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Biomonitoring of heavy metals in feathers of eleven common bird species in urban and rural environments of Tiruchirappalli, India

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Abstract Heavy metals continue to remain as a major environmental concern in spite of emission control measures. In this study, we analyzed the concentrations of heavy metals (Fe, Cr, Mn, Ni, Cu, Zn, and Cd) in the feathers of 11 species of birds collected from urban and rural areas of Tiruchirappalli, Southern India. Metal concentrations followed the order: Fe>Cu>Zn>Cr>Mn>Ni>Cd. Irrespective of sample locations, heavy metals such as Fe, Cr, Ni, Zn, and Cu were detected in high concentrations, while Cd and Mn were observed in lower concentrations. In contrary to our assumption, there were no statistically significant intraspecific and urban-rural differences in the metal concentrations except for Zn. Pairwise comparisons among species irrespective of metal type showed significant interspecific differences between *Acridotheres tristis* and *Centropus phasianinus*, *A. tristis* and *Milvus migrans*, *C. phasianinus* and *M. migrans*, *M. migrans* and *Eudynamys scolopaceus*, and *Psittacula krameri* and *E. scolopaceus.* Principal component analysis carried out for urban data extracted Ni, Mn, Zn, Fe, and Cu accounting for 48 % variance implying dietary intake and external contamination as important sources for metals. In the rural, association of Zn, Cd, Ni, and Cr suggests the impact of metal fabrication industries and leather tanning operations.

Keywords Environmental pollution · Biomonitoring · Heavy metals · Bird feathers · Ecosystem health

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Introduction

Although many heavy metals are nutritionally essential for the growth of living organisms, concentrations exceeding the threshold levels in the environment are considered to be toxic. Furthermore, persistent nature of heavy metals and their bioaccumulation capability continues to cause prolonging threat to the ecosystem health. In recent decades, the anthropogenic sources of heavy metals in the environment have substantially increased due to rapid rise in industrial activities, mine discharges, disposal of hazardous industrial wastes, vehicular emissions, paints, fertilizers and manures, coal combustion, and incineration (Wei and Yang 2010; Xia et al. 2011). Urban-centric development and the related activities including traffic, biomass and solid waste combustion and urban runoff have been recognized as important sources of heavy metals. Urban traffic emits substantial quantities of heavy metals into the atmosphere, and roadside soils act as a reservoir (Manta et al. 2002; Mohanraj et al. 2004; Sternbeck et al. 2002). Chen et al. (2010) have recorded notably higher levels of heavy metals in the urban soils. As the pollution sources increase rapidly in urban environment, an imperative need for multifaceted experimental approaches to assess the ecotoxicity has become inevitable. In the pursuit, biomonitoring of toxic contaminants is an approach that dates back to the early 1960s (Harada

1995). Goede and Bruin (1984), in their experimental report, established that bird feathers can be used as indicators to assess heavy metal exposures. Since then, a number of studies have been carried out using feathers to assess heavy metal bioaccumulation (Burger 2013; Costa et al. 2011; Markowski et al. 2013).

Heavy metals in the environment tend to accumulate in the tissues of living organisms, especially in the blood, liver, kidney, bones, feathers, hairs, and eggs. Therefore, biological organisms have been recognized as bioindicators of metal contamination, of which birds are of interest because they are long-lived, have different dietary habits, represent more than one trophic level, and quantify the overall health of an ecosystem (Markowski et al. 2013). Feathers reflect the amount of metals present in the blood at the time of feather growth, either from current dietary sources or from mobilization of metals from internal organs (Burger 1993). Feathers are connected with the bloodstream through the small blood vessels, and the metals can bind to protein molecules in the feather during its growth (Dauwe et al. 2003). However, the metal concentrations in feathers not only reflect their dietary intake but also the external contamination. Birds are highly exposed to atmospheric pollution, rainfall, through fall, contact with soil, dust, and water, which may potentially represent the sources of external contamination (Jasper et al. 2004; Cardiel et al. 2011).

Majority of studies on biomonitoring of contaminants in feathers were conducted in wetland birds. Investigations on terrestrial birds are relatively scarce except a few studies in passerine birds (Beyer et al. 2004; Dauwe et al. 2000). Among the studies in water birds, a long-term study conducted by Burger et al (2013) at Barnegat Bay, New Jersey from 1989 to 2011, found that heavy metal concentrations in the fledgling feathers of great Egret varied significantly in terms of temporal and spatial aspects. In a terrestrial study, Markowski et al. (2014) found significant differences in feather metal concentrations of Tits (*Parus major*, *Cyanistes caeruleus*) between urban parkland and deciduous forest. In Indian subcontinent, few studies have been conducted to evaluate bioconcentrations of metals in birds and indicated the existence at substantially higher levels (Abdullah et al. 2015; Muralidharan et al. 2004; Malik and Zeb 2009). However, on terrestrial birds, there is no published data, particularly in Southern India. Therefore, the objective of the present study was to examine heavy metal contamination in feathers of common birds present both in urban and rural environments of Tiruchirappalli (Southern India) and elucidate if there is any interspecific, intraspecific, and urban-rural differences.

Materials and methods

Study area

Feather samples for the present study were collected from the urban and rural environs of Tiruchirappalli (located between 10 and 11–30′ Northern Latitude and 77–45′ and 78–50′ Eastern Longitude). Tiruchirappalli is the fourth largest city in Tamilnadu state of Southern India and one of the rapidly growing cities of India. Industrial growth in Tiruchirappalli started after establishment of two major public sector enterprises, namely, Bharat Heavy Electricals Limited and Heavy Alloy Penetrator Project in 1970 and 1980, respectively. These developments subsequently fostered the growth of ancillary industries. At present, more than 300 metal industries operate in this area producing 150,000 metric tons of steel annually. As an offshoot, vehicular growth in Tiruchirappalli increased considerably from 23,276 in the year 1981 to 420,322 in 2012. These anthropogenic developments including industrialization and urbanization act as sources to enrich the metal concentrations of the background environment.

Sample collection

An erstwhile study conducted by the authors found that in Tiruchirappalli, about 140 bird species exist from 17 orders and 44 families (Menon et al. 2014). Among them, 118 are resident birds, 22 are winter migrants, and more than 10 species are abundant both in urban and rural landscapes. Hence, for the present study, feathers of 11 species of birds (abundant in urban and rural) including *Acridotheres tristis*, *Centropus phasianinus*, *Columbia livia*, *Corvus splendens*, *Egretta garzetta*, *Eudynamys scolopaceus*, *Milvus migrans*, *Passer domesticus*, *Pavo cristatus*, *Psittacula krameri*, and *Agapornis roseicollis* (pet bird) were collected from their roosting sites during January–June 2013. In urban Tiruchirappalli, feather samples were collected in and around areas of Cantonment, Wooriyur, Thillai Nagar, Sundarnagar, and Srirangam, while in rural, the sample collections were carried out in Suriyur, Mathur, Ponmallai, Satnur, and Palur (Fig. 1). For each species,

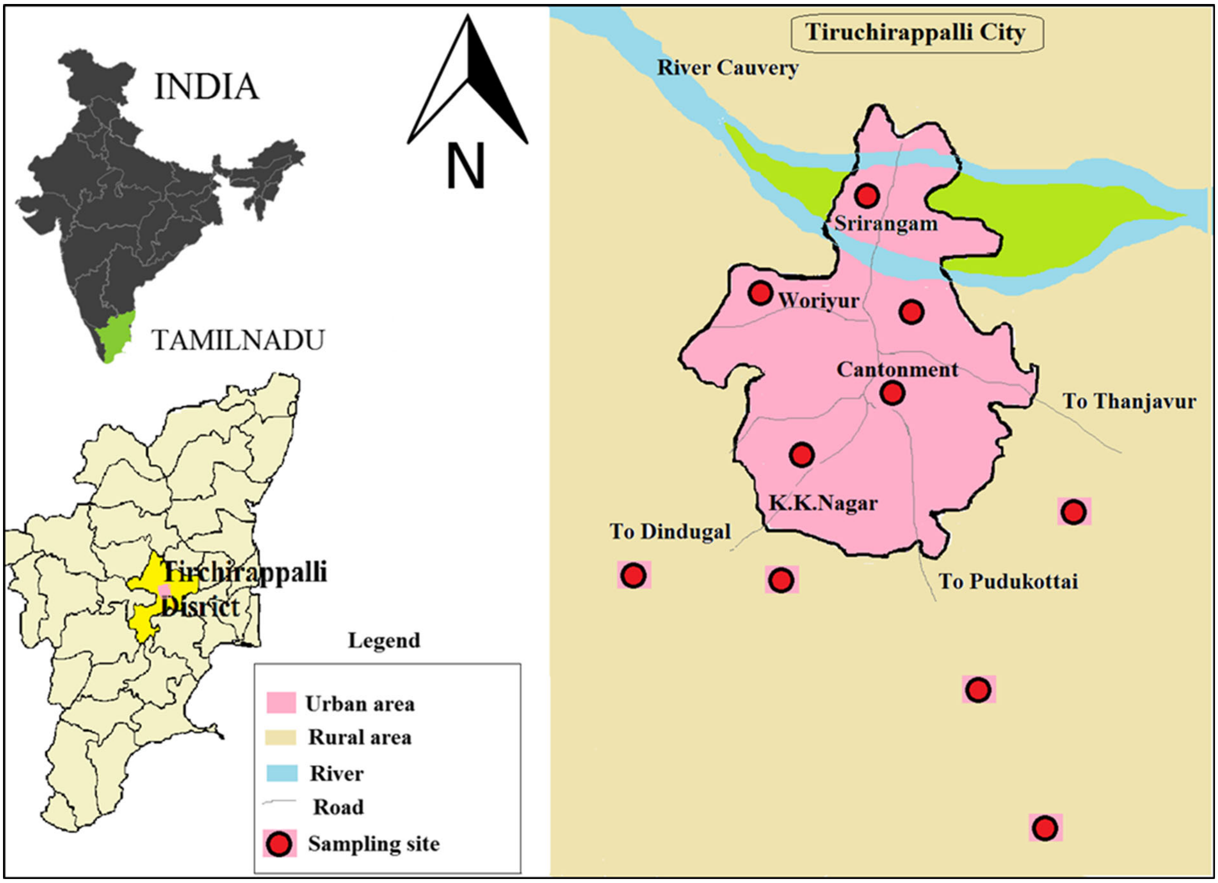

Fig. 1 Study area with sampling locations

a minimum of 2 g of feathers were collected at a specific location and carefully packed in acid-washed (30 % nitric acid) polythene containers for laboratory analysis. Prior to analysis, the samples were washed vigorously in deionized water alternated with acetone to minimize the adherent external contamination and then dried at 48 °C for 2 days.

Chemical extraction of metals and analysis

Concentrations of seven metals, namely, Fe, Cr, Mn, Ni, Cu, Zn, and Cd, were analyzed in 110 samples (55 urban and 55 rural) from 11 species of birds. One gram of feather sample was digested in a microwave digestion system (Model: Sineo Microwave Digestion System MDS-6, Make: China) using 10-ml concentrated HNO_3 acid for 10 min followed by 1 ml $HClO_4$ for 5 min and 7 ml of H_2O_2 for 10 min at 250 W power (Muralidharan et al. 2004). Solutions were made up to 50 ml with deionized water. Duplicate samples were prepared using the same procedure. The digested samples were filtered, stored in amber vials, and subjected for heavy metal residual analysis using atomic absorption spectroscopy (Thermo Fischer-iCE 3000 series). Prior to feather sample analysis, the instrument was calibrated using standard solutions of each metal obtained from Fisher Scientific Company (USA). The recovery rate for each metal was measured using standard solutions at different concentrations to ensure the accuracy of the analytical procedure. Overall, recovery rates for all metals ranged between 80 and 100 %, and the relative standard deviation of triplicate measurements was less than 5 %.

Results obtained were statistically analyzed using SPSS version 22. To understand if there were any interspecific, intraspecific, and urban-rural differences in metal concentrations, analysis of variance was attempted with Tukey's honest significant difference test at a confidence level of 95 % for pairwise comparisons. To test the relationship between the observed

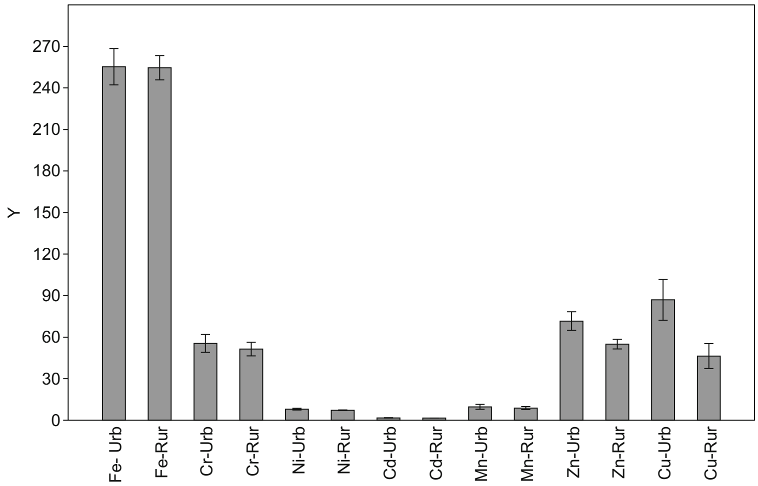

Fig. 2 Barchart showig mean values and standard deviation values of metal concentrations in feathers of 11 species. *Urb* urban samples, *Rur* rural samlples

concentrations of metals, Pearson correlation coefficient analysis was applied. Principal components analysis (PCA) was performed separately for urban and rural samples (data set of 55 samples for each urban and rural) using correlation matrix to identify the source. Extraction was performed in promax rotation with Kaiser normalization, and components were extracted for eigenvalues >1.

Results and discussion

Metal concentrations (Fe, Cr, Ni, Cd, Mn, Zn, and Cu) in feathers of 11 species of birds including urban-rural comparisons are shown as bar chart illustrations with mean and standard deviations (Fig. 2). Irrespective of the sampling locations, mean metal concentrations varied in the order: Fe>Cu>Zn>Cr>Mn>Ni>Cd. Among the various metals observed, the mean concentrations of Fe detected in the urban and rural samples were 255.33 and 254.59 μg/g, respectively (Tables 1 and 2). Among the species, highest concentrations of Fe in the urban samples were recorded in *Corvus splendens* (329.35 μg/g), and in the rural samples in *Columbia livia* (312.21 μg/g). In the study area, passerines were mostly territorial and nonmigratory residents, and therefore, the detected contaminant levels refer to a particular geographic range, reflecting the potential of passerines suitable for identifying local contamination (Chao et al. 2003). Previous studies have recorded Fe in the following range: *Bubulcus ibis* 200.56±87.73 μg/g (Ullah et al. 2014), in *Aegypius monachus* 215±128 μg/g (Kavun 2004), in *Larus crassirostris* from Dokdo 244.57 μg/g, and from Hongdo in South Korea

Table 1 Heavy metal concentrations (μg/g) in the feathers of urban samples (mean and standard deviation)

Bird species	Fe	S.D	Cr	S.D	Ni	S.D	Cd	S.D	Mn	S.D	Zn	S.D	Cu	S.D
A. tristis	228.54	±23.31	85.73	±7.11	8.51	±1.93	1.7	±0.75	11.52	±2.34	70.65	±5.75	80.32	±9.44
C. phasianinus	191.33	±15.6	36.96	±5.72	7.7	±0.87	1.53	±0.38	13.17	±3.71	87.69	±7.6	90.59	±12.73
C. livia	229.03	±15.45	63.14	±11.23	8.57	±2.1	2.33	±0.16	4.16	±1.8	65.76	±8.42	125.66	±11.33
C. splendens	329.35	±18.97	76.47	±3.88	13.31	±1.54	1.75	±0.22	22.82	±2.73	114.28	±12.1	139.01	±20.54
E. garzetta	205.76	±12.67	50.66	±5.31	7.01	±1.21	1.55	±0.31	3.61	±0.79	48.25	±4.92	49.49	±3.78
E. scolopaceus	268.65	±20.34	74.3	±10.33	7.8	±0.99	1.72	±0.72	5.8	±1.12	60.37	±4.74	68.48	±5.62
M. migrans	288.21	±8.58	55.49	±6.6	7.15	±0.34	1.62	±0.08	14.09	±4.21	52.71	±3.89	53.13	±5.22
P. domesticus	264.48	±16.77	53.13	±3.38	76.6	±1.85	1.64	±0.18	6.22	±0.93	98.16	±7.58	148.29	±23.13
P. cristatus	316.51	±30.4	52.24	±4.83	8.21	±2.2	1.78	±0.33	12.8	±2.97	72.85	±10.7	155.63	±18.76
P. krameri	248.63	±12.32	56.14	±8.71	6.4	±1.52	1.62	±0.47	3.58	±0.61	78.07	±6.36	27.77	±1.36
A. roseicollis	238.23	±15.08	6.11	±1.01	6.11	±1.64	1.56	±0.55	8.48	±1.44	38.91	±5.32	18.48	±0.79

Table 2 Heavy metal concentrations (μg/g) in the feathers of rural samples

Bird species	Fe	S.D	Cr	S.D	Ni	S.D	Cd	S.D	Mn	S.D	Zn	S.D	Cu	S.D
A.tristis	221.75	±23.1	55.14	±6.39	7.54	±1.83	1.59	±0.51	7.17	±2.6	65.1	±8.73	25.86	±6.07
C.phasianinus	260.89	±15.7	53.12	±5.39	6.72	±2.4	1.49	±0.72	14.09	±4.27	46.7	±7.39	58.81	±5.65
C.livia	312.21	±17.7	51.65	±2.34	7.3	±1.23	1.64	±1.22	7.19	±2.25	48.86	±2.53	44.42	±1.22
C.splendens	235.98	±13.28	60.13	±8.8	7.99	±0.91	1.57	±0.9	11.18	±3.57	48.17	±5.46	61.1	±5.88
E.garzetta	249.18	±15.31	48.38	±4.31	6.34	±2.31	1.54	±0.42	4.05	±1.15	57.15	±5.03	26.65	±5.31
E.scolopaceus	248.97	±14.11	67.03	±10.4	6.92	±1.77	1.64	±0.22	4.68	±0.93	51.54	±7.69	23.93	±4.05
M.migrans	228.84	±16.45	66.71	±6.38	8.08	±2.62	1.51	±0.73	14.81	±4.6	53.46	±6.31	32.22	±5.62
P.domesticus	238.24	±13.8	55.37	±3.97	8.13	±1.38	1.71	±0.4	6.22	±1.8	75.91	±8.9	21.04	±3.84
P.cristatus	260.04	±10.83	51.39	±4.83	8.01	±0.73	1.72	±0.47	10.97	±3.02	65.54	±10.3	107.64	±14.83
P.krameri	304.04	±16.91	50.85	±7.6	6.42	±1.7	1.68	±0.71	9.15	±2.77	60.07	±9.3	49.16	±6.95
A.roseicollis	240.44	±11.1	6	±3.2	6	±0.7	1.43	±0.18	7.23	±2.08	32.35	±4.94	19.23	±0.08

148.07 μg/g (Kim et al. 2013), which were comparable to the present study. The high concentrations of Fe in feathers reflect the diet and the mobilization quantities stored during the period of feather growth (Dauwe et al. 2000; Rattner et al. 2008). However, the concentrations of metals detected in the present study do not necessarily indicate the dietary source, but also the external sources of contamination, in spite of rigorous cleaning procedures adopted for sample preparation. It is understood that heavy metal adherence to feathers does occur by deposition of chemicals in the atmosphere, from soil, and through preening feathers with oil from the uropygial gland (Burger 1993; Dauwe et al. 2003).

The mean concentration of Cr recorded in the urban and rural samples was 55.48 and 51.43 μg/g, respectively (Tables 1 and 2). Chromium is not an essential element for animals, and it may cause deleterious effects on reproductive health of avian species (Malik and Zeb 2009). In the present study, highest concentrations of Cr in the urban samples were recorded in *Acridotheres tristis* (85.73 μg/g) and in the rural landscape in *Eudynamys scolopaceus* (67.03 μg/g). The Cr concentrations observed in the present study are relatively higher compared to the levels reported by other studies in the Indian subcontinent (Abdullah et al. 2015; Ullah et al. 2014; Muralidharan et al. 2004). The high levels of Cr observed in the samples exceeding the threshold of 2.8 μg/g (Burger and Gochfeld 2000) could be linked to the anthropogenic source of contamination. Tiruchirappalli is also known for leather tanning, and currently, more than 21 units operate in and around the city. Many of these tanneries adopt chrome tanning process, which releases Cr containing effluent and sludge into the environment.

Ni concentrations detected in urban and rural samples ranged between 6.11±1.64–13.31±1.54 and 6±0.7–8.13±1.38, respectively (Tables 1 and 2). Highest concentrations of Ni were detected in *Corvus splendens* and *Passer domesticus* in the urban and rural environments, respectively. Overall, variance analysis of urban-rural samples also did not show any significant differences, implying the ubiquitous distribution of Ni in the food

Table 3 One-way ANOVA followed by Tuckey's comparison between urban-rural concentrations of metals

Urban-rural comparison of metal concentrations	Sum of squares	*df*	*F*	*P*
Fe	3.0118	1	0.002205	0.963
Cr	90.41	1	0.2495	0.6229
Ni	3.50801	1	1.624	0.2171
Cd	0.074	1	2.56	0.1253
Mn	4.11091	1	0.1717	0.683
Zn	1519.73	1	4.807	0.04033
Cu	9567.65	1	1.566	0.2253

Table 4 One-way ANOVA followed by Tuckey's comparison between species irrespective of metals (*p* values)

	A. tristis	*C.phasianinus*	*C. livia*	*C.splendens*	*E.garzetta*	*E.scolopaceus*	*M.migrans*	*P.domesticus*	*P.cristatus*	*P.kramer-i*	*A.roseicollis*
A. tristis		1	1	1	1	1	1	1	0.9901	1	1
C. phasianinus	0.00097		1	1	1	1	1	1	0.99	1	1
C. livia	0.1795	0.1805		1	1	1	1	1	0.9962	1	0.9999
C. splendens	0.7439	0.7449	0.5644		0.9996	1	1	1	1	1	0.9926
E. garzetta	0.3292	0.3282	0.5087	1.073		1	1	1	0.9603	1	1
E. scolopaceus	0.06115	0.06213	0.1183	0.6828	0.3903		1	1	0.9927	1	1
M. migrans	0.0204	0.02137	0.1591	0.7235	0.3496	0.04075		1	0.991	1	1
P. domesticus	0.4868	0.4878	0.3073	0.2571	0.8159	0.4256	0.4664		0.9995	1	0.9984
P. cristatus	1.577	1.578	1.398	0.8332	1.906	1.516	1.557	1.09		0.9939	0.8543
P. krameri	0.09583	0.0968	0.0837	0.6481	0.425	0.03467	0.07543	0.391	1.481		0.9999
A. roseicollis	0.7751	0.7741	0.9546	1.519	0.446	0.8363	0.7955	1.262	2.352	0.8709	

chain of urban and rural environments. Ni detected in the present study is comparatively lower than some of the recent studies: For instance, Abdullah et al. (2015) reported 30–47.5 μg/g at Lahore and 77–89 μg/g at Sialkot in Pakistan; similarly, Nighat et al. (2013) recorded higher concentrations of Ni ranging up to 32.61 μg/g in the feathers of *Milvus migrans* at Pakistan. However, the values of Ni reported by Mansouri et al. (2012) from Southern Iran, in the feathers *Larus heuglini*, are comparatively lower (0.78±0.30 μg/g) than the present study. Nickel is one among the toxic elements that causes health risk to humans, and in the birds, it is likely to interfere with plumage intensity (Eeva et al. 1998).

Cd concentrations detected in the feathers of urban and rural samples were 1.70 and 1.59 μg/g, respectively (Tables 1 and 2). The highest concentration of Cd in the urban samples were recorded in *Columba livia* (2.33 μg/g), a granivorous species, and in the rural samples in *Pavo cristatus* (1.72 μg/g). Analysis of variance carried out to distinguish urban-rural differences did not yield any significant *p* value. The levels of Cd reported in this study are also comparable to the levels reported by Bichet et al. (2013), Pan et al. (2008), and Swaileh and Sansur (2006). Cadmium is reportedly toxic to birds, and it is linked to egg deformation, oviduct malfunctions, and kidney damage (Burger 2008; Scheuhammer 1987).

Mn is an essential micronutrient that plays a vital role in many metabolic and biochemical reactions. The mean concentrations of Mn recorded in the urban and rural samples were 9.65 and 8.79 μg/g, respectively. The highest concentrations of Mn in the urban samples were detected in *Corvus splendens* (22.82 μg/g), while in the rural samples in *Milvus migrans* (14.81 μg/g). The levels of Mn reported in the study are comparable to the levels reported by Abdullah et al. (2015) in *Bubulcus ibis* (21 μg/g), by Kim et al. (2013) in *Ardea cinerea* (9.90±3.62 μg/g), and in *Egretta garzetta* (9.94±2.75 μg/g). Mn contamination in food chain generally occurs as a result of crustal origin; however, certain other anthropogenic sources such as urban waste dumps and industrial effluents also contribute to Mn contamination (Abdullah et al. 2015).

The mean concentrations of Zn recorded in the urban and rural samples were 71.60 and 54.98 μg/g, respectively. The highest concentrations of Zn in the urban samples were detected in *Corvus splendens* (114.28 μg/g), and in the rural samples in *Passer domesticus*

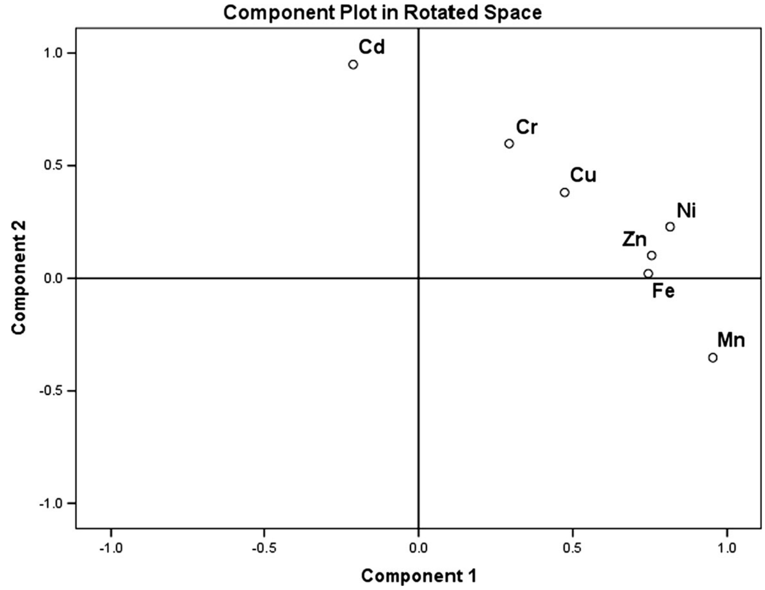

Fig. 3 Principal component analysis of the concentrations of heavy metals in feathers of birds from urban habitats

(75.91 μg/g). Analysis of variance between urban and rural samples showed significant differences in Zn concentrations (*F*, 4.807; *P*, 0.04 (Table 3)). The values of Zn observed in the current study are lower compared to the levels reported by Kim et al. (2013) in feathers of *Ardea cinerea* (204±57.2 μg/g) and *Egretta garzetta* (233±64.7 μg/g).

The mean concentrations of Cu recorded in bird feathers of the urban and rural samples were 86.9 and 42.7 μg/g, respectively. In the case of Cu, substantial interspecific variation was observed ranging between 18.48 and 155.63 μg/g (Table 1). The highest concentration of Cu among species was detected in *Pavo cristatus*, both in the urban and rural samples. The results of the study are in consistent with previous studies by Costa et al. (2011) and Dmowski (1999). Although Cu is considered as an essential element for various physiological functions and structural component of numerous metalloenzymes, its uptake in excess quantity is related to harmful effects including growth irregularity, respiratory malfunctions, carcinogenesis, and

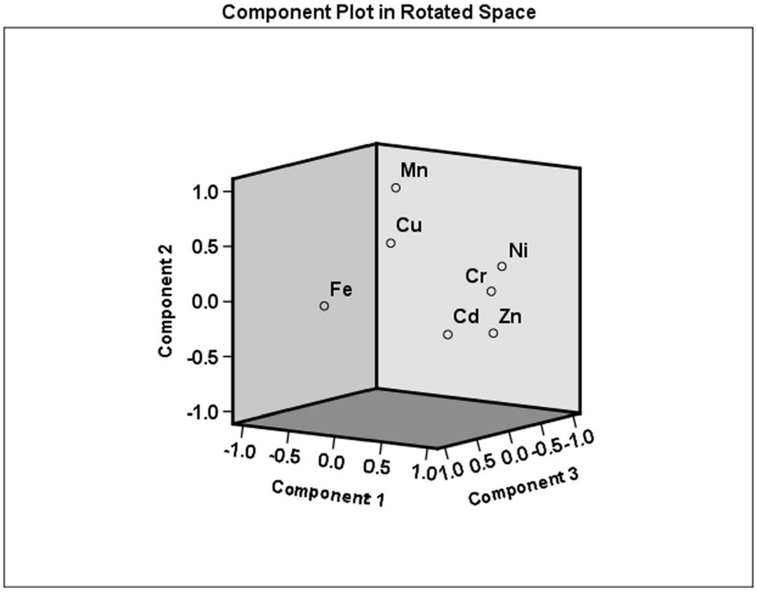

Fig. 4 Principal component analysis of the concentrations of heavy metals in feathers of birds from rural habitats

certain disorders in reproductive, gastrointestinal, hematological, hepatic, and endocrine systems (Stern 2010).

From the present study, it could be inferred that the most impacted bird species due to heavy metal contamination in the urban and rural landscapes are *Pavo cristatus* and *Passer domesticus*. No significant differences of metal concentrations existed between the urban and rural samples except for Zn (f= 1, f=4.80, p=0.004, Table 3). Analysis of variance followed by Tuckey pairwise comparisons for interspecific differences (irrespective of urban-rural samples and metal type) showed significant differences between *A. tristis* and *C. phasianinus*, *A. tristis* and *M. migrans*, *C. phasianinus* and *M. migrans*, *M. migrans* and *E. scolopaceus*, and *P. krameri* and *E. scolopaceus* (Table 4). Earlier studies have also mentioned such interspecific variability (Jansenns et al. 2003; Llacuna et al. 1995; Tsipoura et al. 2008) and emphasized the necessity to record bioaccumulation of metals in bird feathers at a particular site. Many studies also reiterate that metal accumulations in feathers between species are variable, and this may be due to species-specific peculiarities of their diets (Llacuna et al. 1995; Tsipoura et al. 2008). In Tiruchirappalli, the metal enrichment in urban areas and in the biotic components could probably be attributed to traffic and diesel powered generators, while in the rural environs, it could be linked to the recent proliferation of metal fabrication industries and the establishment of new industrial estates.

In the urban landscape, significant positive correlations were obtained between the metals: Ni-Mn (r=0.73, p<0.00) and Ni-Zn (r=0.69, p<0.01). Likewise, in the rural environment, significant positive correlations were observed between the metals: Cr-Ni (r=0.60, p<0.04) and Zn-Cd (r=0.76, p<0.00). These results indicate that in the urban landscape, metal combination like Ni-Mn and Ni-Zn may have a similar source of origin, while in the rural landscape, metal combinations of Cr-Ni and Zn–Cd could be attributed to similar source. However, the association between Cr-Ni and Zn-Cd is unclear and remains to be investigated further.

PCA for urban habitat extracted two components explaining 67 % variance (Fig. 3). Factor 1 accounted for 48 % variance with loadings of Ni, Mn, Zn, Fe, and Cu, while factor 2 accounted for 18 % with loadings of Cd and Cr. The combination of metals in factor 1 probably suggests the dietary source of metals in feathers; however, external contamination from anthropogenic sources such as atmospheric deposition and soil suspension also cannot be ruled out. The second factor (Cr-Cd combination) may be linked to the anthropogenic sources mainly from leather tanning industries and metal fabrication units present in and around Tiruchirappalli. The PCA for rural values extracted three factors accounting for total variation of 81 % (Fig. 4). Factor 1 accounted for 41 % variance with associations of Zn, Cd, Ni, and Cr, which mainly indicates the anthropogenic sources (leather tanneries, metal industries, and vehicular traffic) of metals in the food chain. The second factor which accounted for 22 % variance with loadings of Mn and Cu suggests natural sources of these metals in the diet. The third factor with loadings of Fe indicates the possibility of source from metal fabrication industries present in the rural areas.

Conclusion

The aim of this study is to determine the bioconcentrations of heavy metals using feathers of common birds as biomonitoring tool in the urban and rural environments of Tiruchirappalli, one of the fast growing urban and industrial centers of Tamilnadu, India. It was evident from the results that feather analysis is an effective and nondestructive strategy to study the heavy metal contamination in the food chain. We found higher concentrations of chromium, iron, copper, and zinc in the feather samples compared to the earlier studies in the Indian subcontinent. Principal component analysis revealed potential anthropogenic sources of contamination from leather tanneries, metal fabrication industries, and vehicular traffic. Except for zinc, no significant urban-rural differences were observed in the heavy metal concentrations of the feather samples. Among the 11 species of birds, pairwise comparisons between the species showed significant interspecific differences in heavy metal distribution irrespective of metal type.

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