Zoodiversity, **56**(1): 39–50, 2022
DOI 10.15407/zoo2022.01.039

UDC 598.26:504.06(540.23)

LANDUSE PATTERNS, AIR QUALITY AND BIRD DIVERSITY IN URBAN LANDSCAPES OF DELHI

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Landuse Patterns, Air Quality and Bird Diversity in Urban Landscapes of Delhi. Kumar, V., Jolli, V., Babu, C. R. — In the present paper we attempted to explain the relationships among the landuse pattern, levels of air pollutants and bird diversity based on data from 5 sampling sites in Delhi. Five landuse categories — percent built up area, tree cover, park area and barren area were recognized in the study area. The objective of this study is to find out the effects of landuse changes on air pollution and bird diversity and whether birds can serve as indicator of landuse changes and air pollutants. The levels of six air pollutants (PM_{10}, $PM_{2.5}$, NO_X, SO_2, Ozone and Benzene) from the monitoring stations were used. The bird diversity was assessed using conventional measures. All the sites showed remarkable differences with respect to each of the five landuse categories, air pollution levels, and bird diversity. The results suggest that landuse changes influence air pollution and bird diversity and some bird species can be used as indicator of landuse change and air pollution.
Key words: Delhi, Urban ecosystem, Landuse pattern, Air Pollution, Bird diversity.

Introduction

Urbanization is a global phenomenon and brings out major alterations in landuse, particularly the area under green spaces and their structure. Spillover of zoonotic diseases to human population leading to pandemics is also attributed to large scale changes in landuse and habitat degradation (UNEP, 2016). Delhi — the second most populous city of the world and National Capital Territory of India — is one of the most polluted cities in the world (Marlier et al., 2016; Landrigan, 2017). The city has been witnessing rapid changes in green infrastructure and high levels of air pollution (poor to severe as per the Central Pollution Control Board, Government of India).

Although Delhi is considered as one of the greenest capitals in the world, but the largest greenspace of Delhi, the ridge spreading over an area of 7,700 hectares is largely a monoculture of *Prosopis juliflora* — an invasive alien species introduced by then British Government of India. Data on the extent of green spaces in different localities are known but their structural differences are least known. Kumar et al. (2019) demonstrated that the air quality differs at different locations and is influenced by the structure of the green cover. Further, the kind of tree species, abundance of tree species, and leaf size have significant impacts on air quality.

Bird diversity has been investigated in urban landscapes (Urfi, 2010; Filloy et al., 2019) and birds have been used as indicator species for air quality (Eeva et al., 2000; Birdlife International, 2004) and also for landuse changes (Lawton et al., 1998). However, studies on how the landuse patterns influence the air quality and bird diversity are limited. In the present paper we explain how the changes in land cover impact the air quality and the bird diversity in the worst polluted city of Delhi.

Methods

Study area

Delhi is located between 28°24′ and 28°53′ N latitude and 76°50′ and 77°0′E longitude, with an average altitude of 216 m above m. s. l. The urban landscape of Delhi includes the Ridge Forest spreading over 7,700 hectare and is predominantly composed of an invasive alien species — *Prosopis juliflora*, avenue plantation, green belts and patches of mixed wood lots, besides 52 km stretch of the Yamuna River. The avenue plantations show differences in species compositions among different locations.

The avifauna of Delhi, at one time, was very rich and as many as 400 species have been reported from terrestrial and aquatic habitats. With the loss and/or degradation of native vegetation and structural changes in the green spaces, there has been marked reduction not only in bird diversity but also in their abundance (Khera et al., 2009). The common birds found in urban landscapes of Delhi include the House Crow (*Corvus splendens*), Common Myna (*Acridotheres tristis*), Red-vented Bulbul (*Pycnonotus cafer*), Rock Pigeon (*Columba livia*), Eurasian Collared Dove (*Streptopelia decaocto*), Asian Koel (*Eudynamys scolopacea*), Coppersmith Barbet (*Megalaima haemacephala*), Indian Grey Hornbill (*Ocyceros birostris*), Jungle Babbler (*Turdoides striatus*), Red Wattled Lapwing (*Vanellus indicus*), Black-winged Stilt (*Himantopus Himantopus*), Cattle Egret (*Bubulcus ibis*) etc. The wetlands of Delhi also receive sizeable populations of migratory birds from Siberia, Central Asia, Europe and Ladakh in the months of November–March.

Selection of sampling sites and vegetation

Five sampling sites were selected based on the location of Delhi Pollution Control Committee (DPCC) air pollution monitoring stations. The five sites are: (i) R.K Puram (RK) site dominated with *Alstonia scholaris* and *Polyalthia longifolia* as avenue plantations; (ii) Mandir Marg (MM) site dominated with *Ficus religiosa* and *Polyalthia longifolia* as avenue trees; (iii) Punjabi bagh (PB) site dominated with *Polyalthia longifolia* and *Syzygium cumini* as avenue trees; (iv) Civil lines (CL) site dominated with *Acacia leucocephala* and *Prosopis juliflora* forest; and (v) Anand Vihar (AV) site dominated with *Albizia lebbeck* and *Azadirachta indica* as avenue. The map of Delhi showing sampling sites is given in fig. 1.

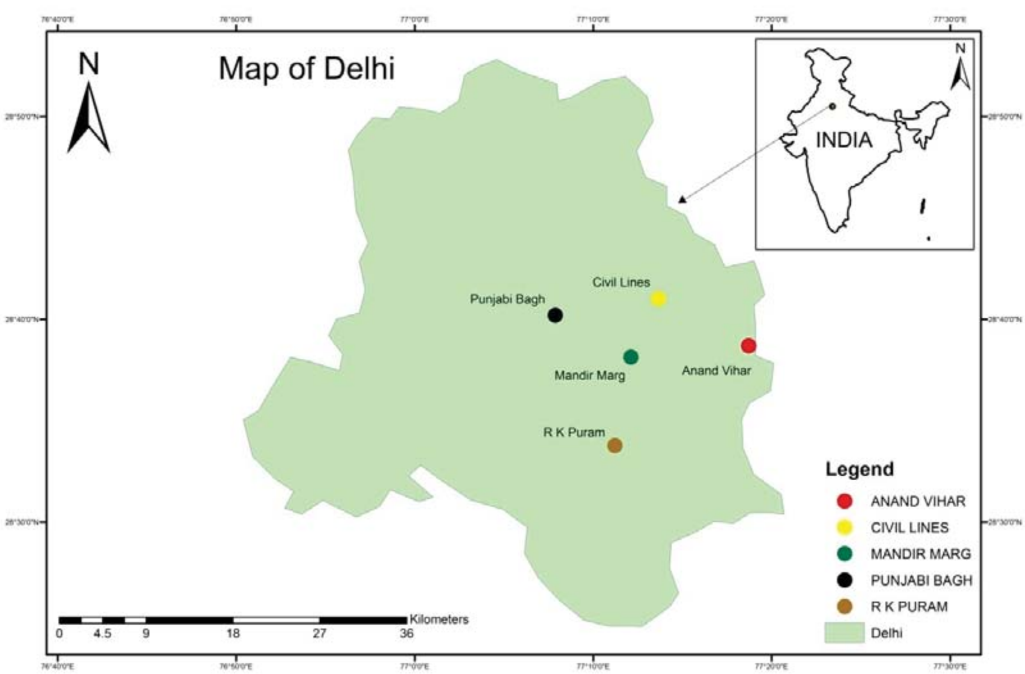

Fig. 1. Map of Delhi showing location of sampling sites.

Air quality data

Secondary data from DPCC monitoring stations were collected and the levels of 6 air pollutants (PM_{10}, $PM_{2.5}$, NO_X, SO_2, Ozone and Benzene) at the five sites were analysed as per the procedures outlined earlier (Kumar et al., 2019) and correlated with bird diversity, richness and abundance, and with landuse categories. Mean value (based on 11months during 2015–2016) were used for assessing the pattern of variation in air pollutants.

Landuse maps of study sites

Landuse maps were generated using Google Earth ver 10 for quantifying the area under five categories- tree cover, park area, built up area and barren area and expressed as percent of total area sampled in each locality. For each site a square plot of (1 × 1) km was demarcated by keeping transect in the middle, using most recent satellite images. The visual image interpretation method was used for characterising land features based on true colour (red, green and blue colour wavelengths) high resolution Google Satellite images (NASA, 2013). Land features in polygon were saved as KML file format and were later converted to shape files using online Mygeodata-GIS Converter (http://converter.mygeodata.eu/). The files were geometrically corrected by UTM WGS84. These files were later added, overlayed and processed using ArcGIS 9.3 software and landuse maps of study sites were generated.

Bird surveys

Surveys were made for monitoring the birds on selected sites during winter and monsoon seasons using line transect method (Bibby et al., 2000). Sample size (n) of RK, MM and PB was nine, whereas for CL and AV it was ten. Birds sighted were identified using a field guide (Kazmierczak & Perlo, 2015). A square plot of (1 × 1) km was demarcated in each site (DPCC monitoring station in its middle position). On each plot a line transect of 1 km length was laid and all bird individuals heard or seen were counted on both sides of the transect in 30 minutes duration. To adjust detection effect, birds were counted up to 50 m of both sides of the transect line using binocular (Nikon Action Ex 10 x 50 mm). Bird counting was carried out only on a clear day from 09:00–11:00 A.M. during 2015–2016. The species richness was expressed as number of species recorded at each site; the diversity was estimating using Shannon–Weiner Index (Hammer et al., 2001). The percent relative abundance of each bird species recorded was estimated. The birds recorded were grouped under foraging guilds based on their food habits known from the published data (Ali & Ripley, 1983).

Data Analyses

To find out the relationships of bird abundance, richness and diversity with landuse categories and air pollutants levels, RMA (Reduced Major Axis) linear regression analyses were carried out and Pearson's correlations (r) were computed. Further, Canonical Correspondence Analysis (CCA) was also performed. PAST Version 4.09 statistical software was used to analyse the data (Hammer et al., 2001).

Results

Landuse patterns and air pollution

The five different sites selected in the study area showed marked difference in all the four parameters — area under tree cover, park area, built up area and barren area (table 1). For example, PB site showed maximum (61.17 %) built up area as compared to all other four sites where the built up area was 22.33 (CL) to 44.39 % (RK); on the other hand, the tree cover was maximum (59.32%) at MM and values at other sites varied from to 18.31 (AV) to 58.93 % (CL). The area under park was maximum (16.82 %) at CL but in other sites the values ranged from 6.15 (AV) to 15.66 % (RK). No barren land was observed at PB and CL, but more than one fourth of the area i. e. 27.99 % area was barren at AV. RK and MM sites also showed markedly less barren area than other sites (table 1).

The five sampling sites showed characteristic landuse patterns specific to each site. For example, the MM site showed highest tree cover, lesser built up area, moderate area under park and very small barren area; on the other hand, the maximum barren area was observed at AV site, where the values for all other categories were also low. The range of variation in the park area among the sampling sites was rather narrow (i. e. 10.15–16.82 %).

The five different sampling sites also showed marked differences in the levels of all the six air pollutants analysed. Although the variation in the levels of each of the six pollutants among different sites has already been published (Kumar et al., 2019), for the purpose of assessing the impact of landuse patterns on the air quality, air pollution data was also presented in the table 1.

Table 1. Landuse categories and levels of air pollutants at different sampling sites

		RK Puram, RK	Mandir Marg, MM	Punjabi Bagh, PB	Civil Lines, CL	Anand Vihar, AV
Landuse Categories, % (1 x 1) km	Tree cover	35.71	59.32	24.13	58.93	18.31
	Park area	15.66	14.28	10.15	16.82	6.15
	Built up area	44.39	23.36	61.17	22.23	36.88
	Barren area	0.85	0.28	0	0	27.59
Air Pollutants, μg/m^3	PM_{10}	278.85 ± 37.87	237.01 ± 31.67	286.44 ± 38.95	319.9 ± 18.89	418.02 ± 61.55
	$PM_{2.5}$	143.89 ± 26.05	113.63 ± 24.19	133.8 ± 27.28	191.78 ± 14.03	169.65 ± 30.13
	SO_2	26.22 ± 4.59	18.39 ± 2.55	21.6 ± 2.78	21.44 ± 1.26	21.05 ± 3.04
	NO_X	74.42 ± 6.32	57.96 ± 5.57	80.02 ± 6.08	78.28 ± 7.04	78.74 ± 7.29
	Benzene	6.33 ± 1.37	3.27 ± 50.52	0.87 ± 0.14	10.55 ± 2.92	13.78 ± 2.33
	Ozone	56.41 ± 7.03	34.19 ± 4	58.33 ± 7.51	78.05 ± 11.09	30.08 ± 3.07

The PB sampling site, which showed the maximum built up area, low tree cover and moderate area under park, also showed higher concentration of PM_{10}, $PM_{2.5}$, NO_X and Ozone; AV site, which had the maximum barren area, the least tree cover, relatively low built up area and also least park area, showed highest levels of all air pollutants except Ozone. Moderate levels of air pollutants were observed at CL site which was characterised by maximum park area, relatively high tree cover but relatively low built up area. MM site with maximum tree cover, moderate park area and relatively low built up area showed lowest levels of air pollutants (table 1).

Table 2. Mean relative abundance (%) of bird species recorded at different sampling sites (2015–2016)

English Name	Scientific Name	R K Puram, RK (n = 9)	Mandir Marg, MM (n = 9)	Punjabi Bagh, PB (n = 9)	Civil Lines, CL (n = 10)	Anand Vihar, AV (n = 10)
Cattle Egret	*Bubulcus ibis*	0	0	0	0	8.78
Red Wattled Lapwing	*Vanellus indicus*	0	0	0	0	1.25
Black-winged Stilt	*Himantopus himantopus*	0	0	0	0	4.08
Black Kite	*Milvus migrans*	6.19	4.14	12.34	4.5	15.67
Shikra	*Accipiter badius*	0	0	0.11	0	0
Egyptian Vulture	*Neophron percnopterus*	0	0	0	0	0.31
Eurasian Collared Dove	*Streptopelia decaocto*	0.61	7.56	2.08	2.14	1.25
Laughing Dove	*Streptopelia senegalensis*	0.31	0	0	0	0
Rock Pigeon	*Columba livia*	21.37	28.23	55.24	34.26	36.99
Asian Koel	*Eudynamys scolopaceus*	0	0	0.11	0	0
Rose-ringed Parakeet	*Psittacula krameri*	1.56	5.39	0.92	7.28	0
Asian Palm Swift	*Cypsiurus balasiensis*	0.61	0	0	0	0.31
Brown-headed Barbet	*Megalaima zeylanica*	0.31	0.53	0	0	0
Coppersmith Barbet	*Megalaima haemacephala*	0	0.18	0	0	0
Indian Grey Hornbill	*Ocyceros birostris*	0	0.53	0	0	0
Rufous Treepie	*Dendrocitta vagabunda*	0.31	0	0.11	0	0
Common Myna	*Acridotheres tristis*	16.1	16.01	11.42	21.84	9.72
House Crow	*Corvus splendens*	23.52	20.87	13.04	19.49	21
Large-billed Crow	*Corvus macrorhynchos*	0	0.18	0	0	0
Red-vented Bulbul	*Pycnonotus cafer*	13.32	7.56	3.11	3.21	0
Red-whiskered Bulbul	*Pycnonotus jocosus*	0.31	0	0	1.71	0
Jungle Babbler	*Turdoides striata*	15.49	3.42	0.34	3.64	0
Common Tailorbird	*Orthotomus sutorius*	0	0	0.58	0	0.63
Purple Sunbird	*Nectariniaasiaticus*	0	1.08	0.58	1.07	0
Oriental White-eye	*Zosterops palpebrosus*	0	3.77	0	0	0
House Sparrow	*Passer domesticus*	0	0.53	0	0.86	0

Bird surveys

A total of 26 bird species were recorded from all the sampling sites (table 2). Species richness and the diversity of birds varied significantly among different sampling sites (fig. 2). The MM site, which had the highest tree cover, showed the maximum number of species (8 ± 0.53) and highest diversity (1.82 ± 0.05); on the other hand, AV site which showed least tree cover, highest barren area and low park area, had lowest number of bird species (5.8 ± 0.36) and relatively low bird species diversity (1.34 ± 0.06); sites like PB with highest built up area, low tree cover and no barren area and relatively low park area had least species diversity of birds (1.26 ± 0.07) but species richness was moderate and inhabited by Rock Pigeon, House Crow, Common Myna and Black Kite; the RK site, which had moderate tree cover and park area, relatively high built up area and low barren area, also showed relatively higher bird species diversity (1.65 ± 0.05) and moderate species richness (fig. 2; table 1). The number of species (7.3 ± 0.47) and diversity of birds (1.66 ± 0.06) was relatively low at CL site as compared to MM which had highest species diversity (1.82 ± 0.05) and species richness (8 ± 0.53), although both sites had more area under tree cover.

The percent relative abundance of different bird species not only varied within the site but also among sites (table 2). For example, percent relative abundance of Rock Pigeon varied from 21.37 % to 55.24 % across the sampling sites with maximum value at PB and lowest value at RK; on the other hand, the variation in percent relative abundance of House Crow was 13.04 % to 23.52 % across the sampling sites.

Some birds such as Large-billed Crow, House Sparrow and Coppersmith Barbet were extremely rare at MM site;

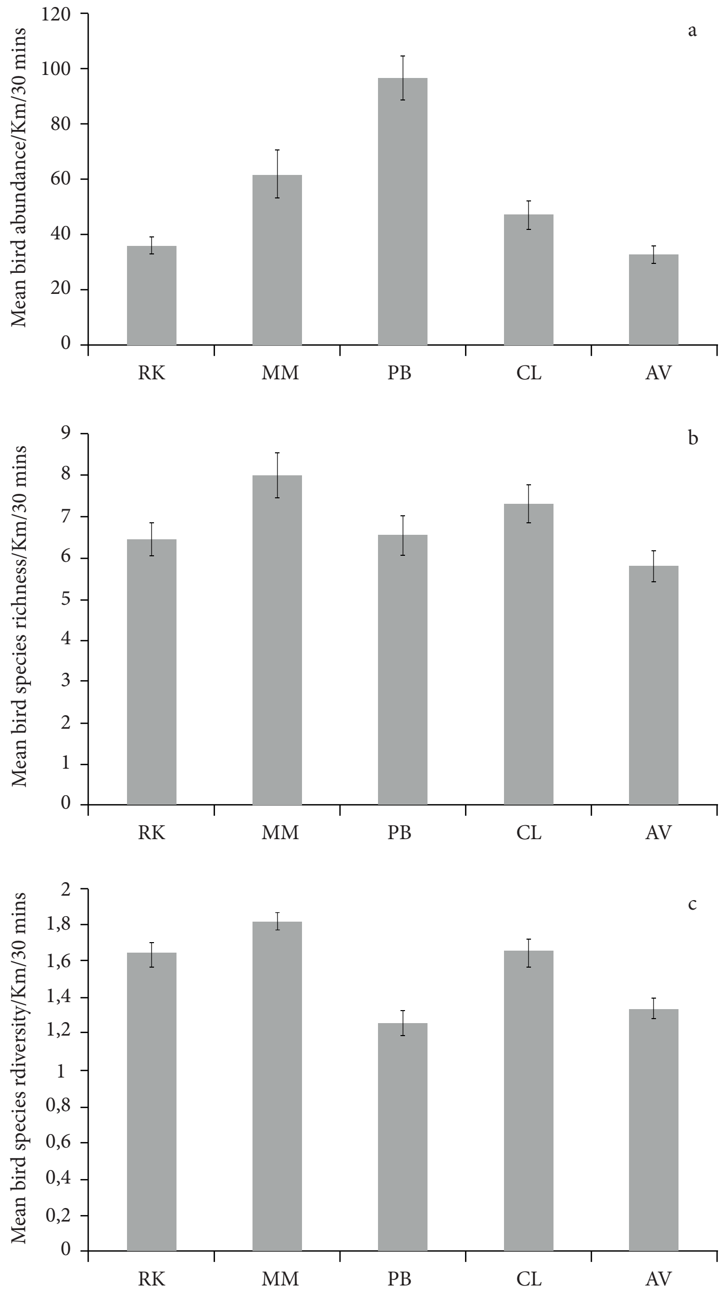

Fig. 2. Variation in mean bird abundance (a); mean bird species richness (b); and mean bird species diversity (c) among different sampling sites. N o t e .Y bar indicates standard error.

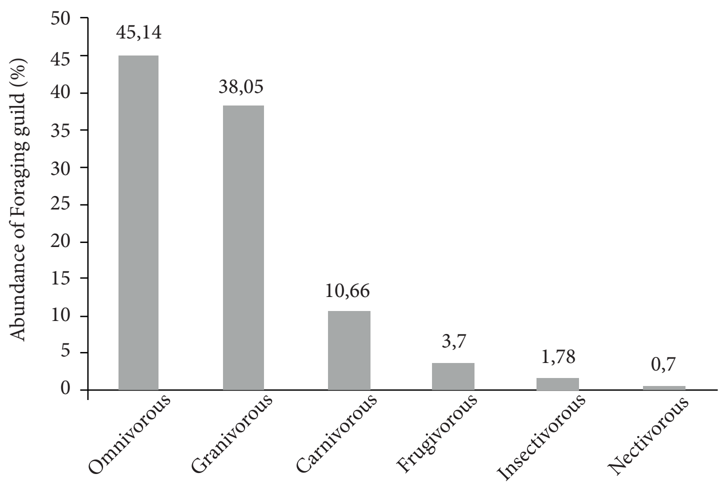

Fig. 3. Variation in abundance of foraging guilds (%) of birds of all the sampling sites together.

birds such as Indian Grey Hornbill, Oriental White-eye, Coppersmith Barbet were absent at all other sampling sites except MM site. The most dominant birds in the study area were Rock Pigeon, House Crow and Common Myna and these were in higher abundances at the sampling sites (table 2). Mean abundance of birds was maximum at PB (96.33 ± 8.13) and minimum at AV (32.4 ± 3.29) (fig. 2, a).

Foraging guilds

To understand the distribution patterns of foraging guilds among the sampling sites, the birds recorded in the study area were grouped under six different foraging guilds, based upon their food preferences. The highest percentage of birds (45.14 %) belonged to omnivorous guild, whereas 38.05 % of birds were granivorous; about 10.66 % of birds were carnivorous; and 3.7 % of birds were frugivorous. The insectivorous and nectivorous birds constituted 1.78 % and 0.7 %, respectively (fig. 3).

The MM Site showed relatively high percentage of frugivorous, insectivorous and nectivorous as compared to other sites; whereas, AV site showed high percentage granivorous and omnivorous birds but frugivorous and nectivorous birds were absent (fig. 4).

Correlative analyses

Relationship between landuse categories and air pollution

The relationships between landuse categories and air pollution levels are given in the table 3. The levels of PM_{10} and NOx showed negative and statistically significant ($p < 0.05$) relationships with percentage of tree cover, but their relationships with percent built up area and barren area were positive and statistically significant ($p < 0.05$). The 'r' values for

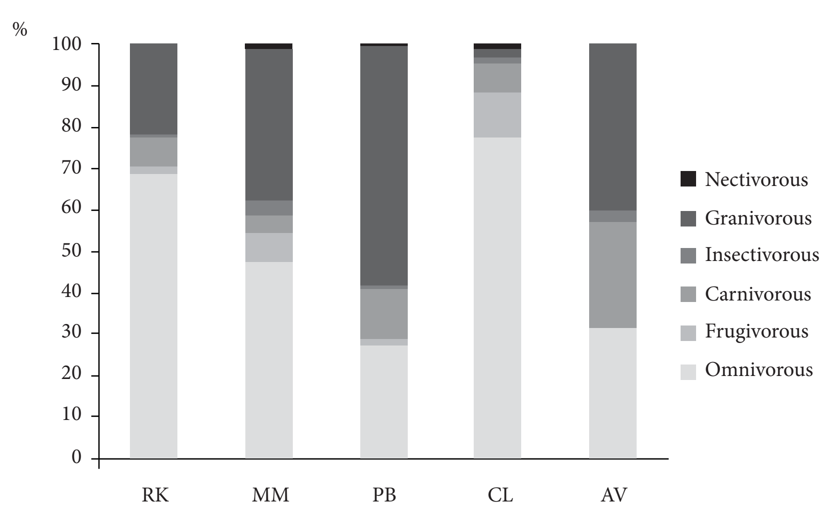

Fig. 4. Variation in abundance of foraging guilds (%) of birds among different sampling sites.

Table 3. **'r' and 'r²' values between logarithms of percentage of landuse categories (measured as in percent area) and levels of air pollutants (PM_{10}, $PM_{2.5}$, NO_X, SO_2, Benzene and Ozone measured as µg/m³)**

Landuse Categories, %	PM_{10}		$PM_{2.5}$		SO_2		NOx		Ozone		Benzene	
	r	r^2	r	r^2	R	r^2	r	r^2	r	r^2	r	r^2
Tree cover	–0.66*	0.43	–0.13	0.016	–0.25	0.06	–0.59*	0.35	0.37	0.13	0.07	0.005
Park area	–0.72*	0.52	–0.12	0.014	0.18	0.03	–0.35*	0.12	0.65	0.42	–0.08	0.006
Built up area	0.011	0.012	–0.19	0.03	0.51*	0.26	0.52*	0.27	0.06	0.003	–0.54	0.29
Barren area	0.89*	0.8	0.34	0.12	–0.11	0.01	0.29	0.08	-0.62*	0.38	0.73*	0.53

*Highly significant at $p < 0.05$.

all the combinations involving the percent tree cover with air pollutants showed statistically insignificant correlations. Similar patterns of relationships were observed for combinations involving PM_{10}, NOx with percent area under park (table 3).

The percent of built up area did not show statistically significant relationships with all the air pollutants except for SO_2 for which the relationship was positive and statistically significant ($p < 0.05$). Similarly, percent barren area showed statistically significant ($p < 0.05$) positive relationship with PM_{10} and Benzene, but its relationship with Ozone was negative and statistically significant ($p < 0.05$). The 'r' values for all other combinations involving barren area and levels of air pollutants were low and statistically non-significant (table 3).

The regression analysis of the data also showed similar relationship patterns among the variable tested.

Table 4. **'r' and ' r² 'values between logarithms of mean bird species diversity and levels of air pollutants (PM_{10}, $PM_{2.5}$, NO_X, SO_2, Benzene and Ozone as µg/m³) and landuse categories**

Bird species diversity versus air pollutants	r	r^2
Particulate Matter*, PM_{10}	–0.59	0.34
Particulate Matter, $PM_{2.5}$	–0.20	0.04
Oxides of Nitrogen*, NO_X	–0.72	0.52
Sulphur Dioxide, SO_2	–0.14	0.02
Benzene	0.29	0.09
Ozone, O_3	0.08	0.005
Bird species diversity versus landuse categories	r	r^2
Tree cover*	0.90	0.81
Parkland*	0.77	0.60
Builtcover*	–0.76	0.58

*Highly significant at $p < 0.05$

Table 5. **'r' and ' r²' values between logarithms of mean bird species richness and levels of air pollutants (PM_{10}, $PM_{2.5}$, NO_X, SO_2, Benzene and Ozone as µg/m³) and different landuse categories**

Bird species richness versus air pollutants	r	r^2
Particulate Matter, PM_{10})	0.32	0.32
Particulate Matter, $PM_{2.5}$	–0.20	0.10
Oxides of Nitrogen, NO_X	–0.29	0.08
Sulphur Dioxide, SO_2	–0.42	0.17
Benzene	0.11	0.01
Ozone*, O_3	–0.98	0.96
Bird species richness versus landuse categories	r	r^2
Tree cover*	0.91	0.83
Parkland*	0.72	0.52
Builtcover*	–0.66	0.43

*Highly significant at $p < 0.05$.

Relationship between bird diversity and landuse categories

The relationships of landuse categories with bird diversity were analysed (table 4). The percent tree cover ($r = 0.89$, $p = 0.008$) and park area ($r = 0.77$, $p = 0.02$) showed statistically significant positive relationships with bird diversity; and the bird diversity showed negative and significant relationship ($r = –0.76$, $p = 0.002$) with built up area.

Relationship between bird diversity and air pollutants

The relationship of air pollutants with bird diversity were also analysed (table 4). Bird diversity showed statistically significant negative relationship with NOx ($r = –0.72$, $p = 0.02$) and PM_{10} ($r = –0.58$, $p = 0.01$), but its relationship with other air pollutants were negative and weak.

The relationship of percent relative abundance of individual bird species with PM_{10}, NO_X and Ozone pollutants were analyzed. The percent relative abundances of the House

Table 6. 'r' and 'r^2' values between logarithms of mean bird species abundance and levels of PM_{10}, NO_X and Ozone

Name of Bird Species	r_{PM10}	r^2_{PM10}	r_{NOX}	r^2_{NOX}	r_{Ozone}	r^2_{Ozone}
Common Myna	–0.73074*	0.53398	–0.26519	0.070326	0.57945	0.33577
Rock Pigeon	-0.20878	0.043589	0.14066	0.019785	0.202633	0.041057
House Crow	–0.83474*	0.69679	–0.51645*	0.26672	0.15851	0.025124
Red-vented Bulbul	–0.95875*	0.9192	–0.52102	0.27146	0.31653	0.10019
Common Tailorbird	0.21184	0.044877	0.48887	0.239	–0.00956	0.0001
Eurasian Collared Dove	–0.671*	0.45024	–0.72418	0.52443	–0.19355	0.03746
Black Kite	0.86016	0.73987	0.42329	0.17917	–0.09105	0.00829
Shikra	–0.62355	0.38882	0.35972	0.1294	0.26387*	0.06963
Cattle Egret	–0.64827*	0.42025	0.2928	0.085735	–0.66648*	0.44419
Red Wattled Lapwing	–0.62938	0.39612	0.2928	0.085735	–0.66648*	0.44419
Black-winged Stilt	0.86016	0.73987	0.2928	0.085735	0.66648*	0.44419
Jungle Babbler	0.19499	0.038021	–0.38062	0.14487	0.36053	0.12998
Oriental White-eye	–0.14477	0.020958	–0.97949*	0.95941	–0.48664*	0.23682
Rose-ringed Parakeet	0.86016	0.73987	–0.53697	0.28833	0.37566	0.14112
Brown-headed Barbet	–0.74589*	0.55635	–0.98245*	0.96521	–0.41775*	0.17452
Red-whiskered Bulbul	0.11395	0.012985	0.28712	0.082438	0.73237	0.53637
Rufous Treepie	–0.29467	0.086833	0.34155	0.11666	0.39231*	0.1539
Purple Sunbird	–0.5975*	0.357	–0.41478	0.17204	0.24957	0.062284
Grey Hornbill	–0.64827*	0.42025	–0.97949*	0.95941	–0.48664*	0.23682
Coppersmith Barbet	–0.64827*	0.42025	–0.97949*	0.95941	–0.48664*	0.23682
Jungle Crow	–0.64827*	0.42025	–0.97949*	0.95941	0.36053*	0.12998
House Sparrow	–0.35194	0.12386	–0.49376*	0.2438	0.22868	0.052293
Asian Koel	–0.14477	0.020958	0.35972	0.1294	0.26387	0.06963
Egyptian Vulture	0.86016*	0.73987	0.2928	0.085735	–0.6648*	0.44419
Laughing Dove	–0.21613	0.046714	0.058592	0.003433	0.2166	0.046916
Asian Palm Swift	0.19712	0.038858	0.19993	0.039972	0.10336	0.010683

*Highly significant at $p < 0.05$.

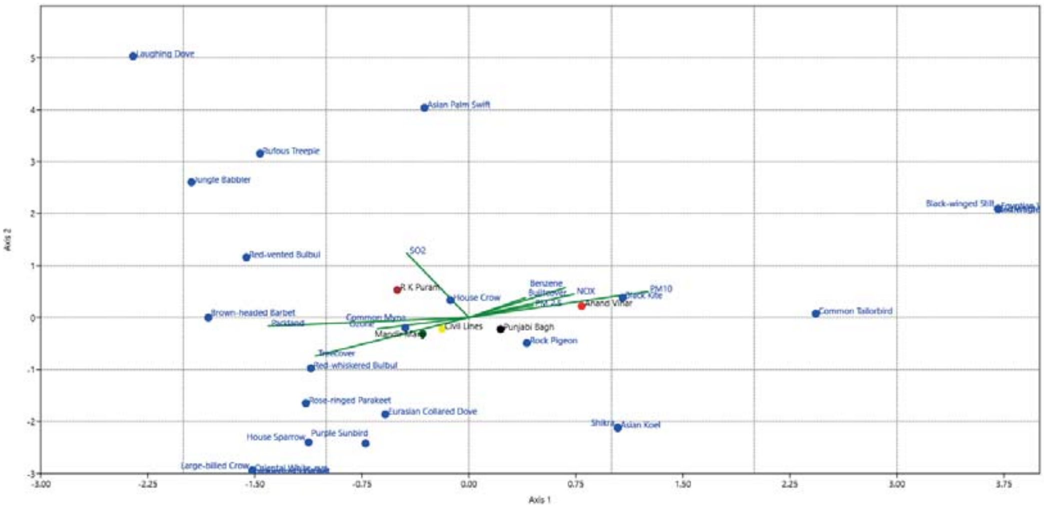

Fig. 5. CCA plot showing the relationships of landuse patterns, air pollutants and bird species abundance.

Crow, Red-vented Bulbul, Common Myna, Brown-head barbet, Coppersmith Barbet, Cattle Egret, Jungle Crow, Black-winged Stilt and Purple Sunbird showed negative and statistically significant relationship with PM_{10} but r-value was low. House Sparrow showed negative relationship with PM_{10}; however, Egyptian Vulture showed positive relationship with PM_{10} (table 6).

Similarly, the percent relative abundance of the Oriental White-eye, Grey Hornbill, Brown-headed Barbet, Coppersmith Barbet, Jungle Crow, House Crow and House Sparrow showed statistically significant ($p < 0.05$) negative relationships with NO_X; the percent relative abundance of Asian Koel and Shikra showed negative relationship with NO_X but 'r' values were low (table 6). The relative abundances of bird species like Indian Grey Hornbill, Coppersmith Barbet, Egyptian Vulture, Black-winged Stilt, Red Wattled Lapwing showed negative relationship with Ozone, whereas Rufous Treepie and Jungle Crow showed low positive r values (table 6).

Similar patterns of relationships were observed when regression analysis was carried out.

Relationships of landuse patterns, air pollutants and birds abundance

CCA was performed to assess the relationships of landuse patterns, air pollutants and bird species abundance (fig. 5). CCA plot with axis 1 and 2 were plotted as they explained 75 % variance in the data. Among the landuse categories, tree cover was found to be the most dominant variable affecting the bird species abundance. Bird species such as the Brown-headed Barbet, Rose-ringed Parakeet, Purple Sunbird and House Sparrow were associated with increase in percentage of tree cover (fig. 5). Whereas, among the air pollutants PM_{10} was affecting the bird species abundance. Few bird species such as Black Kite, Rock Pigeon were found in sites having high concentration of PM_{10} (fig. 5).

Discussion

Human dominated landscapes are rapidly undergoing changes in landuse pattern and quality of environment, both of which have been impacting other forms of life (Grimm et al., 2008). Delhi is one of the worst polluted cities in the world and rapid urbanization has been resulting in marked changes in landuse and enhanced levels of air pollutants (Marlier et al., 2016).

A number of studies have been carried out on the impacts of landuse changes on the avian biodiversity (Newbold et al., 2016; Herrando et al., 2016). But studies on the impact of landuse on air quality and bird diversity are limited. It has been demonstrated that birds serve as indicators of habitat change (Lawton et al. 1998; Gregory & Strien, 2010), air quality (Eeva et al., 2000; Eeva et al., 2003) and also water quality (Ormerod & Tyler, 1993; Sorace et al., 1999). We attempted to discuss our results on the impact of changes in landuse patterns on the air quality and bird diversity, particularly to find out whether bird diversity can be used as an indicator of air pollution and landuse changes.

Our earlier investigations indicated that kinds of tree species, relative abundance of tree species and leaf size influence the efficacy of the avenue plantations as filter in mitigating air pollution (Kumar et al., 2019). We have taken the same secondary data on the levels of air pollutants (PM_{10}, $PM_{2.5}$, NOx SO_2, Ozone and Benzene) from the same sampling sites used in our earlier investigation (Kumar et al., 2019); in the present investigation we also examined here the impact of landuse changes on air quality and bird diversity. The AV site is remarkably different from all other sites in having the lowest tree cover (18.31 %), moderately high built up area (36.88 %), low park area (6.15 %) and very high barren area (27.59 %), in contrast to highest tree cover (59.32 %) high park area (10.15 %), low built up area (23.36 %) with very low barren areas (0.28 %) of MM site. This indicates site specific landuse pattern in the study area resulting from urbanization.

The four different categories of landuse (tree cover, park area, built up area and barren area) showed marked differences among the five sampling sites (table 1). The site-specific landuse patterns did show site specific air quality profiles, indicating that landuse patterns influence the air quality and bird diversity, relative abundance of birds and diversity in foraging guilds. For example, AV site has highest level of air pollutants, least bird species richness, low bird diversity and very low relative abundance of birds with high percent of granivorous, omnivorous and carnivorous birds and absence of nectivorous and frugivorous birds, all of which are negatively correlated to built up area and barren area but positively correlated with percent tree cover (fig. 2 and 3; table 4 and 5). On the other hand, MM site (dominated with broad-leaved tree species such as *Ficus religiosa*) showed highest species diversity and species richness of birds with moderately high bird abundance and presence of all the foraging guilds at higher percentage, all of which are positively correlated with tree cover and negatively correlated with air pollutant levels (fig. 2 and 3; table 4 and 5). In other words, birds not only serve as indicators of habitat change but also air quality. These results substantiate that landuse pattern not only influence air quality but also impact on bird richness, diversity and their relative abundance and foraging guilds. Similar observation was made by other workers (Aronson et al., 2014).

CL site, had large area under tree cover which is predominantly composed of microphyllus tree species like *Prosopis juliflora*, but the site had higher values of air pollutants and relatively low bird richness, diversity and relative abundance (fig. 2) suggesting that structure of green spaces also influence air quality and bird diversity. In fact, Kumar et al. (2019) showed that *P. juliflora* and other microphyllous trees are ineffective as filters for air pollutants; Khera et al. (2009) mentioned that abundance of tree cover of *P. juliflora* was negatively correlated with bird diversity.

The PB site had a maximum built up area and high bird abundance but the lowest bird species diversity (fig. 2; table 4) suggesting that built up area has adverse impacts on bird diversity and air pollution. This is also evident from the negative relationship of built up area with bird diversity whereas positive relationship with air pollutants (table 4). Further, our results also showed avian homogenization with increase in percentage of built up area in Delhi. For example, two bird species (Rock Pigeon and House Crow) constitute 58 % of the total relative abundance of birds at PB site. Similar observations were made by McKinney (2006); Devictor et al. (2007); Aronson et al. (2014) on the impact of urbanization on bird communities.

It may be noted that some of the birds such as Oriental White-eye, Brown-headed Barbet and Asian Koel, Laughing Dove, Coppersmith Barbet, Indian Grey Hornbill were absent at AV and PB sites, both of which have low tree cover, and high levels of air pollutants. These sites have less number of foraging guilds (4) and relatively higher area under parks as compared to tree cover. These observations suggest that landuse change has marked effect on the air quality as well as on the bird diversity, and tree cover is more effective in mitigating air pollution and also support habitat specific bird species. However, the park area has more generalist birds and less effective in mitigating air pollution. This is evident from the fact that the sites such as RK and PB sites, had higher park area, lesser tree cover and relatively low barren area, showed higher abundance of generalist birds such as Common Myna, Rock Pigeon and House Crow, and relatively moderate levels of air pollutants except SO_2 and Ozone. Of the different species analysed for the foraging behaviour, we found the nectrivorous birds are more sensitive to air pollutants, as these are either rare or absent in highly polluted sites. For example, nectrivorous birds were recorded only at MM and CL sites which showed relatively low levels of air pollutants and higher area under tree cover (fig. 3; table 1) suggesting that nectrivorous birds likely to be served as sentinal species for monitoring air quality. In fact, other workers also observed reduction in nectivorous birds due to urbanization (Pauw & Louw, 2012).

It is interesting to note that the relationships between species richness and relative abundance of birds with Ozone was negative and statistically highly significant (table 5 & 6). For example, Egyptian Vulture, Coppersmith Barbet, Indian Grey Hornbill, Brown-headed Barbet, Oriental White-eye abundance showed decline in abundance with increase in concentration of Ozone (table 6). This suggests that Ozone might be impacting bird species richness. In fact, bird species like Coppersmith barbet, Indian Grey Hornbill, Asian Palm Swift and Oriental White-eye were not observed in the PB site which has highest Ozone level (table 2).

CCA analysis revealed decrease in bird species abundance with increase in concentration of PM_{10} whereas bird species abundance increased with increase in percentage of tree cover (fig. 5). Thus PM_{10} and tree cover likely to affect the bird species abundance in the current study. These observations further confirmed the relationships derived from Pearson's correlation analysis.

Conclusions

Our study suggests that landuse changes, particularly area under tree cover and structure of greenspaces do influence the air quality and the bird diversity. For example, bird diversity is higher in areas where tree cover is high and low levels of air pollutants and vice versa. Some of the bird species may serve as indicator of air pollutants. For example, birds such as Oriental White-eye, Coppersmith Barbet, Indian Grey Hornbill, Brown-headed Barbet are sensitive to Ozone and are absent in areas with high level of Ozone. The species composition of greenspaces is critical in mitigating air pollution and also to sustain avian diversity in urban landscape. Detailed studies involving larger number of sampling sites may further substantiate the conclusions drawn from the present study.

We like to thank University of Delhi for providing research grant (SHC 307) under Innovation Project Scheme. We are thankful to the Principal Dr. Shashi Nijhawan for supporting and encouraging us throughout this project. We acknowledge Delhi Pollution Control Committee, Government of NCT Delhi for access to the data on air pollution. The contributions of Arunender, Aakash, Hitakshi, Shruti and Tarun for their help during field data collection are also duly acknowledged.

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Received 28 June 2021
Accepted