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Impact of heavy metals from electronic waste on bird species concerning biodiversity: A case study in Bellandur lake, Bengaluru, India

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Abstract

Background: Heavy metals are one of the global environmental challenges from the informal disposal of electronic waste, especially after the post-COVID phase. In the present study, the concentration of three heavy metals (Pb, Cd, and Cr) in the feathers of *Corvus splendens*, *Passer domesticus* and roosting sites at Bellandur Lake, Bengaluru, India were analyzed.

Methods: A total of nine sediment samples (0-15 cm) were collected from the roosting sites and stored in polyethylene bags, and nine samples of *C. splendens* and *P. domesticus* bird shedding feathers through the molting phenomenon were collected naturally to avoid stimuli that can create conflict for the bird. The samples were collected early morning from 5.00 a.m. to 9 a.m. To determine heavy metals (Pb, Cd, and Cr) in feathers and sediments, the samples were digested and subjected to AAS and inductively coupled plasma-mass spectroscopy (ICP-MS). Furthermore, the generalized linear model was analyzed to test the covariance structure of bird diversity.

Results: The Pearson's correlation is found to be significant ($P<0.05$) for contaminated sediments and the feathers of the bird. Analysis of variance for the difference in the concentration of heavy metals within the bird's species feathers was not statistically significant ($P<0.05$).

Conclusion: The feathers of *C. splendens* and *P. domesticus* bird species are associated with blood vessels and heavy metals deposited in the blood through the food chain, which are contaminated with heavy metals. *C. Splendens* feathers were more contaminated with Cr, Pb, and Cd compared to *P. domesticus* feathers bird species.

Keywords: Electronic waste, Heavy metals, Birds, Feathers

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Introduction

The expansion of infrastructure and services through the digital platform has exponential growth of electronic and personal computing devices. Consequently, it is estimated that 20 to 50 million tons of electronic waste are produced globally each year (1). According to the UN report e-waste increase to 75 million tons in 2030 and if not managed effectively in rising to 111 million tons in 2050 (2).

E-waste disposal by the informal sector is a major effect on bird biodiversity (3). Compared to agricultural activities, e-waste with a concentration of heavy metals is the main cause of sediment pollution and threats to biodiversity (4). Bird species are sensitive to environmental changes especially House Sparrow (*Passer domesticus*) and House Crow (*Corvus splendens*) are observed in human habitation. The feeding habit depends on waste, which is from human habitats, insects, and fruits (5). The food chain acts as a carrier for heavy metals and results in biodiversity loss. The feathers are used as biomonitors (6) to determine the concentration of heavy metals in the blood vessels as, during the molting process, feathers isolate from the body after the formation (7). Bellandur Lake is one of the largest water body (8) with a catchment area of 148 square kilometers. Sediment quality with heavy metals concentrations, foam appearance, and accidental burning are the main issues. The study aimed to determine the concentration and correlation of three heavy metals (Pb, Cd, and Cr) in the feathers of bird species (*C. splendens* and *P. domesticus*) and sediments. The generalized linear model was studied for further analysis of the diversity of bird species with the concentration of heavy metals.

Materials and Methods

Study area

The study was conducted in Bellandur with a latitude of 12°57'36.000" N and a longitude of 77°42'0.000" E (Figure 1) in Bengaluru, Karnataka. According to the census (2011), the population was 80,180 with a density of 3,041/km^2. April month is the hottest month (33.4°C) and December is the coolest month (15.3°C) with average annual rainfall of 859 mm (9).

Sediment samples (S1 to S9) were collected from the roosting sites from June 2020 to July 2021 at Bellandur Lake, Bellandur. The sediment was collected to determine the concentration of heavy metals. Bird's feathers were collected from roosting sites especially downward of the lake because of cultivable land area and human settlements. Nine birds' feathers of *C. splendens* and *P. domesticus* were collected at a distance of a minimum of 3 meters from the sediment sample. The molting phenomenon was provided to collect feathers naturally early morning from 5.00 AM to 9 AM from June 2020 to July 2021.

Sample treatment, extraction, and analysis

The sediments were stored in polyethylene bags and were oven dried at 60°C for 2 days, followed by grinding with mortar and pestle and sieved using a 2 mm sieve. The samples were digested with a mixture of HNO_3 and H_2O_2 using EPA method 3050B (10). The solution was filtered through a 0.45 µm cellulose membrane filter and diluted to 10 mL with water that has been purified using an ion exchange cartridge (Milli-Q water), then, stored at 4°C before analysis. The concentration of each metal in the digestion solution was determined by inductively coupled plasma-mass spectroscopy (ICP-MS). Sample digests and blanks were arranged in duplicate for the analysis of the samples.

Feathers were washed with distilled water and cleaned with acetone (11) to reduce external contamination. The sample dried for 2 days at 48°C. A microwave digestion method was used to digest one gram of feather sample using 250 W power and 10 mL concentrated nitric acid for 10 minutes, 1 mL perchloric acid for 5 minutes, and 7 mL hydrogen peroxide for 10 minutes (12). The digested samples were diluted with deionized water and solutions until 50 mL solution was made. The same process was used to prepare duplicate samples. The atomic absorption spectroscopy (AAS, Thermo Fischer-iCE 3000 series) was used to analyze the concentration of heavy metals.

Quality control

The AAS is calibrated from standard solutions of each metal according to Fisher Scientific Company (USA). The sample was divided into each smaller portion (Aliquot) so that it represents the parent sample with different concentrations (0.5, 1, 2 ppm). The aliquot of the sample represents the sample of quality control (13). To evaluate the stability of the instruments, this QC sample was injected every 15 minutes. Conditions for repeatability were used for the measurements. The relative standard deviation was less than 10% for duplicate measurements in this experiment (14).

The limit of detection (LOD) and the limit of quantification (LOQ) were determined according to the International Conference on Harmonisation (ICH).

Statistical package for social sciences (SPSS version 22.0) was used for statistical analysis. Pearson's correlation test was used to determine the correlation between the concentration of various heavy metals (Pb, Cd, and Cr) in sediments and bird's feathers (15). ANOVA was used to test the significant difference between the concentrations of various heavy metals and further generalized linear model analysis for the data. The Cronbach's alpha value was 0.956, which is acceptable as a measure of scale reliability (16).

Results

Table 1 and Table 2 show the concentration of Cr, Pb, and Cd across all the sampling sites for the House Crow and House Sparrow, respectively. The sampling sites from where the sediments were collected are the roosting sites of bird species. The mean concentration of Cr was higher compared to Pb and Cd in roosting sites (Cr > Pb > Cd).

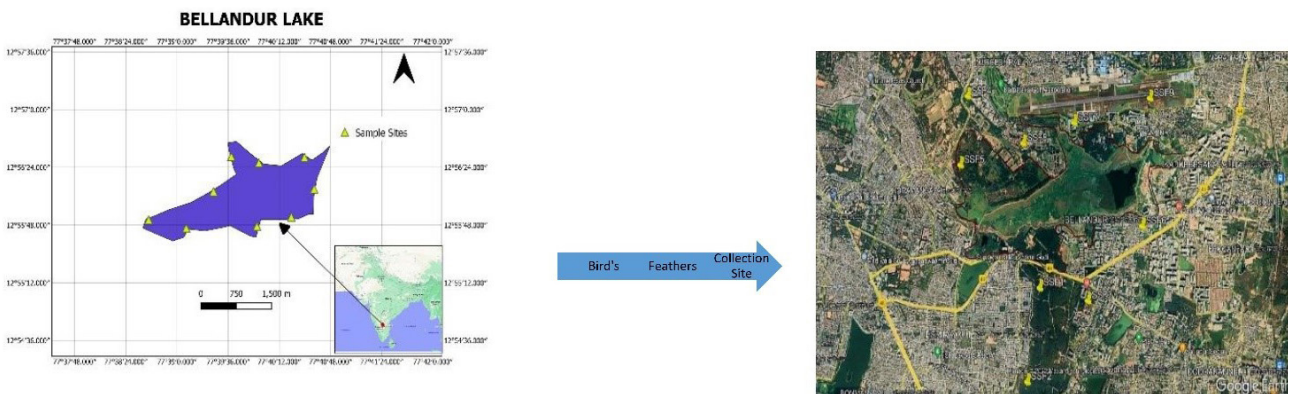

Figure 1. Map of the sampling sites sample collection

Thus, mean of lake sediments of roosting sites were Cr (46.98) > Pb (29.16) > Cd (6.06). Analysis of variance for the difference in the concentration of heavy metals between the roosting site was not statistically significant ($P > 0.05$). The mean concentration of Cr was higher compared to Pb and Cd in roosting sites (Cr > Pb > Cd). The mean of *C. splendens* feathers was Cr (49.56) > Pb (24.59) > Cd (3.40) and the mean of *P. domesticus* feathers was Cr (21.65) > Pb (21.36) > Cd (2.66). Analysis of variance for the difference in the concentration of heavy metals between the feathers of bird species was not statistically significant ($P > 0.05$).

However, the feathers of birds (Table 3) species show Pearson's correlation was significant ($P < 0.05$) with the sediments of roosting sites.

The correlation coefficient of the concentration of heavy metals with feathers was all positive values. The concentrations of Pb and Cr in feathers had a stronger relationship with the sediments of roosting sites (17). Whereas the Cd concentration in feathers had a moderate relationship with the sediments of roosting sites. The

Table 1. Mean concentration of heavy metals in sediments and House Crow feathers

Roosting Sites < 3 km of Bellandur Lake (House Crow)	Sediments			Feathers		
	Pb	Cd	Cr	Pb	Cd	Cr
S1	28.23	6.51	53.2	24.01	2.54	48.18
S2	37.12	4.32	50.1	28.13	2.67	46.98
S3	26.31	3.21	48.2	19.21	2.09	41.23
S4	33.21	6	82.1	28.12	4.65	54.56
S5	22.1	8.9	63	18.28	6.32	39.61
S6	41.02	7.8	70.8	36.32	4.13	49.76
S7	35.68	8.2	72.3	29.89	3.14	59.65
S8	29.74	9.9	77.8	22.43	3.01	56.02
S9	19.02	9.2	81.2	14.98	2.12	50.13
Mean	30.27	7.1155	66.5222	24.5966	3.40777	49.5688
SD	7.1922	2.28052	13.3802	6.67822	1.39050	6.57510

Table 2. Mean concentration of heavy metals in sediments and House Sparrow feathers

Roosting Sites > 3 km of Bellandur Lake (House Sparrow)	Sediments			Feathers		
	Pb	Cd	Cr	Pb	Cd	Cr
S1	10.78	7.8	40.9	7.01	2.98	33.32
S2	43.12	6.5	61.3	32.09	3.76	45.09
S3	24.31	5.2	62.1	19.87	2.71	51.12
S4	16.04	2.1	37.1	11.97	1.87	29.04
S5	33.02	1.9	21.3	23.91	1.52	19.98
S6	42.9	3.2	10.2	33.78	2.67	6.91
S7	45.3	10.9	8.1	36.76	4.29	5.04
S8	16.8	2.3	3.2	13.89	2.16	2.76
S9	20.19	5.3	2.9	12.98	2.02	1.65
Mean	28.0511	5.02222	27.4555	21.3622	2.66444	21.6566
SD	13.2980	3.03264	23.772	10.8131	0.90519	18.912

Table 3. Pearson's correlation between bird species feathers and sediments

	Pb (Feather)	Cd (Feather)	Cr (Feather)	Pb (Sediment)	Cd (Sediment)	Cr (Sediment)
Pb (Feather)	1	0.12442	0.60149	0.00	0.36972	0.63595
Cd (Feather)	0.37571	1	0.31958	0.22689	0.0094952	0.13656
Cr (Feather)	0.13203	0.24874	1	0.78107	0.14369	0.00
Pb (Sediment)	0.9817	0.29973	0.070487	1	0.50038	0.84882
Cd (Sediment)	0.22484	0.59298	0.3588	0.16987	1	0.055879
Cr (Sediment)	0.11977	0.36486	0.96486	0.048376	0.45813	1

Pearson's correlation shows that heavy metals in feathers (Pbf, Cdf, Crf) had a significant ($P<0.05$) relationship with the sediments (Pbs, Cds, Crs). In regression analysis, the equation (y = 1.37 + 0.84*x) for Pb, (y = 1.5 + 0.25*x) for Cd, and (y = 2.81 + 0.7*x) for Cr show the coefficient for sediments of roosting sites with the feathers of bird species in Figure 2, respectively. The coefficient represents that for the addition of every heavy metal concentration, the increase in contamination of feathers would be expected. The regression was linear and observed in a fitted line plot. The analysis of variance (F = 35.978) between the feathers and sediments of roosting sites ($P<0.05$) was significant. Generalized linear mixed models are the extension of the linear model from linear regression analysis for the target bird species of *C. splendens* and *P. domesticus* (Table 4).

The value of predictors was heavy metals concentration (Pb, Cd, and Cr). The target House Sparrow and House Crow diversity were normally distributed related to the predictors in Figure 3.

Discussion

The concentration of heavy metals in sediments of roosting sites shows a positive and significant correlation coefficient ($P<0.05$) with that of bird species feathers. The feathers from the various roosting sites also showed no significant difference in the concentration of heavy metals ($P>0.05$). In the roosting sites with a distance less than 3 km of the lake, the Pb mean concentration (Table 1) was higher in the sampling sites (S6) and in feathers of *C. splendens* compared to the Cd concentration. In the roosting sites with a distance higher than 3 km of the lake, the Pb mean concentration was higher in the sampling sites i.e., S7 > S6 > S2 for *P. domesticus* feathers compared to the Cd concentration. It was found that the informal sectors of electronic waste are mainly responsible. Human habitation and hospitals were nearby sites, and random surveys show that more demand for smartphones with no access to proper collection management of e-waste led to the accumulation of the heavy metals. The Cr mean concentration was higher compared to Pb because of

Table 4. Covariance structure: Scale identity of Bird's diversity (target)

Residual Effect	Estimate	Standard error	Z	Sig	95% Confidence interval	
					Lower	Upper
Variance (House Crow)	43.611	20.558	2.121	0.034	17.312	109.865
Variance (House Sparrow)	24.970	10.647	2.345	0.019	10.826	57.593

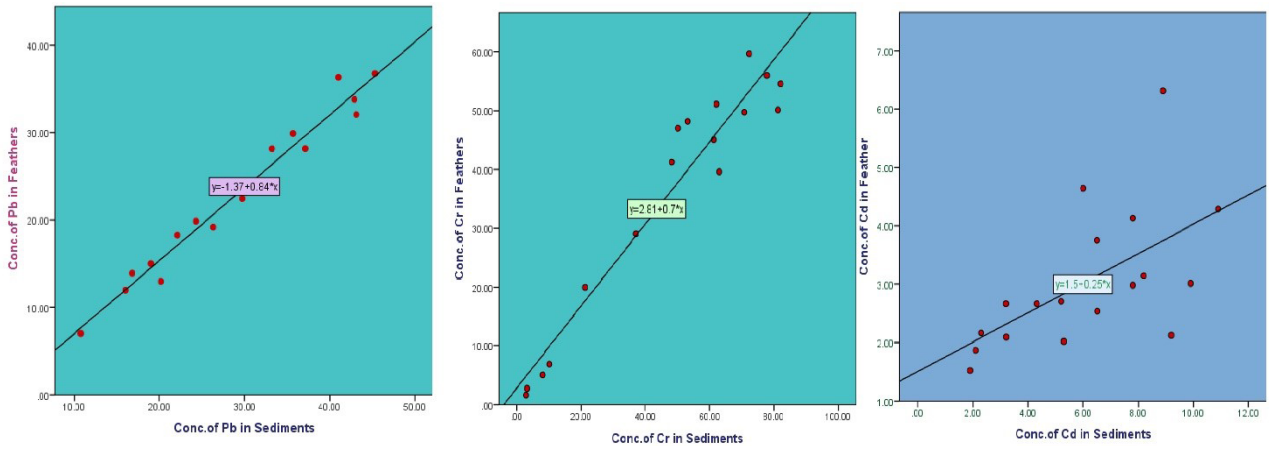

Figure 2. Linear regression between bird species feathers and sediments of Pb, Cd, and Cr concentration

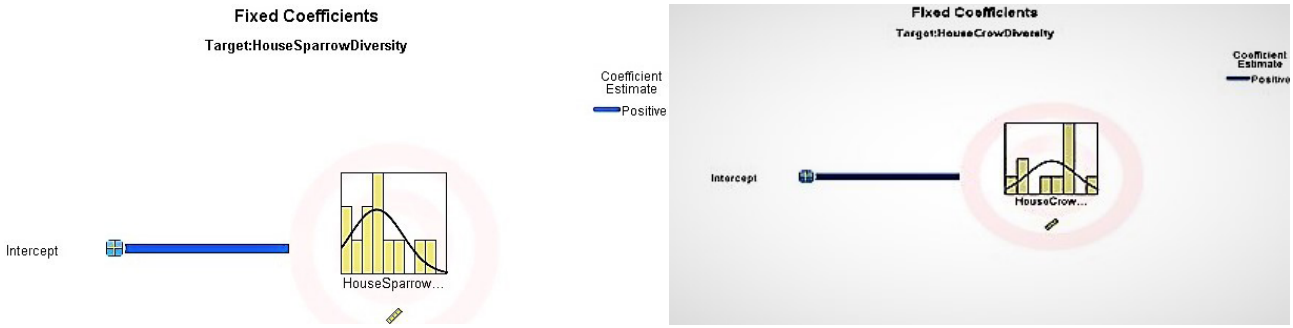

Figure 3. Generalized linear mixed model for bird's diversity

their prolonged residence times, and inlet and shoreline samples contained higher concentrations of Cr (18). The concentration of heavy metals in birds' feathers increases with the addition of informal disposal of parts of the printed circuit board and fewer disposal of broken pieces of keypad mobile phones (19). The concentration of heavy metals was assessed with linear regression methods. The diversity of bird species was observed with the target of *C. splendens* and *P. domesticus* (20). The predictor of heavy metals shows that there is a relationship between biodiversity of target species with normal probability. The coefficient estimate was observed to be positive and significant for the diversity of bird species ($P < 0.05$).

Conclusion

The feather of *C. splendens* (House Crow) and *P. domesticus* (House Sparrow) across all the sampling sites consists of heavy metals Pb, Cd, and Cr. The printed circuit boards and batteries were informally disposed in large quantities in sampling sites (S6 and S7). These sources e-waste contain mainly Pb (lead) and Cd (cadmium). Chromium is used in metal housing for electronic products which would have contributed to Cr (chromium) contamination. Sampling site (S6) in a distance less than 3 km from the lake consists heavy metals and is a threat to ecotone between the urban lake and terrestrial ecosystem. Sampling site (S6) was a common threat to the biodiversity of *C. splendens* (House Crow) and *P. domesticus* (House Sparrow). Whereas sampling site (S7) of the cultivable and residential area in a distance more than 3 km from the lake was mainly at risk to *P. domesticus* (House Sparrow) through the food chain in the ecosystem.

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Authors' contribution

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Funding acquisition: Abhishek Kumar.
Investigation: Abhishek Kumar, Ravichandran Chandrahasan.
Methodology: Abhishek Kumar, Ravichandran Chandrahasan.
Project administration: Abhishek Kumar, Ravichandran Chandrahasan.
Resources: Abhishek Kumar, Ravichandran Chandrahasan.
Software: Abhishek Kumar, Ravichandran Chandrahasan.
Supervision: Ravichandran Chandrahasan.
Validation: Abhishek Kumar, Ravichandran Chandrahasan.
Visualization: Abhishek Kumar, Ravichandran Chandrahasan.
Writing–original draft: Abhishek Kumar, Ravichandran Chandrahasan.
Writing–review & editing: Abhishek Kumar, Ravichandran Chandrahasan.

Competing interests

The authors declare that they have no conflict of interests.

Ethical issues

The authors certify that all data collected during the study are as stated in the manuscript, and no data from the study has been or will be published separately elsewhere. Ethical approval was obtained from Department of Environmental Sciences, Bishop Heber College, Trichy, India (R/N/15900/K1).

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