinc	Lead	Cadmium	Copper	Iron
1.	*Acanthospermum hispidum*	L	4.38	0.82	1 03	2.98	0.16
		S	3.11	1.88	3.19	11.10	0.08
2.	*Aegle marmelos*	L	1.13	1.22	—	1.41	0.(8
		S	0.78	2.19	—	4.22	0.06
3.	*Celosia argentea*	L	2.65	1.23	2.81	5.34	0.23
		S	1.92	2.21	5.12	13.53	0.15
4.	*Crotalaria linifolia*	L	2.98	1.44	3.89	3.76	0.13
		S	1.91	2.67	6.49	6.26	0.09
5.	*Dyerophytum indicum*	L	3.65	0.94	3.48	3.31	0.26
		S	2.20	3.08	9.08	16.39	0.13
6.	*Grewia flavescens*	L	2.55	1.23	1.98	2.25	0.18
		S	1.97	2.30	3.91	5.78	0.09
7.	*Hemigraphis latebrosa*	L	2.60	2.39	0.74	2.76	0.07
		S	1.83	6.21	4.59	14.56	0.58
		R	1.44	6.78	5.64	35.98	—
8.	*Impatiens balsamina*	L	5.08	1.66	5.74	2.95	0.32
		S	4.38	4.52	13.07	9.75	0.18
		R	2.72	4.10	13.63	56.49	—
		Fl+Fr	4.61	1.31	5.87	7.81	—
9.	*Lannea coromandelica*	L	1.49	1.05	—	1.29	0 16
		S	0.64	2.08	—	3.22	0.11
10.	*Lepidagathis trinervis*	L	2.25	1.16	—	4.62	0.22
		S	1.54	3.11	—	39.38	0.15
11.	*Lindenbergia muraria*	L	3.94	3.71	3.54	3 87	0.53
		S	3.33	15.26	15.99	7.19	0.25
12.	*Melhania futteyporensis*	L	4.17	2.01	4.81	8.93	1.10
		S	1.15	4.20	11.08	45.86	0.07
		Fl+Fr	2.65	0.98	5.14	10.00	—
13.	*Nyctanthes arbor-tristis*	L	1.40	1.32	—	3.11	0.15
		S	1.02	2.09	—	7.02	0.12
14.	*Triumfetta pentandra*	L	4.52	1.59	4.61	7.41	0.39
15.	*Wrightia tinctoria*	L	1.85	5.10	4.59	1.23	0.31
		S	1.21	7.96	12.29	7.59	0.18

L=Leaf; *S*=Stem; *R*=Root; *Fl*=Flower; *Fr*=Fruit for differences in elemental content of plants, either stems alone or leaves alone could be used. Since leaves accumulate more of zinc and stems more of lead, cadmium and copper, it would be advisable to sample leaves and stems, respectively, while prospecting for these metals. However, our findings are in sharp contrast to those of Keith (1968) and Warren et al. (1952) who reported comparatively higher accumulation of zinc in stems than leaves.

Plant-Soil Relationship

The correlation between the elemental concentration in plants and the underlying soils of the study sites were examined. The concentration of certain elements in the plant is dependent upon the amount present in the soil, unless its concentration is so high as to be toxic to the plant. However, certain plants absorb these elements, in quantities much more than are required for their metabolic processes, the so-called "luxury consumption"; if plenty of them are available in the soil (Shacklette et al. 1970). Several elements such as lead, cadmium, cobalt, gold and silver which at present are not considered essential to plant growth are regularly encountered in plant tissues and may usually be said to indicate the normality of the underlying crustal material.

The present data (figures 2–6) show that the zinc content in the ash of leaves of 15 species studied and that of the soil usually give very highly significant correlations. Elemental concentrations in the plant ash increase with a linear dependence on the soil concentration, on a log to log basis. No evidence for any partial exclusion mechanism, i.e., at low concentration of the element in the soil, the plant excludes a large proportion of it, as reported by Nicolls et al. (1964) in *Tephrosia* sp. nov. could be observed in the present study. A linear uptake relation, thus

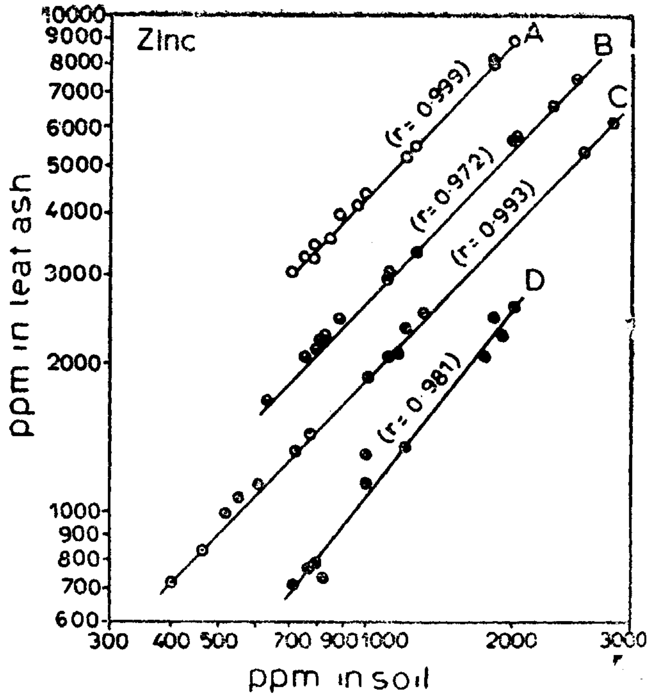

Figure 2 A–D Regression lines showing the relation between the concentration of zinc in the soil and certain plant species growing upon it; **A**, *Acanthospermum hispidum*; **B**, *Celosia argentea*; **C**, *Wrightia tinctoria*; **D**, *Aegle marmelos*

allows better contrast between an anomaly and background.

Relative Accumulation

The difference in the elemental contents among different plant species is more pronounced than among their underlying soils. This suggests that different species vary greatly in their ability to concentrate various elements. In several cases, the plant ash contains much more of the elements than the soil itself. Table 6 depicts the relative accumulation (mean plant ash concentration/mean soil concentration) of several elements by certain plant species. In order of decreasing relative accumulation of zinc, the species are:

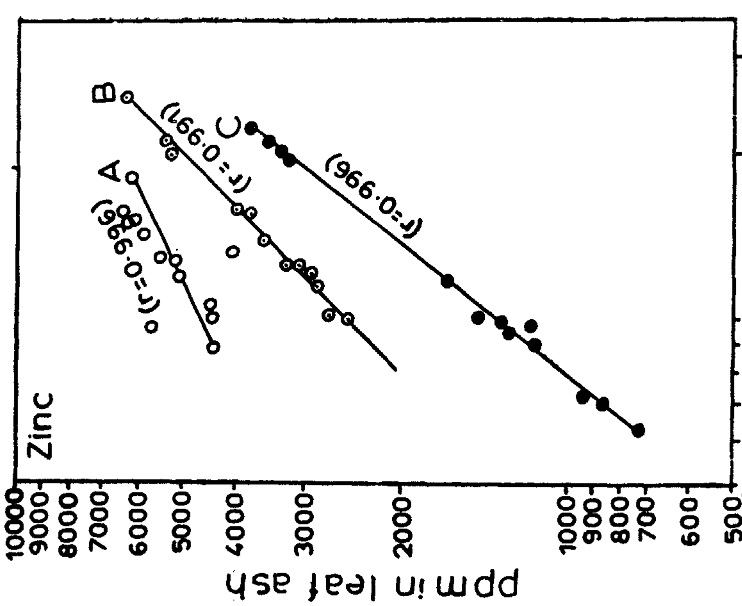

Figure 3 A–C, A, *Mellania futteyporensis;* B, *Grewia flavescens;* C. *Nyctanthes arbor-tristis*

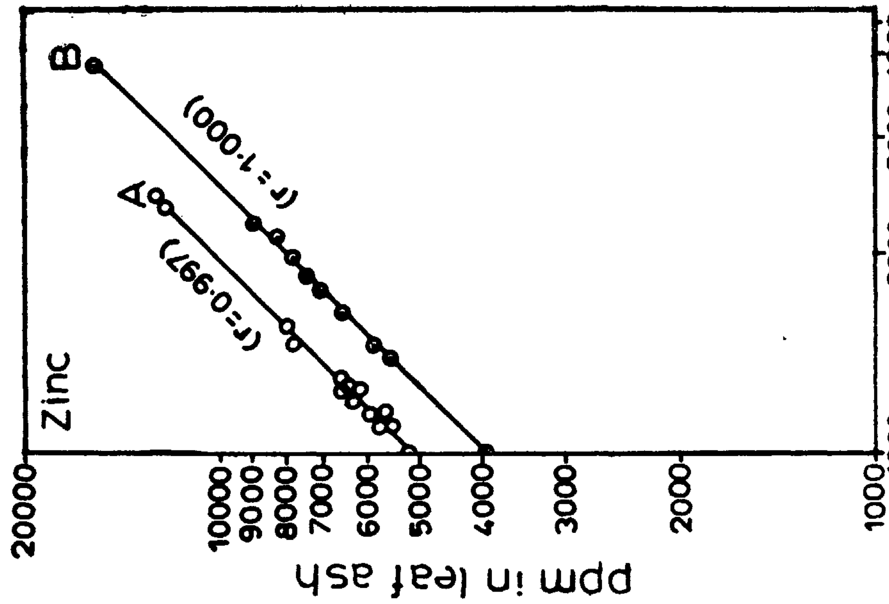

Figure 4 A–B A, *Impatiens balsamina;* B, *Lindenbergia muraria*

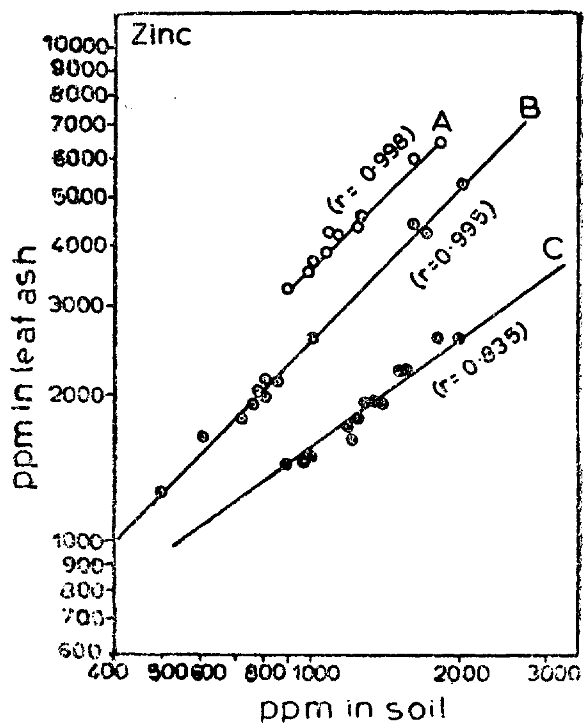

Figure 5 A–C, A, *Dyerophytum indicum*; **B,** *Hemigraphis latebrosa*; **C.** *Lannea coromandelica*

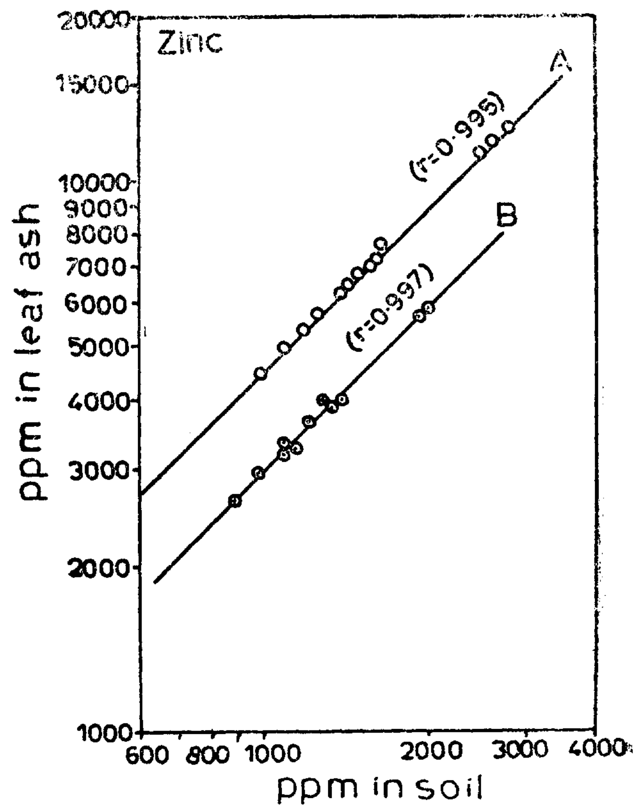

Figure 6 A–B, A, *Triumfetta pentandra*; **B,** *Crotalaria linifolia*

Table 7 *Statistical analysis for zinc contents in certain plant species growing in mineralized and non-mineralized areas*

S. No.	Name of the plant	Organ	No. of samples	Zinc content of plant species (ppm in ash)				Student's *t*
				Anomalous		Background		
				AM	GM	AM	GM	
1.	*Acanthospermum hispidum*	L	20	4760	4493	845.88	810.0	5.325**
		S	20	3338	3190	608.14	584.6	5.730**
2.	*Celosia argentea*	L+Fl	21	3478	3120	174.00	159.0	6.706**
		S	21	2507	2258	123.29	111.0	6.646**
3.	*Crotalaria linifolia*	L	18	4034	3918	406.85	380.40	7.941**
		S	18	2569	2515	270.15	252.40	8.525**
4.	*Dyerophytum indicum*	L	18	4294	4236	394.34	368.1	8.014**
		S	18	2590	2557	240.92	229.6	8.903**
5.	*Grewia flavescens*	L	16	3656	3544	339.93	283.1	5.472**
		S	16	2825	2743	299.22	240.4	4.973**
6.	*Hemigraphis latebrosa*	L	17	2489	2329	548.93	523.50	4.318**
		S	17	1745	1638	397.60	372.50	4.047**
7.	*Impatiens balsamina*	L	22	6648	6482	867.53	845.7	8.957**
		S	22	5742	5591	706.60	672.5	7.463**
		R	22	3644	3467	491.77	469.3	7.411**
		Fl+Fr	22	6032	5879	2483.07	2440.0	4.199**
8.	*Lannea coromandelica*	L	20	1924	1945	386.19	376.5	8.220**
		S	20	848	834	202.80	199.8	7.646**
9.	*Lepidagathis trinervis*	L	18	3191	3131	373.25	354.20	7.790**
		S	18	2189	2149	255.75	248.20	9.222**
10.	*Lindenbergia muraria*	L	18	8138	7732	407.65	383.6	8.926**
		S	18	6826	6534	337.21	316.5	9.091**
11.	*Melhania futteyporensis*	L	20	5367	5301	311.43	267.7	7.209**
		S	20	1484	1468	131.55	106.9	5.616**
		Fr	20	3419	3375	247.44	212.0	6.874**
12.	*Triumfetta pentandra*	L	20	7108	6817	791.44	769.80	7.931**
13.	*Wrightia tinctoria*	L	20	1864	1591	291.46	273.30	3.770**

Fl=Flower; *Fr*=Fruit; *R*=Root; *S*=Stem; *L*=Leaf; *AM*=Arithmetic mean; *GM*=Geometric mean; **=Highly Significant (at 1%)

Table 8 *Statistical analysis for lead contents in certain plant species growing in mineralized and non-mineralized areas*

S. No.	Name of the plant	Organ	No. of Samples	Lead content of plant species (ppm in ash) Anomalous AM	Anomalous GM	Background AM	Background GM	Student's *t*
1.	*Acanthospermum hispidum*	L	20	162	151	28.02	26.20	4.713**
		S	20	373	346	94.71	89.04	3.566**
2.	*Celosia argentea*	L+Fl	21	210	190	22.99	17.10	3 848**
		S	21	383	340	53.67	39.86	3.315**
3.	*Crotalaria linifolia*	L	18	215	210	34.12	30.18	4.315**
		S	18	399	389	80.70	74.15	4.025**
4.	*Dyerophytum indicum*	L	18	318	314	66.16	48.03	8.014**
		S	18	1030	1020	184.85	159.70	8.903**
5.	*Grewia flavescens*	L	16	202	195	23.91	22.35	6.529**
		S	16	376	365	43.85	41.36	4.638**
6.	*Hemigraphis latebrosa*	L	17	249	238	28.30	27.04	6.355**
		S	17	662	618	64.45	61.49	6.375**
7.	*Impatiens balsamina*	L	22	436	421	12.17	9.68	6.481**
		S	22	1184	1143	22.10	17.55	8.842**
		R	22	1076	1036	30.51	25.14	5.673**
		Fl+Fr	22	352	333	14.05	10.76	6.275**
8.	*Lannea coromandelica*	L	20	230	226	41.12	29.44	3.370**
		S	20	455	445	88.93	63.33	3.175**
9.	*Lepidagathis trinervis*	L	18	235	230	34.90	22.25	5.882**
		S	18	622	615	91.15	75.53	4.785**
10.	*Lindenbergia muraria*	L	18	1094	1014	38.56	33.98	7.712**
		S	18	4454	4169	146.47	134.00	8.667**
11.	*Melhania futteyporensis*	L	20	512	493	18.95	14.91	6.778**
		S	20	1093	1026	52.83	41.59	5.756**
		Fr	20	250	240	11.44	8.97	6.172**
12.	*Triumfetta pentandra*	L	20	538	516	26.65	25.86	10.774**
13.	*Wrightia tinctoria*	L	20	433	387	78 98	62.38	3.048**
		S	20	1328	1177	255.73	202.10	2.911**

Fl=Flower; *Fr*=Fruit; *R*=Root; *S*=Stem; *L*=Leaf; *AM*=Arithmetic mean; *GM*=Geometric mean; **=Highly significant (at 1%)

Table 9 *Statistical analysis for copper contents in certain plant species growing in mineralized and non mineralized areas*

S. No.	Name of the plant	Organ	No. of samples	Copper content of plant species (ppm in ash)				Student's *t*
				Anomalous		Background		
				AM	GM	AM	GM	
1.	*Acanthospermum hispidum*	L	20	121.24	113.2	105.69	101.5	0.665
		S	20	448.50	420.6	328.94	316.4	1.846
2.	*Celosia argentea*	L+Fl	21	158.90	143.4	66.85	61.2	3.380**
		S	21	402.27	363.5	159.23	147.1	2.104*
3.	*Crotalaria linifolia*	L	18	101.22	98.7	80.34	75.1	1.215
		S	18	166.11	164.4	150.20	142.7	1.198
4.	*Dyerophytum indicum*	L	18	117.10	117.0	77.42	72.9	2.838*
		S	18	594.28	578.4	355.12	336.8	1.746
5.	*Grewia flavescens*	L	16	92.08	89.50	95.19	92.0	0.108
		S	16	231.61	229.1	222.72	217.7	0.271
6.	*Hemigraphis latebrosa*	L	17	75.74	68.8	48.76	46.5	1.008
		S	17	502.72	362.3	232.68	221.2	1.054
7.	*Impatiens balsamina*	L	22	106.99	103.2	49.21	44.2	2.343*
		S	22	353.00	340.2	197.25	178.9	1.839
		R	22	2040.75	1971.0	291.63	263.4	5.614**
		Fl+Fr	22	282.66	272.6	77.37	69.2	3.747**
8.	*Lannea coromandelica*	L	20	70.34	29.8	160.34	143.0	1.329
		S	20	197.26	124.5	533.36	472.6	1.536
9.	*Lepidagathis trinervis*	L	18	157.63	154.5	78.27	73.3	2.448*
		S	18	1329.55	1317.0	620.79	543.3	1.917
10.	*Lindenbergia muraria*	L	18	239.43	231.1	71.83	69.2	4.171**
		S	18	445.12	428.7	134.03	129.3	4.196**
11.	*Melhania futteyporensis*	L	20	258.50	242.1	134.27	128.4	1.751
		S	20	1330.00	1243.0	718.74	690.5	1.626
		Fr	20	285.80	271.0	184.55	177.9	1.287
12.	*Triumfetta pentandra*	F	20	446.19	425.4	158.14	153.1	3.454**
13.	*Wrightia tinctoria*	L	20	108.16	89.3	89.56	89.3	0.002
		S	20	668.74	549.6	553.88	497.3	0.179

Fl=Flower; *Fr*=Fruit; *R*=Root; *S*=Stem; *L*=Leaf; *AM*=Arithmetic mean; *GM*=Geometric mean, *=Significant (at 5%); **=Highly significant (at 1%)

Impatiens balsamina (5.58), *Acanthospermum hispidum* (4.83), *Triumfetta pentandra* (4.52), and *Melhania futteyporensis* (4.17). The highest relative accumulation of lead is in the stems of *Lindenbergia muraria* (15.26) while the leaves show a relative accumulation value of 3.71 only. The stems of *Melhania futteyporensis* show the highest relative accumulation of copper (45.86). The highest enrichment of cadmium is in the stems of *Lindenbergia muraria* (15.99). All these plants accumulate very high concentrations of these elements. Warren et al. (1955) have shown that higher average contents in plants or plant parts usually results in more reliable data and an anomaly can be easily differentiated from the background. The present results conform to this principle.

The average concentration of zinc in the plant ash observed by us, is considerably higher than 800 ppm, as reported in the stem ash of trees in Georgia, USA (Shacklette et al. 1970). Certain plants accumulate very high concentration of different elements. The highest cadmium level in the leaves and stems was found respectively in *Crotalaria linifolia* and *Impatiens balsamina* (table 4). Cadmium concentration in the stems of *Impatiens balsamina* is more than twice the highest value reported for *Minuartia verna* (Ernst 1975). *Lindenbergia muraria* was found to concentrate the highest amount of lead (2121 ppm in leaves and 8004 ppm in stems) and zinc (15384 ppm in leaves and 12341 ppm in stems) in its ash (tables 1–2).

Elemental Concentration in Plants on Mineralized versus Nonmineralized Zones

Differences between the averages of two sets of values, i.e., the elemental concentrations in plants from the areas deficient and rich in minerals were worked out by applying the "Student's *t* test" (tables 7–9). Most of the plants studied, showed highly significant differences between the zinc and lead values of plants from the mineralized and nonmineralised areas. However, the copper content of plants from the mineralized and background areas show no significant differences except for the leaves of *Dyerophytum indicum*, *Impatiens balsamina*, *Celosia argentea*, *Lepidagathis trinervis*, *Triumfetta pentandra;* the stems of *Celosia argentea* and the roots of *Impatiens balsamina.* Cadmium, if present at all, was in non-detectable quantities (detection limit of AAS-1 being 0.5 ppm) and could not be studied in the background samples.

It is concluded that geobotanical and biogeochemical techniques show considerable promise as tool in the search for the metals in India. It is proposed to extend the present investigation to areas of different geological, vegetational, topographical and climatic environments with this object in veiw.

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