

Zn in Tolerant Roadside Plants in Relation to the Metal in the Soils in South India

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Abstract: Heavy metal contamination of urban environment is a global phenomenon and road traffic is one of the major line sources of these pollutants in the urban centers. Zn is the most abundant available heavy metal on roadsides and urban environment in general. Zn in roadsides has traffic sources, especially vehicle tires or other metallic parts of vehicles and road paints. Zn is a trace element essential for the growth of plants and animals but excess of the metal is toxic to all forms of life in diverse ways. Plants of metal contaminated roadsides are significant as they exclude/accumulate or hyper-accumulate the metal. Learning these potentials of them as well as their role in the inflow of the toxins through food chains has ecological implications. Two-year investigation of Zn content in plants occupying 1 m margins close to tar-edge of about 110 km of two very busy roadsides of South India in relation to the metal content in roadside soils revealed the degree of Zn contamination here in detail. Comparison of the degree of Zn contamination of roadsides of both urban and rural sites in the monsoon and summer seasons is discussed. Zn accumulation in the most relatively abundant 19 species of plants in relation to Zn in these moderately polluted soils showed that many plants accumulate Zn in their shoots or roots excess of that in the soils and in some of them the amount of Zn in shoots is above that of the limit of tolerance to the metal.

Key words: Heavy metal pollutants • Zinc • Metal Excluder/Accumulator/ Hyper-accumulator • Urban and Rural • Traffic Sources • Phytoremediation

INTRODUCTION

Zinc (Zn) is one of the major pollutants of roadsides [1] and among heavy metals in roadside soils; Zn is the most abundant metal [2]. Zn level correlates with average daily traffic in the roads and the mean levels of Zn vary exponentially with distance [3-5]. It is the twenty-fifth most abundant element that makes up 0.02% by weight of the earth's crust [6] and is an essential trace element for the growth of both plants and animals. Plants require Zn in trace amounts and the metal is the component of thousands of proteins in them, but toxic in high concentrations [7]. Plant uptake of Zn depends on factors other than Zn concentrations in soil solution, as there exist large differences in the solubility of Zn among different soils and plants do differ in their ability to absorb Zn [8].

High Zn content in street dusts come from traffic sources, especially vehicle tires [9-13]. Zn in the urban environment originates not only from tire dust but also

from road traffic materials such as brake lining and road paint [14]. Zn on roadsides is higher than that of Pb and Cu and galvanized crash barriers constitute an additional source of Zn in roadside soil [15]. Moreover, Zn may come from lubricating oils [16] as well.

Metal contamination of natural environment is a global phenomenon [17]. Public motor roads influence natural environment to a very high degree [18] because automobile traffic act as line sources of heavy metal pollutants. There is a significant relationship between heavy metals in street soils and traffic density [19]. In fast developing countries such as India, where increase in traffic density is coupled with increase in human populations, heavy metals in urban soils will exceed tolerable limits if correction measures are not taken [20]. Excess of metal pollutants deposited on soils may be transformed and transported to vegetation [21] and from plants they pass on to animals and human beings [22]. Heavy metals affect the immune systems of humans and animals [23]. Therefore, learning of the

extent of heavy metal contaminations on roadsides and its inflow into plants is highly relevant to the management of sustainable urban environmental quality everywhere. Moreover, Zn is potentially more bio-available than other heavy metals in soils [24]. Though bio-availability of Zn in soils depends on its solubility and many other physical, chemical and the biological characteristics of soils including soil pH, normal levels of Zn in most crops and pastures are in the range 10–100 mg kg⁻¹ dry weight [25].

Resilient plants in contaminated environments have different strategies to deal with excess of toxic metals in the environment. They may exclude/accumulate or hyper accumulate heavy metals. Knowledge of these strategies of plants towards heavy metals in soils enables the understanding of the ecological potentials of many different species, otherwise ignored as weeds. Emerging environment cleaning techniques such as phytoremediation requires resilient hyper-accumulator plants. Phytoremediations are promising alternatives to conventional techniques for the remediation of diffused or moderately metal contaminated soils [26]. Degrees of metal accumulations in plants of contaminated sites such as roadsides provide the preliminary information on metal exclusion/accumulation/hyper-accumulation potentials, which enable further experimentation. Native plant species growing on contaminated sites may have the potential for phytoremediation [27] and are of high demand as they may be useful in different phytoremediation strategies such as phytomining or phytostabilizations depending on their metal accumulation patterns. Zn hyper-accumulators are plants with Zn content (shoot tissue concentration) in excess of 10 mg Zn g⁻¹ of dry weight, when growing in their natural habitats [28]. Zn hyper-accumulators have active mechanisms of Zn uptake and translocation to the shoot, as well as the ability to detoxify excessive Zn within the shoot [29]. Metal resistant plants found in Zn polluted areas do not show visual toxicity symptoms, indicating Zn tolerance [30].

Practically no literature is available on the amount of Zn contaminations on roadsides or Zn content of plants on the roadsides of this part of the world. It is well accepted that all kinds of environmental assessments shall always be meaningful on site-specific basis [25]. Thus it was hypothesized that it would be worth investigating Zn on roadsides of Kerala, one of the fast urbanizing biodiversity rich parts of the Indian subcontinent. The current investigations of Zn content of roadside plants in relation to Zn content of soils was conceived in these contexts.

MATERIALS AND METHODS

Sampling Area and Collection Procedure: The roadsides investigated are about 55 km each of two roads - the 'Main Central Road' (MC road) and the 'Kottayam-Kumily Road' (KK road) of average traffic densities of 15300 vehicles per day - in Kottayam District (total area 2208 km²; total population 1952901; population density of 884 per km²; latitude 9°15' to 10° 21' and longitude 76°22' to 77° 25') of Kerala State, South India [31, 32]. The region has a tropical wet climate with total annual average rainfall of about 3130.33 mm received mainly in two monsoons – southwest monsoon (May to August) and northeast monsoon (September to December), separated by a break of summer (January to April). During the summer also, there are random summer showers in the zone.

Specific urban and rural sampling sites of 1 m distance from tar-edge and 1 km length of both the sides were identified on both the roads. Urban sites were those with high degree of traffic densities and other anthropogenic disturbances (trampling by people and crushing by vehicles) whereas rural sites were those with comparatively lower degree of disturbances of both the types. Samples representing monsoons (south-west and northeast monsoons; May to December) and summer (January to April) seasons were collected from these sites using quadrat methods [33]. Quadrats of 40 cm x 40 cm area, of approximately 0.1 m² [34] were used; at each site, 100 to 110 quadrats from both sides of the roads at random (of both the seasons) were observed. Altogether there are eight urban sites (4 from KK road and 4 from MC road) and five different rural (3 from KK road and 2 from MC road) sites (Fig. 1). Total 1350 quadrats were taken from all the sites in two seasons.

Plants and soil samples were collected separately (at random) in pre-washed polythene bags. Phytosociological measures were done in the field and recorded in the field book. Plant species were dug out carefully using a polythene shovel. From all the different sites specimens of each plant species available was collected from different quadrats at random during different months of the monsoon and the summer seasons. Different specimens of each species from a site were kept in a common bag; different species were kept in separate bags. During each sampling time, surface soil samples (about 500 g of top soil 0-5cm) of each site were taken from quadrats at random and the soil samples from different quadrat of a site were put in separate labeled bags.

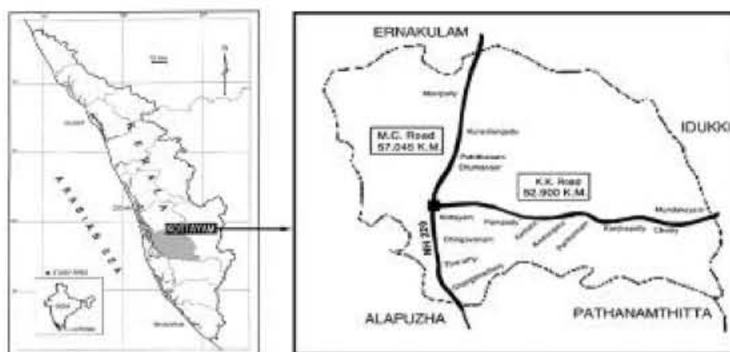


Fig. 1: Sampling sites on the two roads

Measurement of Zn in Soil Samples: Altogether there were 30-40 packets of monthly soil samples representing both the seasons from a specific roadside site, kept undisturbed for air drying in dust-free racks in the laboratory. Prior to chemical analysis, soil samples representing a season (15-20) of each site was divided into three equal groups and each group was mixed thoroughly. The three different composite soil samples from each site were treated as three distinct samples of each season. 500 g of each air dried composite sample was ground separately to pass through a 2 mm sieve. About 5g of the homogenized sample from each group was ground into fine powder using agate mortar and pestle and further dried in hot air oven at 70°C for 72 hrs to constant weights [58]. Exactly 1 g from each of these finely ground soil samples were weighed out using an electronic balance into properly cleaned 250 ml glass beakers.

Digestion was performed by adding 12 ml of *aquaregia* (3:1, v/v, Concentrated HCl to Concentrated HNO₃) into the beaker covered with watch glasses on a hotplate for 3 h at 110°C. After evaporation to near dryness carefully, the sample was diluted with 20 ml of 2% (v/v with water) nitric acid and transferred into a 100 ml volumetric flask after filtering through Whatman no. 42 filter paper and diluted to 100ml with double distilled water [59,60] and used for chemical analyses. Average of the three samples of each season was taken as the average amount of Zn of the site in that specific season. Thus the average Zn content of all the thirteen sites for both the seasons was found out.

Measurement of Zn in Plant Samples: Plant specimens were uprooted along with the entire roots from the field using a polythene shovel. From each site, mature plants (plant in the flowering stage) from different quadrats (where the species were available) of a site were

brought to the laboratory; each species in separately labeled packet. In the laboratory, after each collection, all specimens of each species from different quadrats of a site were washed together thoroughly many times with tap water followed by distilled water to remove completely the adhered dust and dirt and air-dried. After the air-drying all specimens of each species from a site were separated into roots and shoots and kept in separate paper bags labeled as root or shoot a species with a site code; specimens were then dried in hot air oven at 70°C for 72 hrs to constant weights and kept undisturbed for chemical analyses.

For each species, for each rural or urban site, there were many mature plants (plant in the flowering stage) collected at random from different quadrats of both the seasons. However, all species were not available at all sites. The number of available sites for a species varied from 7 to 13. Altogether 30-40 specimens were collected for each available species from a site belonging to the two seasons. At the time of chemical analyses (carried out after field studies) the roots and shoots of all plant specimens of each species from a site were powdered separately using agate mortar and pestle and thoroughly mixed. About 25 g each of the root and shoot sample of a species from a site was then further ground to fine powder. Shoot and root sample preparations for chemical analysis of all species were carried out similarly. Shoot samples of all the species were analyzed, whereas the analysis of root samples were carried out for only four species of grasses, which had significantly high root mass.

The digestion procedure was carried out on a hot plate as per standard methods [35-38]. 500 mg each of powdered sample of root and shoot of different species from each site were placed separately into 250 ml beakers (in triplicate) and added 10 ml of concentrated nitric acid, heated for 45 min at 90°C, swirled if frothing occurred and

occasionally washed down the sides of the beaker with double distilled water. Increased the temperature to 120°C and continued digestion at this temperature until about 1 ml of acid remained. Continued the heating and added concentrated HNO₃ in necessary volume until digestion became complete as was shown by a light colored, clear solution. The samples were not permitted to drying during digestion. After the digestion, the extract was cooled and diluted to 20 ml with 1% v/v nitric acid. The extract was filtered through Whatman no. 42 filter paper into a 100 ml volumetric flask and made up to 100 ml by adding doubled distilled water and used for chemical analysis. Reagent blanks for both the plant and soil analysis were also prepared in all cases for calibrations. Average of Zn in a species from all the sites was taken as the average Zn of the species on roadsides.

All the chemicals used were analytical grade compounds of Merck Company. Reagent bottles, beakers and volumetric flasks were cleaned by soaking overnight in 2 N hydrochloric acid, rinsed with water and oven dried at 60°C. Chemical analyses for Zn of both soil and plant

samples were carried out in a Flame Atomic Absorption Spectrophotometer (Perkin Elmer model 3110) at the Chemical Oceanography Lab of the Department of Marine Science, Cochin University of Science and Technology, Kochi, Kerala, India. Concentrations of the metal in both the soil and plant samples were computed as mg metal per kg dry sample (mg kg⁻¹). In order to compare Zn content of soils with that of plant samples, average of the metal in sites from where plant specimens of each species were collected was used. Statistical analyses such as ANOVA and correlations were carried out using SPSS package and MATLAB.

RESULTS

Zn in the Soil: Details of the averages of Zn found in roadside soils at all the different urban and rural sites corresponding to the monsoon and summer seasons are given in Tables 1 and 2, respectively. The seasonal differences of Zn in soils at the different urban sites ($0.05 < P = 0.3977$) or different rural sites ($0.05 < P = 0.7318$)

Table 1: Zn in soils at urban sites of two roadsides in two seasons

		Seasonal Soil Zinc (mg kg ⁻¹)	
Sl No	Sites	Monsoon	Summer
Road 1 - MC Road			
1	Changanacherry	189.30	116.80
2	Chingavanam	252.20	227.70
3	Kottayam	235.20	143.30
4	Ettumanoor	178.40	239.50
Road 2 - KK Road			
5	Mundakayam	180.90	184.20
6	Kanjirapally	193.50	178.90
7	Ponkunnam	269.40	206.20
8	Pampady	103.70	137.30
Mean Value with SD		200.33±52.16	179.24±44.21

Table 2: Zn in soils at rural sites of two roadsides in two seasons

		Seasonal average of Soil Zinc (mg kg ⁻¹)	
Sl No	Sites	Monsoon	Summer
Road 1 - MC Road			
1	Thuruthy	120.20	131.40
2	Pattithanam	184.10	192.70
Road 2 - KK Road			
5	Chotty	87.90	97.50
6	Kidangoor	131.50	140.60
7	Kothala	187.00	196.20
Mean Value with SD		142.14±42.75	151.68±42.23

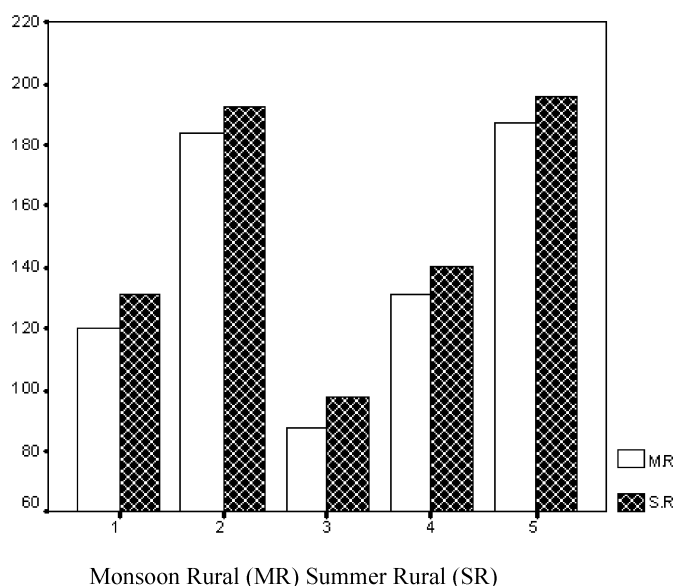


Fig. 2: Correlations of Zn in soils of two seasons at rural sites (mg kg^{-1})

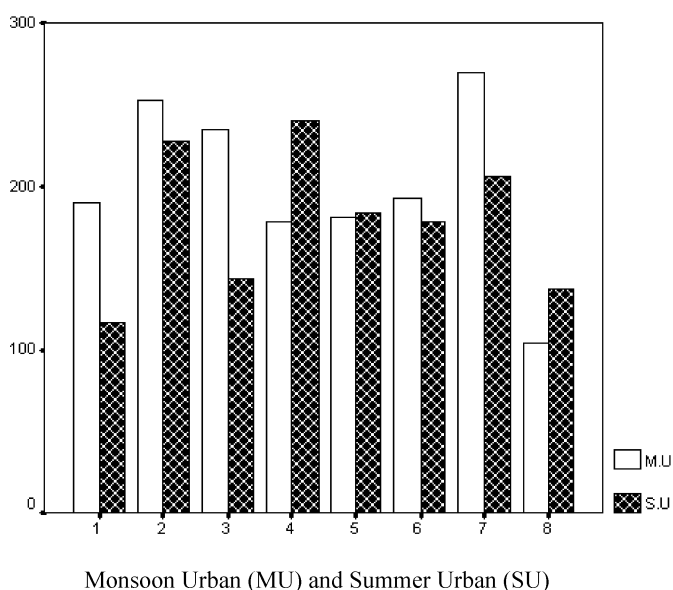
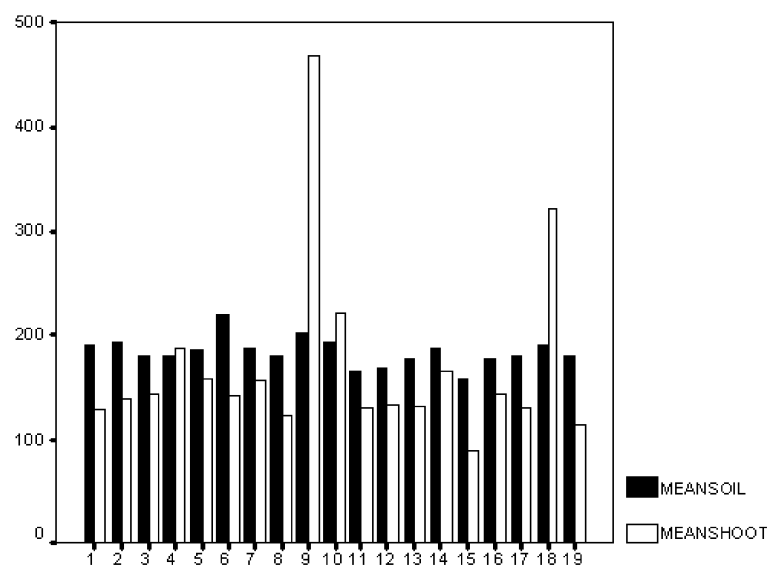


Fig. 3: Correlations of Zn in soils of two seasons at different urban sites (mg kg^{-1})

were not significant among themselves. However, significant differences were there in Zn in soils of urban sites over that of rural sites ($0.05 > P = 0.0288$), in the monsoon season. At the urban site, the highest average Zn contamination found in the monsoon was $269.40 \text{ mg kg}^{-1}$ and the lowest average Zn observed in the season was $178.40 \text{ mg kg}^{-1}$ (average 200.33 ± 52.16); in the rural site the highest average Zn content of soil observed in monsoon was $187.00 \text{ mg kg}^{-1}$ and the lowest amount

observed in the season was 87.90 mg kg^{-1} (average 142.14 ± 42.75).

In the summer season, no significant differences in Zn in soils was observed ($0.05 < P = 0.3408$) over urban and rural sites; the highest average amount of Zn found among different urban sites during summer was $227.70 \text{ mg kg}^{-1}$ and the lowest amount observed during summer was $116.80 \text{ mg kg}^{-1}$. Among the rural sites, the highest amount of Zn observed in the summer



In Plants No.9 and 18 have difference Zn over soil shoot were significant

Fig. 4: Correlations of Zn in Soil and plant shoots (mg kg^{-1})

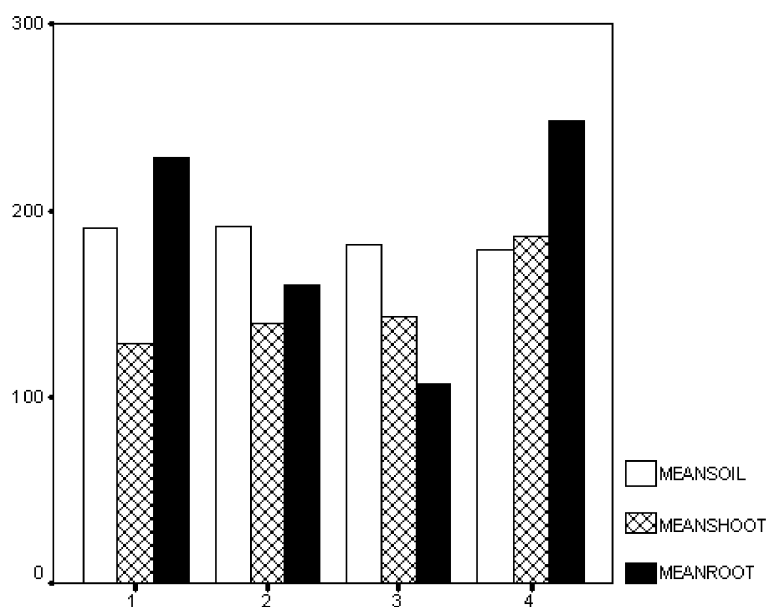


Fig. 5: Correlations of Zn in Soil, Shoots and Roots of grasses (mg kg^{-1})

1. *Eleusine indica* (L.) Gaertn.
2. *Cynodon dactylon* (L.) Pers.
3. *Axonopus compressus* (Sw.) P.Beauv
4. *Cyperus compressus* L.

was $196.20 \text{ mg kg}^{-1}$ and the lowest observed was 97.50 mg kg^{-1} .

Correlation studies of Zn in soils at different sites showed certain definite trends. Strong positive correlations were observed in the amounts of Zn over two seasons in the rural sites ($r = 1.000$). In the urban sites the correlations between Zn in

soils over two seasons was weak ($r = 0.400$). In summer, the correlation between urban and rural sites was weak and positive ($r = 0.533$) whereas in the monsoon the correlations between urban and rural sites was nearly zero. Seasonal correlations of Zn at the rural and urban sites are depicted in Figures 2 and 3, respectively.

Table 3: Zn in Plant samples in relation to corresponding soil samples

		Zn in samples mg kg ⁻¹						Relative abundance of Plants	
		Soil		Plant shoot		Plant root			
Sl No	Name of Species	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	<i>Eleusine indica</i> (L.) Gaertn.	190.82	± 48.27	129.31	± 56.99	229.10	± 82.29	13.59	±04.63
2	<i>Cynodon dactylon</i> (L.) Pers.	192.56	±54.78	139.05	±51.99	159.80	±10.46	08.38	±08.48
3	<i>Axonopus compressus</i> (Sw.) P.Beaurv.	181.34	±48.54	144.09	±57.98	106.46	±23.99	21.19	±19.93
4	<i>Cyperus compressus</i> L.	180.05	±48.75	186.65	±74.86	248.13	±62.73	01.57	±01.53
5	<i>Chloris barbata</i> Sw.	185.4	±37.84	159.05	±74.49	-	-	02.62	±08.83
6	<i>Kyllinga nemoralis</i> (J.R and G. Fors.) <i>Dandeyx Hutch. and Dalz.</i>	219.25	±41.07	141.95	±30.86	-	-	02.08	±01.84
7	<i>Hedyotis corymbosa</i> (L) Lam.	186.60	±48.99	156.62	±48.92	-	-	03.41	±02.74
8	<i>Scoparia dulcis</i> L.	180.23	±51.53	122.78	±48.62	-	-	02.06	±01.08
9	<i>Cleome ruidosperma</i> DC.	201.86	±46.83	468.20	±210.58	-	-	02.37	±01.63
10	<i>Vernonia cinerea</i> (L.)	192.40	±41.39	220.66	±96.37	-	-	02.05	±01.29
11	<i>Phyllanthus amarus</i> Schum. and Thonn	164.49	±45.88	129.86	±37.63	-	-	01.26	±01.16
12	<i>Pilea microphylla</i> (L.) Liebm.	169.63	±45.27	132.94	±43.59	-	-	03.77	±03.43
13	<i>Portulaca oleracea</i> L.	177.22	±46.68	131.86	±42.64	-	-	03.11	±03.10
14	<i>Amaranthus viridis</i> L.	187.54	±44.59	163.98	±54.60	-	-	01.99	±02.07
15	<i>Euphorbia hirta</i> L.	158.65	±60.66	90.35	±70.54	-	-	00.95	±00.85
16	<i>Eclipta prostrata</i> (L.) L.	176.97	±59.22	143.07	±23.10	-	-	00.64	±00.64
17	<i>Leucas aspera</i> (Willd.) Spreng.	180.43	±59.69	130.53	±52.92	-	-	00.18	±00.38
18	<i>Peperomia pellucida</i> (L.) Kunth	189.77	±14.48	321.40	±98.43	-	-	00.07	±00.20
19	<i>Aerva lanata</i> (L.) Juss. ex Schult.	180.43	±59.69	114.33	±15.25	-	-	00.56	±00.57

Table 4: Correlations between Zn plant shoots and soils at different sites

		N	Correlation	Significance
Plant 1	SO1 and SH1...	14	.069	.815
Plant 2	SO2 and SH2...	11	.459	.155
Plant 3	SO3 and SH3...	11	.411	.209
Plant 4	SO4 and SH4...	4	.129	.871
Plant 5	SO5 and SH5...	4	-.525	.475
Plant 6	SO6 and SH6...	4	-.272	.728
Plant 7	SO7 and SH7...	13	-.445	.127
Plant 8	SO8 and SH8...	12	-.239	.455
Plant 9	SO9 and SH9...	7	-.353	.438
Plant 10	SO10 and SH10...	7	-.283	.539
Plant 11	SO11 and SH11...	7	.166	.722
Plant 12	SO12 and SH12...	7	-.261	.572
Plant 13	SO13 and SH13...	10	-.323	.363
Plant 14	SO14 and SH14...	8	-.254	.544
Plant 15	SO15 and SH15...	4	.093	.907
Plant 16	SO16 and SH16...	3	-.473	.686
Plant 17	SO17 and SH17...	3	.166	.894
Plant 18	SO18 and SH18...	3	.503	.665
Plant 19	SO19 and SH19...	3	.713	.495

SO = soil; SH = Shoot; No significant correlation between soil and shoots

Zn in the Roadside Plants: Relative Abundance (RA) of the different species of plants on the whole length of roadsides was studied and the mean Zn content in shoots of the most significant 19 of them and roots of four of the grasses, in relation to the mean Zn in soils from they were collected were calculated (Table 3). Statistical analysis showed that the mean of Zn in soils corresponding to soils from where

each species was collected (average of Urban and Rural sites from where specimens of a species was collected for chemical analysis) were significantly different ($0.05 > P = 0.000$). The mean of Zn in both the shoots and roots of different grasses were also significantly different ($0.05 > P = 0.011$) and the RA of the 19 different species studied were significantly different ($0.05 > P = 0.006$).

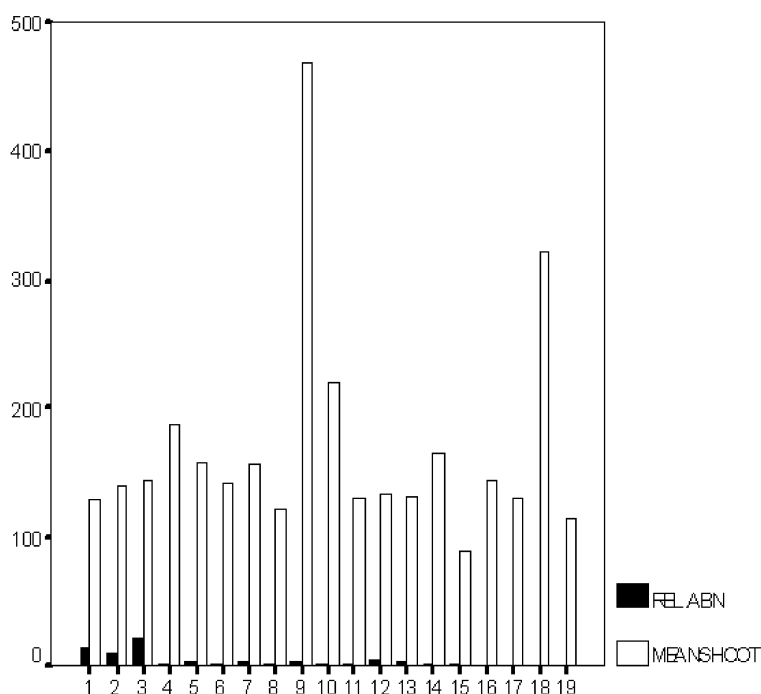


Fig. 6: Zn in shoots of plants (mg kg^{-1}) in relation to their relative abundances (%)

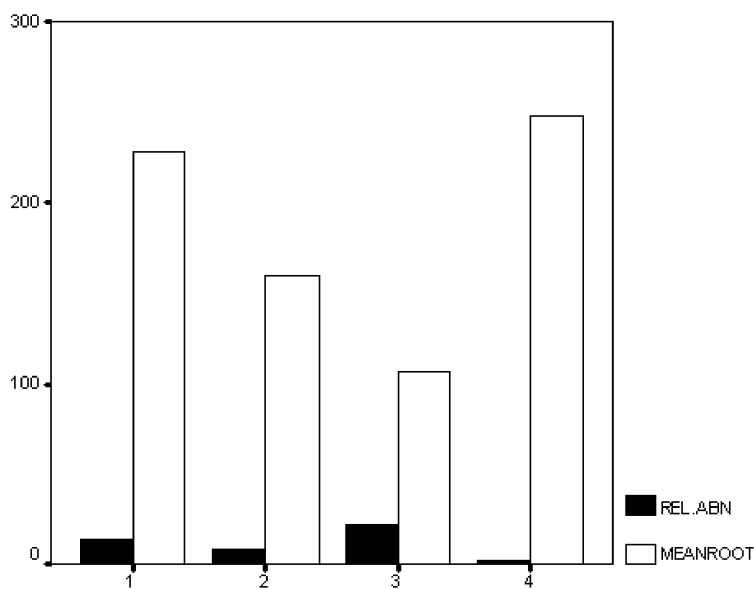


Fig. 7: Zn in roots of grasses (mg kg^{-1}) in relation to their relative abundances (%)

Depictions of the mean of Zn in soils and shoots of plants (Fig. 4) and that of soils, shoots and roots of grasses (Fig. 5); and the RA and Zn in shoot (Figs. 6 and 7) clearly explain the actual interrelationships. Examinations of correlations between Zn in the shoots of all plants or roots of the different grasses and that in different soil samples from where each of the 19

species was collected (Table 4) showed that the correlations were significant; in some plants, the correlations were negative as well. Paired sample t- test (Table 5) revealed that in two species *Cleome rutidosperma* and *Peperomia pellucida* the shoot accumulation of Zn was significantly higher than that in the soils from where they were collected.

DISCUSSIONS

Zn is a toxic heavy metal common to roadside soils and vegetations in high amounts, but specific investigations on its accumulation in roadside soils and plants in India are not found in the literature. Therefore, the current investigation was highly relevant to fill that vacuum of data on Zn accumulation in urban systems in India. Moreover, measure of heavy metals including Zn contributes to generation of specific information significant to the environmental quality of urban life [39]. Zn phytotoxicity is the second most microelement phytotoxicities known in the world after that of Aluminium and Manganese [40]. Therefore, information of relative abundance of roadside plant species in relation to Zn in roadside soils and the degree of accumulation of the metal in shoots or roots of the most tolerant (in terms of increase in RA) of them has wide applications, including the monitoring of Zn in urban environments.

The amounts of Zn in the currently examined Indian roadsides soils were comparable to and higher than that of roadsides in European cities. According to Biasioli *et al.* [39] in three European cities, the average of Zn on roadside soils are $97 (\pm 53)$, $116 (\pm 81)$ and $165 (\pm 97)$ mg kg⁻¹, respectively. In the current observations of Indian roadsides, the general average of Zn in different urban sites was 190 ± 48 and that in the rural sites were 147 ± 42.5 (Table 1 and 2). The absence of seasonal differences at all sites (both at urban and rural sites) also revealed the traffic origin of the metal, because average traffic densities do not change in accordance with the season on main roads examined; significant differences in Zn over urban and rural sites also substantiate this traffic origin of Zn on roadsides. It may also be noticed that in many of the urban sites examined the Zn content was above the maximum permissible zinc concentration limit prescribed (of 200 mg Zn kg⁻¹) by European Commission [41] and in many sites the concentration exceeded the general phyto-toxicity level of 250 mg Zn kg⁻¹ [25].

Metal tolerance in higher plants is species specific [42-44, 26] related to genus or even family level [45]. Species specificity is related to many plant factors such as root length, rate of water uptake and microbial activity in the rhizosphere [46]. It is based on the species specific higher rate of accumulation and tolerance that hyper accumulating plant species significant in phytoremediation are selected. Metal hyper accumulation is a rare trait found in approximately 440 plant taxa, 11 of which only have been reported to hyper accumulate zinc [47]. It is true that one of the best known heavy metal hyper accumulator plant species is *Thlaspi caerulescens*

which can accumulate up to 3% Zn in dry shoots without showing any sign of toxicity [48] and usually hyper tolerant and hyper accumulator species of plants are identified from extremely metal contaminated zones. However, if plants growing in moderately metal polluted soils accumulate heavy metals in excess of that in the soils, the information can also be utilized to identify hyper-accumulation potentials of plant species growing there after subjecting them to experimental applications. Most hyper accumulators are endemic to metalliferous soils, but some have also been described growing on uncontaminated sites [49]. Therefore, the identification of 19 tolerant species from the Zn contaminated roadsides along with Zn content in shoots and roots of these plants in relation to the amount Zn in the soil (Fig. 4 and 5) is useful for further experimentation with them. This is especially significant, when the scientific world is in the look out for more efficient hyper accumulators that produce more biomass [50].

The critical leaf tissue concentration of Zn for a toxicity effect on growth in most plant species is in the range 200–300 mg kg⁻¹ [25], but Zn in tolerant plant tissue can be in the range of 387 to 1221 mg kg⁻¹ [51]. The range of Zn content in the shoots 19 plants varied from 90.35 mg kg⁻¹ (*Euphorbia hirta*.) to 468.20 mg kg⁻¹ (*Cleome rutidosperma*) and was quite high. Though the normal range for Zn in plants is 10 to 300 mg kg⁻¹ [52], in *Cleome rutidosperma*, the amount was at levels close to limit of toxicity exhibition of 500 mg kg⁻¹ reported by Chaney [53]; but this plant was found luxuriantly growing on roadsides with normal morphological features. *Peperomia pellucida*, the species with the second highest amount of Zn in the region also showed an accumulation (321.40 mg kg⁻¹) much above that of the Zn in soils from where they were collected. Since both of these species showed a statistically significant increase in Zn in the shoot than that of soils, both of them deserve further experimental trials to establish whether they possess hyper accumulation potential or not. However, Zn in soils and Zn in the shoot of many of these species were found positively correlated. Therefore, all such tolerant species may be subjected to experimental trials. Moreover, in species which showed a negative correlation with Zn in soils and shoot, investigations shall be focused to the mechanism of tolerance or metal avoidance in such plants.

In general heavy metal tolerance is considered as a common feature of the *Poaceae* family [54]. Some of the most relatively abundant plants found on roadsides were grasses and these grasses in general showed high shoot and root biomass. Therefore, Zn content in both the shoot

and roots of these four relatively abundant grass species were analyzed and compared. It was interesting to note that in all of these grasses, the shoot content of Zn was either lesser or close to the amount of Zn in the soils from where they were collected; however in two of them (*Eleusine indica* and *Cyperus compressus*) the root content of Zn was much higher than that in the soils. In all of them, except in one, (*Axonopus compressus*) the amount of Zn in the roots was higher than that in the shoots. Since the accumulation of higher metal concentrations in shoots than in roots has been described as a characteristic of hyperaccumulation [55-57] *Axonopus compressus* may be subjected to further experimental investigations to assess its potential, as a Zn providing fodder for cattle. Overall conclusion is that traffic related Zn contamination is significant to urban systems and monitoring of the metal content of plants on roadsides are beneficial in multiple ways.

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