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Full Length Article

Phyto-Monitoring of Spatio-Temporal Variations in Traffic Related Metal Pollution using Native Species

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Abstract

Zinc (Zn) is an essential plant nutrient but it becomes toxic heavy metal when increased from its permissible limit. This two years' study was conducted to monitor the roadside traffic related Zn pollution by using native plant species i.e., *Cenchrus cilliaris*, *Cynodon dactylon*, *Calotropis procera*, *Nerium oleander* and *Ricinus communis*. Two roads *i.e*., Faisalabad to Okara road (FOR) and Okara to Lahore road (N-5) were selected for study. Soil and leaf samples of selected plants were collected from five sites along each road for analysis and control samples from a distance of ~50 meters of sites. The results showed higher Zn contents in roadside soil and plants as compared to control. Metal contents at N-5 were higher than Faisalabad to Okara road (FOR). Among the seasons, Zn concentration was highest during summer and minimum during winter in both plants and soils. Furthermore, *R. communis* accumulated maximum Zn than other plant species; therefore, it may be proposed as a suitable species for phytomonitoring purposes. © 2020 Friends Science Publishers

Keywords: Phytomonitoring; Zinc; Vehicular pollution; Soil; Ricinus communis; Atomic absorption spectrophotometer; Traffic

Introduction

Zinc (Zn) was acknowledged as essential nutrient for plants in 1926 and soon after for mammals in 1934 (Nielsen 2012). It is vital for many enzymes of protein synthesis, energy transfer and nitrogen metabolism. Its deficiency not only impedes plant growth and yield, but also adversely affects human health (Graham *et al*. 2001; Cakmak 2002) that's why soil deficits in Zn have to be applied with Zn fertilizers to fulfill the nutritional requirements of plants (Wyszkowska *et al.* 2013). However, being the most mobile and bioavailable nutrient its higher concentration in soil may cause phytotoxicity in plants (Reichman 2002; Sagardoy *et al.* 2009).

Supra-optimal Zn concentration in plants causes leaf chlorosis, instabilities in photosynthesis and chlorophyll synthesis (Wang *et al.* 2009). Its excess also induces oxidative damage, disturbs the protein synthesis and development of organelles in plants (Panda *et al.* 2003; Wang *et al.* 2009).

Zinc is also a common pollutant in the area of traffic routes (Malinowska *et al*. 2015), most of its quantity comes from petrol, lubricant oil leaks, brake linings, by wear and tear of tyres and from galvanized parts of automobiles (Thorpe and Harrison 2008; Nazzal *et al.* 2013) as well as from soot and heavy metal oxides, which runoff into roadside soil after precipitation (Malinowska *et al.* 2015). The plants growing on such soils accumulate metals that may enter into human and animal body through consumption of these plants (Nauciene *et al.* 2002; Liu *et al.* 2007).

The contamination of roadside soil by trace metals is directly proportional to traffic density on roads (Werkenthin *et al.* 2014), moreover, level of vehicular released metals in roadside soil and plants got increased considerably during last few years (Onder and Dursun 2006). Celik *et al.* (2005) reported four times higher metal concentration in roadside vegetation than control sites vegetation. This concentration drops with distance from roadsides (Joshi *et al.* 2010; Mmolawa *et al.* 2010; Werkenthin *et al.* 2014). Seasonal and spatial variations also influence metal contents in soil (Pathak *et al.* 2015). The use of native plant species to monitor the level of metal contamination is quite economic, convenient, and aesthetically pleasing technique in which the natural ability of environment is benefited to restore itself (Hernandez-Allica *et al.* 2008).

Several plant species have been reported as good indicator/monitor of metal pollution. Amongst them, the role of *Nerium oleander* (Mignorance and Oliva 2006), *Robinia pseudo-acacia* (Celik *et al.* 2005), *Eucalyptu* spp., *Prosopis juliflora* and *Dalbergia sissoo* (Naveed *et al.* 2010), *Casuarina equisetifolia* (Aissa and Keloufi 2012), *Ageratum conyzoides* (Deepalakshmi *et al.* 2014) and

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Synedrella nodiflora and *Chromolaena odorata* (Okoronkwo *et al.* 2014) to monitor environmental metal pollution has already been studied. The present study monitored the Zn contamination in roadside soil and plants. Information obtained can contribute in identification of phytomonitors of metal pollution.

Materials and Methods

Study area description

Punjab, the most populated province of Pakistan, has a huge network of roads. "National Highway (N-5)"and "Faisalabad to Okara Road (FOR)" are two high trafficked roads in the central Punjab. "Faisalabad to Okara Road (FOR)" is 103 km long and interconnect Faisalabad to Okara by passing the Ravi River. This road has numerous human settings (villages, towns), cultivated field areas and marketplaces along it. Animal driven carts, motorbikes, rickshaw, vans and mini buses are major contributors of traffic load on this road. National Highway 5 (N-5) is 1819 km long and interconnects Karachi to Torkham. A section of it from Okara to Lahore (129 km) was selected for study. This road is quite busy and in good state having several urban settlements along it. The vehicles on N-5 includes multi wheeler loaders, air-conditioned buses, vans, mini buses, oil tankers, trucks and cars and remains busy throughout the year.

Sampling and metal analysis

Excluding the markets and residential areas, five sites were selected randomly along each (FOR and N-5) road (Fig. 1). Samples and data were collected in the mid of each of four seasons. The five commonly growing native plant species (*Cenchrus ciliaris* L., *Cynodon dactylon* L., *Calotropis procera* A., *Ricinus communis* L., and *N. oleander* L.) were selected for study at each site along both roads (Table 1). Leaves from each selected plant and soil samples (up to 10 cm deep) were collected at each site along roadside. Same plant species and soil samples were collected at a distance of ~ 50 m from roadside and labeled as control (Jian-Hua *et al.* 2009). All leaf samples were washed with deionized distilled water to get rid of soil particles and dried in an oven (65°C) then ground to powder using Wiley Mill. Collected soil samples were sieved (2-mm) and dried in oven (65°C) for 72 h. By using HNO_3 and H_2O_2, plant and soil samples were digested on a hot block digester (Environmental Express, Mt. Pleasant, SC) by following USEPA method 3050B for metal analysis (de Oliveira *et al.* 2015) and analyzed by atomic absorption spectrophotometer (AAS). Standard plant leaves and soil reference materials (accuracy=100 ± 20%), Internal standards and reagent blanks were used to ensure precision and accuracy in analysis.

Table 1: Description (botanical and vernacular names) of plant species grown in the study area

Botanical name	English name	Vernacular name	Abbreviations used
Cenchrus ciliaris L.	Buffel grass	Dhaman	*C. ciliaris*
Cynodon dactylon L.	Bermuda grass	Khabbal	*C. dactylon*
Calotropis procera A.	Apple of Sodom	Ak	*C. procera*
Nerium oleander L.	Oleander	Kaner	*N. oleander*
Ricinus communis L.	Castor oil plant	Arind	*R. communis*

Statistical analyses

Statistical analyses were carried through program COSTAT computer package by Cohort software (2003) Monterey, California, U.S.A. Means were compared with LSD test ($\alpha = 0.05$) (Steel and Torrie 1997). The correlation was determined by Excel.

Results

Zn contents in roadside soil

Zn contents in roadside soil were higher than the control samples (Table 2). During seasons, highest Zn concentration was recorded at "Tandaliawala" site along "FOR" and "Chung" site along "N-5". Furthermore, seasonal variations were also noticed for soil Zn content with highest during summer and least during winter season along both roads.

Zn contents in roadside plant leaves

Zn content in plant leaves were higher than the control (Table 3). Among all plants along "FOR", maximum Zn accumulation was found in *R. communis* and minimum in *C. ciliaris* (Fig. 2). Similarly, along "N-5", maximum Zn concentration was also noted in *R. communis* and minimum in *C. ciliaris* (Fig. 3). The spatial comparison along "FOR" showed that Zn content in plant leaves at "Tandaliawala" site was highest among all sites while "Satghara More" site presented least Zn content along this road (Fig. 4). Along "N-5" highest Zn content in plant leaves were observed at "Chung" and lowest at "Pattoki" site (Fig. 5). Nevertheless, Zn content in all trafficked sites were significantly higher than the non-trafficked site. The seasonal comparison for accumulation of Zn in plant leaves along both roads were observed in the following order summer>autumn >spring > winter (Fig. 6, 7).

Comparison among Roads ("FOR" and "N-5") for Zn contents in soil and plant leaves

A comparison between roads for Zn content in both plant leaves and soil showed highest Zn content along N-5 and least along 'FOR" (Fig. 8, 9).

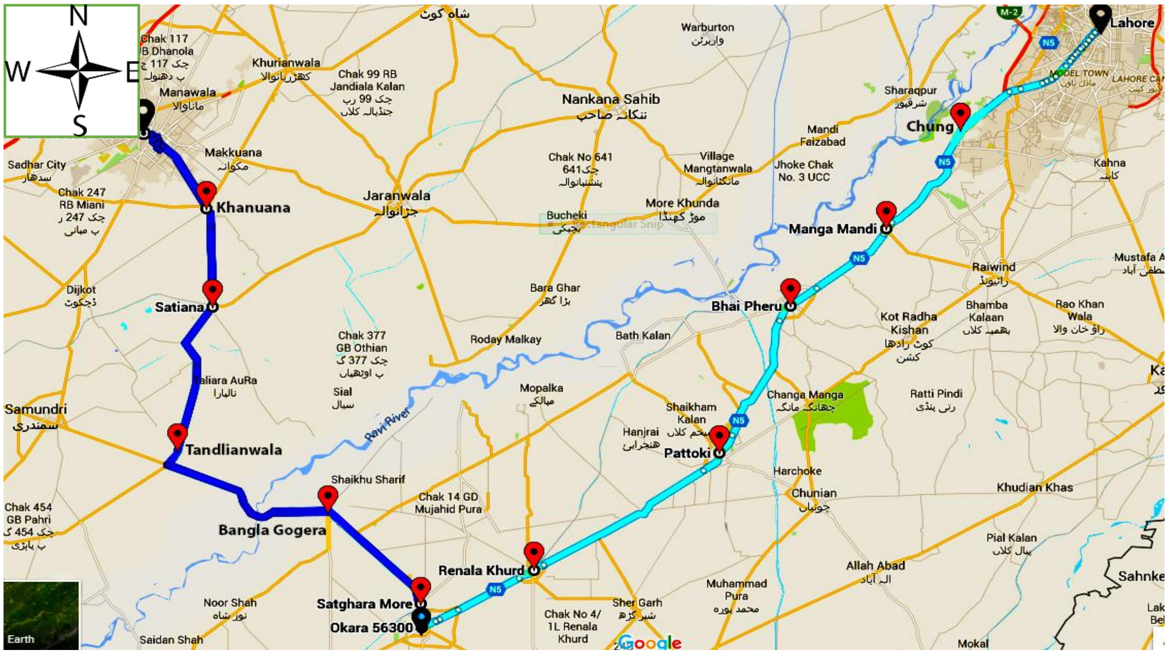

Fig. 1: Map showing sites on "FOR" and "N-5"
Khanuana, Sataiana, Tandaliawala, Bangla Gogera, Satghara More, Renala Khurd, Pattoki, Bhai Phero, Manga Manadi and Chung
Source: https://www.google.com/maps

Table 2: Zn contents (mg kg^{-1}) in roadside soil along FOR and N-5 during different seasons (mean ± SD)

	Sites along Faisalabad to Okara Road (FOR)					
Seasons	Control	Khanuana	Sataiana	Tandaliawala	Bangla Gogera	Satghara More
Summer	35.14 ± 4.55	158.09 ± 11.47	167.73 ± 6.01	183.43 ± 4.65	145.10 ± 12.25	136.76 ± 5.40
Autumn	28.43 ± 3.91	151.12 ± 4.73	169.41 ± 6.53	174.84 ± 2.54	117.09 ± 4.67	128.36 ± 5.30
Winter	13.26 ± 4.12	101.91 ± 6.05	113.01 ± 3.86	139.32 ± 7.57	83.10 ± 6.43	78.96 ± 6.72
Spring	19.12 ± 7.78	134.66 ± 4.65	127.13 ± 2.22	153.08 ± 6.62	104.42 ± 4.80	87.36 ± 5.72
	Sites along Okara to Lahore Road (N-5)					
	Control	Renala Khurd	Pattoki	Bhai Phero	Manga Mandi	Chung
Summer	38.47 ± 3.93	164.71 ± 4.60	139.31 ± 6.01	189.18 ± 4.02	199.75 ± 3.71	209.73 ± 7.44
Autumn	15.14 ± 5.32	140.29 ± 4.24	119.03 ± 6.67	154.17 ± 4.46	176.30 ± 5.46	192.17 ± 3.11
Winter	14.96 ± 4.19	81.31 ± 6.51	64.98 ± 4.46	110.89 ± 10.75	130.45 ± 2.57	154.45 ± 1.99
Spring	24.35 ± 3.30	84.77 ± 7.02	71.88 ± 6.52	134.75 ± 8.47	157.73 ± 3.83	176.07 ± 10.19

Correlation of traffic density with soil and plant metal

Correlations were calculated to estimate the relationship between traffic density and metal content in soil and plant leaves. During all four seasons, a strong correlation was found between average daily traffic and metal content in soil and plant leaves along both roads (Table 4).

Discussion

The present study revealed that Zn content in roadside soil along both "Faisalabad to Okara" and "Okara to Lahore" roads was significantly higher than control (~50 m away from road) site. Many studies have described that the Zn content in roadside soil decreased exponentially with per increase in distance from road (Akbar *et al.* 2006; Akan *et al.* 2013; Jankowski *et al.* 2015; Rolli *et al.* 2016). Significant amounts of Zn in roadside soil come from wear and tear of tyres, from galvanized parts of automobiles (Hjortenkrans 2008), soot and metal oxides, which run off from the road, into soil after precipitation (Malinowska *et al.* 2015). Furthermore, the release of metals also varies with vehicle type and age, type of fuel used, driving speed and road structure (Smith 1976).

Significant variations in Zn contamination existed among sites with highest Zn content at "Tandaliawala" and "Chung" site along "FOR" and "N-5" roads respectively. This was due to high vehicle traffic in these areas. Many studies have reported that sites with high vehicular density are more contaminated with metals (Apeagyei *et al.* 2011; Duong and Lee 2011; Popescu 2011). At "Pattoki" site minimum contamination was noted that could be due to protection by significant number of plants which include herbs shrubs and trees and the metal content in roadside soil with vegetation shield are significantly lower than without vegetation (Liu *et al.* 2012). Khan *et al.* (2011) reported that Zn content in soil ranged from 13.8 to 180 mg

Table 3: Zn contents (mg kg^{-1}) in roadside plant leaves along FOR and N-5 during different seasons (mean ± SD)

Seasons	Plants	Sites along Faisalabad to Okara Road (FOR)						
		Control	Khanuana	Sataiana	Tandaliawala	Bangla Gogera	Satghara More	Mean
Summer	*C. ciliaris*	12.55 ± 3.07	85.56 ± 3.01	85.59 ± 4.51	92.89 ± 2.10	88.91 ± 4.53	64.77 ± 4.73	83.54 ± 10.92
	C. dactylon	17.73 ± 2.11	100.88 ± 6.52	108.08 ± 6.05	114.69 ± 5.05	104.59 ± 5.68	92.47 ± 3.53	104.14 ± 8.27
	C. procera	14.05 ± 1.73	90.54 ± 3.11	103.90 ± 8.00	108.96 ± 3.92	91.67 ± 2.12	47.47 ± 8.54	88.51 ± 24.26
	N. oleander	13.46 ± 3.72	89.22 ± 6.00	78.92 ± 6.10	101.65 ± 3.52	79.55 ± 3.84	75.22 ± 2.95	84.91 ± 10.69
	R. communis	18.97 ± 3.84	118.51 ± 7.01	99.44 ± 4.78	127.56 ± 12.04	112.25 ± 3.01	98.47 ± 7.90	111.25 ± 12.48
Autumn	*C. ciliaris*	11.47 ± 1.86	74.62 ± 4.22	55.24 ± 2.83	57.33 ± 5.44	71.77 ± 3.53	58.11 ± 3.50	63.41 ± 9.04
	C. dactylon	15.76 ± 1.17	92.29 ± 5.79	100.30 ± 4.46	95.76 ± 3.55	85.81 ± 3.63	60.46 ± 3.49	86.92 ± 15.71
	C. procera	13.72 ± 1.82	88.56 ± 2.64	92.01 ± 4.63	98.56 ± 2.81	85.16 ± 2.96	75.54 ± 3.56	87.97 ± 8.53
	N. oleander	11.37 ± 1.56	80.02 ± 4.03	61.33 ± 3.02	93.86 ± 3.05	77.84 ± 3.61	68.12 ± 2.51	76.23 ± 12.41
	R. communis	16.16 ± 2.67	101.84 ± 3.51	107.83 ± 4.57	114.38 ± 3.71	96.78 ± 2.54	66.53 ± 4.58	97.47 ± 18.51
Winter	*C. ciliaris*	7.65 ± 1.78	61.84 ± 1.59	64.57 ± 3.60	60.94 ± 9.75	54.14 ± 9.27	48.19 ± 2.50	57.94 ± 6.66
	C. dactylon	9.47 ± 1.69	70.76 ± 2.55	76.64 ± 7.20	84.51 ± 2.01	58.99 ± 3.06	65.28 ± 3.51	71.24 ± 9.89
	C. procera	9.06 ± 2.10	70.59 ± 5.62	75.69 ± 3.16	82.64 ± 2.63	65.89 ± 2.93	59.81 ± 12.30	70.92 ± 8.79
	N. oleander	8.30 ± 0.33	63.09 ± 2.68	53.66 ± 4.72	76.81 ± 2.57	59.48 ± 4.01	53.80 ± 3.56	61.37 ± 9.51
	R. communis	11.28 ± 1.56	86.19 ± 3.50	92.52 ± 6.74	100.14 ± 6.08	79.17 ± 2.50	70.97 ± 3.04	85.80 ± 11.35
Spring	*C. ciliaris*	8.81 ± 1.49	62.34 ± 2.87	68.15 ± 4.57	75.09 ± 2.50	53.77 ± 3.79	54.07 ± 3.07	62.68 ± 9.19
	C. dactylon	12.77 ± 2.83	81.52 ± 2.65	88.11 ± 2.84	81.95 ± 5.18	82.80 ± 3.47	74.83 ± 3.58	81.84 ± 4.73
	C. procera	11.72 ± 1.98	66.43 ± 2.40	61.11 ± 5.73	90.79 ± 2.52	61.82 ± 9.09	67.35 ± 3.86	69.50 ± 12.21
	N. oleander	9.71 ± 2.12	71.97 ± 4.20	78.74 ± 1.57	84.71 ± 3.05	69.09 ± 2.50	58.07 ± 2.12	72.52 ± 10.10
	R. communis	13.82 ± 2.49	93.81 ± 3.97	81.95 ± 6.96	107.53 ± 2.64	96.15 ± 2.53	80.19 ± 2.50	91.93 ± 11.21
Seasons	Plants	Sites along Okara to Lahore Road (N-5)						
		Control	Renala Khurd	Pattoki	Bhai Phero	Manga Mandi	Chung	Mean
Summer	*C. ciliaris*	13.55 ± 2.10	82.74 ± 2.33	66.18 ± 4.08	89.13 ± 3.33	94.12 ± 2.47	99.44 ± 3.00	86.32 ± 12.84
	C. dactylon	18.73 ± 3.01	108.46 ± 7.57	95.73 ± 4.22	91.21 ± 4.41	112.27 ± 3.44	122.08 ± 2.84	105.95 ± 12.53
	C. procera	17.05 ± 2.00	89.01 ± 1.66	82.71 ± 3.56	111.47 ± 6.65	83.78 ± 2.62	112.13 ± 2.56	95.82 ± 14.78
	N. oleander	15.19 ± 1.53	79.52 ± 6.71	51.81 ± 3.02	92.65 ± 2.03	96.78 ± 3.75	105.15 ± 4.00	85.18 ± 20.83
	R. communis	22.31 ± 3.80	112.86 ± 4.09	101.25 ± 4.77	117.78 ± 3.51	121.91 ± 3.07	130.23 ± 5.39	116.80 ± 10.78
Autumn	*C. ciliaris*	12.92 ± 1.54	59.12 ± 3.09	59.21 ± 6.19	75.78 ± 4.20	83.57 ± 3.79	92.89 ± 2.50	74.11 ± 14.93
	C. dactylon	17.00 ± 2.92	87.16 ± 3.46	79.86 ± 1.12	93.46 ± 3.01	104.07 ± 4.88	113.91 ± 3.27	95.69 ± 13.51
	C. procera	14.64 ± 0.99	83.79 ± 2.04	63.11 ± 3.17	92.49 ± 3.20	111.68 ± 2.65	103.98 ± 7.31	91.01 ± 18.90
	N. oleander	13.29 ± 2.53	97.79 ± 3.76	58.41 ± 6.03	82.81 ± 3.47	89.52 ± 8.24	97.69 ± 3.76	85.24 ± 16.25
	R. communis	19.08 ± 3.18	97.91 ± 3.56	84.82 ± 3.55	106.14 ± 5.02	111.01 ± 5.31	118.48 ± 3.03	103.67 ± 12.92
Winter	*C. ciliaris*	7.27 ± 0.57	52.14 ± 1.94	43.95 ± 4.36	67.51 ± 5.37	65.98 ± 3.36	73.18 ± 1.50	60.55 ± 12.08
	C. dactylon	9.96 ± 0.55	68.38 ± 1.81	61.14 ± 2.50	75.81 ± 7.52	84.58 ± 1.91	93.85 ± 2.03	76.75 ± 12.93
	C. procera	12.94 ± 7.62	64.81 ± 1.61	69.61 ± 7.59	86.32 ± 7.02	78.18 ± 2.50	86.14 ± 3.50	77.01 ± 9.68
	N. oleander	4.52 ± 1.63	61.94 ± 3.77	48.50 ± 2.00	64.10 ± 3.10	72.14 ± 9.01	80.15 ± 5.50	65.37 ± 11.86
	R. communis	10.05 ± 1.85	88.32 ± 3.79	67.15 ± 4.50	87.82 ± 2.57	101.51 ± 3.02	107.99 ± 4.73	90.56 ± 15.68
Spring	*C. ciliaris*	8.93 ± 1.09	60.81 ± 1.61	38.79 ± 7.11	68.62 ± 4.44	71.50 ± 3.65	81.10 ± 0.98	64.16 ± 15.94
	C. dactylon	11.64 ± 1.01	82.18 ± 3.50	71.49 ± 4.01	86.82 ± 4.53	97.49 ± 4.77	101.81 ± 0.72	87.96 ± 12.13
	C. procera	11.05 ± 0.45	73.65 ± 3.61	65.22 ± 4.26	91.64 ± 6.23	86.15 ± 3.50	94.80 ± 4.55	82.29 ± 12.50
	N. oleander	10.39 ± 1.28	67.17 ± 1.11	59.47 ± 3.00	75.85 ± 1.59	97.48 ± 5.50	93.48 ± 5.56	78.69 ± 16.44
	R. communis	14.25 ± 1.15	92.14 ± 7.25	76.80 ± 2.58	102.18 ± 8.42	106.66 ± 3.33	113.82 ± 4.54	98.32 ± 14.37

Table 4: Pearson's correlation coefficient between average daily traffic and Zn content in soil and plant leaves during different seasons along "FOR" and "N-5"

	FOR				N-5			
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Soil	0.98***	0.84*	0.90**	0.89**	0.95***	0.99***	0.98***	0.81*
C. ciliaris	0.85*	-0.11 ns	0.91**	0.80*	0.93**	0.97***	0.97***	0.96***
C. dactylon	0.95***	0.92**	0.80*	0.80*	0.72 ns	0.99***	0.98***	0.83*
C. procera	0.92**	0.99***	0.95***	0.39 ns	0.61 ns	0.90**	0.75 ns	0.93***
N. oleander	0.83*	0.51 ns	0.68 ns	0.97***	0.91**	0.64 ns	0.99***	0.69 ns
R. communis	0.68 ns	0.97***	0.96***	0.65 ns	0.97***	0.96***	0.97***	0.93***

ns=non-significant; * , ** and ***= significant at 0.1, 0.05, 0.01 levels, respectively

kg^{-1} along National Highway (Hyderabad, Pakistan). The Zn content in soil found during present study were higher than reported by others studies, 90.43 $\mu g\ g^{-1}$ in Nigeria (Akan *et al.* 2013), 123.2 mg kg^{-1} in Karak, Jordan (Al-Khashman 2004) and lower than 499.20 mg kg^{-1} in Delhi (Banerjee 2003). However, the limit of Zn in soil is 100–150 mg kg^{-1} (ECDGE 2010).

A comparison between roads showed higher Zn content along "N-5" than "FOR". This might be due to high traffic density along "N-5". The contamination of Zn along roads is always directly linked to the age of road and "FOR" is a newly constructed road so it's not only about the traffic density at a specific time but a lifetime traffic flow counts as well (Morse *et al.* 2016). The presence of Zn in the roadside soil indicated that vehicles are the key anthropogenic source of Zn pollution and the Zn contents may vary at different sites due to meteorological variations, road structure and traffic density (Khan *et al.* 2011).

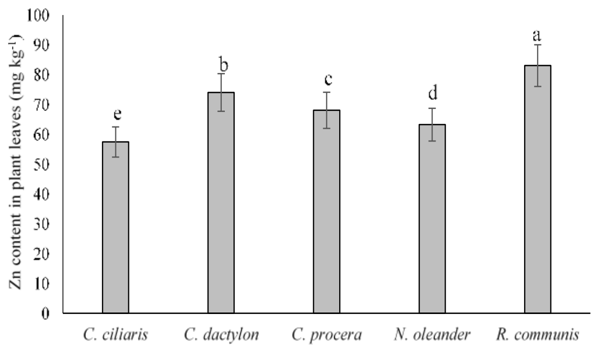

Fig. 2: Mean of Zn content (mg kg^{-1} dry wt.) in plant leaves along "FOR"

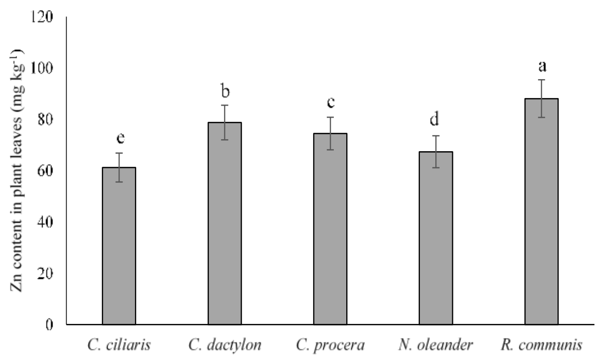

Fig. 3: Mean of Zn content (mg kg^{-1} dry wt.) in plant leaves along "N-5"

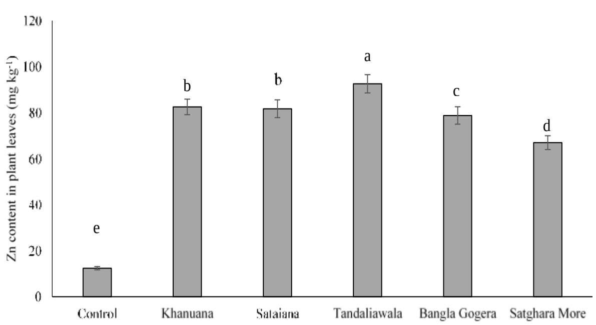

Fig. 4: Spatial variations in mean Zn content (mg kg^{-1} dry wt.) in plant leaves along "FOR"

The vehicular released metal that gets deposited on roadside soil may enter into plants and plants act as a sink of metal accumulation (Liu *et al*. 2012). These plants could be used as indicator of metal pollution (Berlizov *et al*. 2007). In present study maximum Zn contents in plants were recorded in "Tandaliawala "site along "FOR" and "Chung" site along "N-5". The uptake of Zn by plants at different sites showed a linear relationship with Zn content in soil (Kabata-Pendias 2011).

During present study, the mean Zn contents in plant leaves along "FOR" and "N-5" were recorded in the following order *R. communis* > *C. dactylon* > *C. procera* >

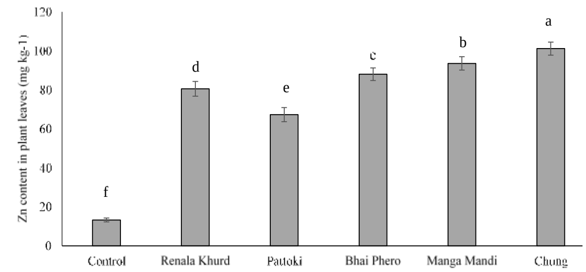

Fig. 5: Spatial variations in mean Zn content (mg kg^{-1} dry wt.) in plant leaves along "N-5"

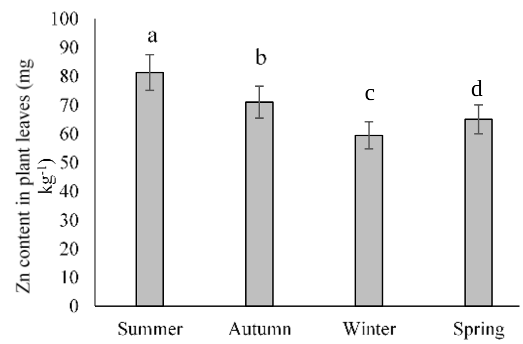

Fig. 6: Temporal variations in mean Zn content (mg kg^{-1} dry wt.) in plant leaves along "FOR"

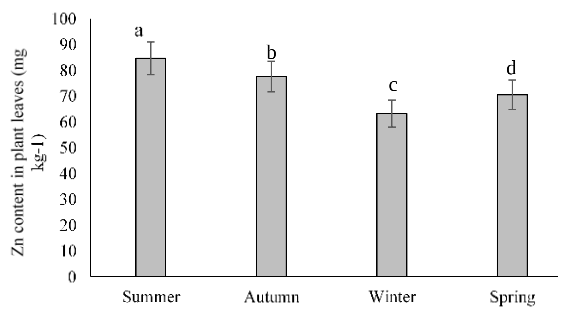

Fig. 7: Temporal variations in mean Zn content (mg kg^{-1} dry wt.) in plant leaves along "N-5"

N. oleander > *C. ciliaris.* The Zn content in plant leaves varied significantly among different species (Nabulo *et al.* 2006) due to environmental factors and genotypes (Kabata-Pendias 2011). Hesami *et al.* (2018) noticed 740 mg kg^{-1} Zn uptake in *Roemeria hybrid*. In Gillgit, Pakistan, the highest Zn content (271.0 mg kg^{-1}) was found in *Brassica campestris* and 247.0 mg kg^{-1} in *Malva sylvestris* (Khan *et al.* 2010). The standard limit of Zn in plant is 100 mg kg^{-1} (Allen *et al.* 1974). However, the safe limit of Zn for plant recommended by FAO/WHO (2011) is 60.0 mg kg^{-1}. The mean Zn content in all plant species along both roads under investigation were above the permissible limit except for *C. ciliaris* along "FOR", while at control site were within the safety limit. Concentrations of Zn in plants at polluted sites persisted to be significantly higher than control site plants.

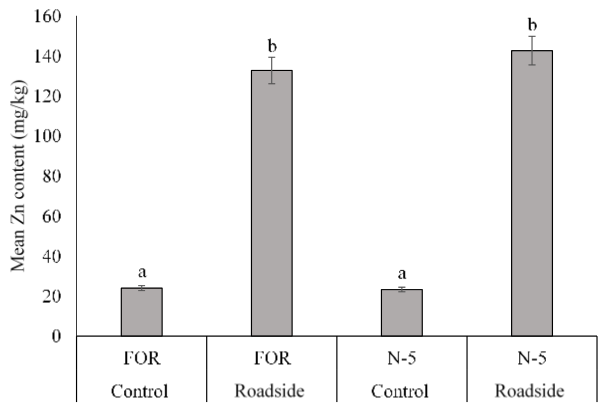

Fig. 8: Comparison among roads for mean Zn contents (mg kg^{-1} dry wt.) in soil

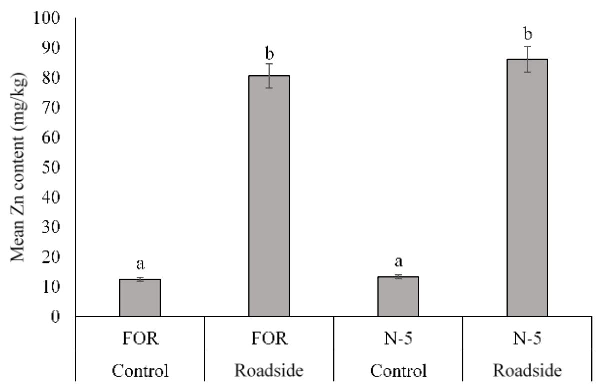

Fig. 9: Comparison among roads for mean Zn contents (mg kg^{-1} dry wt.) in plant leaves

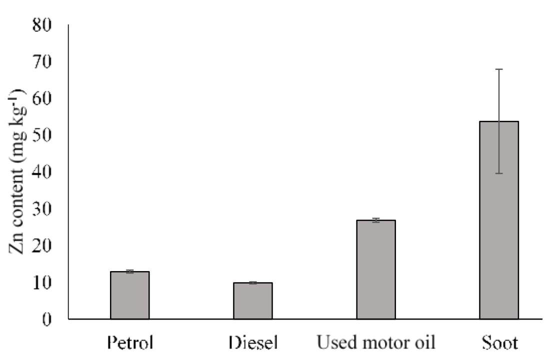

Fig. 10: Zinc content in fuel and soot (mg kg^{-1})

This showed a direct relationship of plant metal content with traffic volume signifying vehicles as the major source of heavy metals. All the selected plants are good indicator of Zn toxicity however, *R. communis* with highest levels of Zn could be used as the best indicator among all selected plant species and can be used to monitor and ameliorate heavy metal pollution along roadsides. All the plant species and soil samples showed highest Zn contents in summer and lowest in winter season. This might be due to high traffic density and wear of tyres at high temperature (Aksoy *et al.* 2000; Zaidi *et al.* 2005; Naveed *et al.* 2010).

A significant amount of Zn was found in petrol, diesel, used motor oil and soot (Fig. 10). A high level of Zn in diesel and lubrication oil was detected by Betha *et al.* (2012). Chin-Hsiang *et al.* (2009) observed that the relative contents of Zn by weight were 19.9% in diesel soot. Traces of Zn (0.7%) in soot were detected by Uy *et al.* (2014). Metal in soot was also reported by Fino *et al.* (2016). Diesel soot is responsible for $1/4^{th}$ of total perilous atmospheric pollution (Omidvarborna *et al.* 2014). Hence, it can be concluded that a considerable amount of Zn come into the surroundings from vehicle soot (Malinowska *et al.* 2015).

Conclusion

Metal (Zn) contamination in the soil and plants along roadside was higher as compared to the control site (~ 50 meters from roadside). These concentrations were higher than the permissible levels set by WHO/FAO. This shows that environment along these roads is contaminated with vehicular released Zn metal. This could be hazardous for crops along roads and human residing near roads. Safety measures are requisite to overcome this toxicity problem. The results also indicated that all selected plants are reasonable indicators of vehicular related Zn pollution in the area. The maximum Zn uptake was detected in *R. communis* during Summer season so it could be a good choice for phytomonitoring purpose.

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