Urbanization, Electromagnetic Radiation and Sparrows: A Case Study from Guwahati, India

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Research Article

Keywords: birds, cellphone tower, EMR, public-health, urbanization, India

Posted Date: December 28th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-461355/v1>

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Abstract

The persisting growth of wireless telecommunication technology causes increased electrosmog. Exposure to wide-ranging radiofrequency electromagnetic fields is thought to be a concern for all the living species across the globe. Studies have shown possible effects of electromagnetic radiation on various organisms including electromagnetic radiation risk on birds, but the outcomes were inconsistent. Here, we investigated if there is any impact of electromagnetic radiation on the abundance and habitat use of sympatric House Sparrow and Tree Sparrow in Guwahati City, India. In addition, we did a comparative analysis of previous work that had been conducted on possible effects of EMR on wild birds in field condition. We collected sparrow abundance in selected urbanization gradients temporally over a period of two years in 45 locations and spatially covering 168 locations in the eastern part of Guwahati City. Point counts were carried out, and successively we measured the electromagnetic radiation along with other ecological covariates. It was observed that ecological variables contributed significant variation to explain the habitat use of sparrows in Guwahati City compared to electromagnetic radiation. We observed that House Sparrow had quadratic relationship and Tree sparrow had negative association with increasing urbanization. Studies carried out in the past on the impacts of electromagnetic radiation on birds outside the lab condition had not considered other ecological covariates, which could also influence the life history needs of the bird species. Our study emphasized that the ecological covariates should be taken into consideration while studying the effect of electromagnetic radiation on wild organisms.

Introduction

On a global scale, humans are shifting the composition of habitats, with ever-increasing human population. In recent years, the importance of incorporating the impact of human activities into the study of ecology is becoming more widely recognized (Bürgi et al. 2017). The incremental growth of wireless telecommunication technologies has caused increased electrosmog (Cucurachi et al. 2013). Exposure to wide-ranging radiofrequency electromagnetic fields (RF-EMF) shown as a concern for variety of species and groups across the globe. Studies have recognized possible effects on organisms (e.g., bees, fruit flies, frogs, birds, bats, and humans) with the increase of RF-EMF in the environment (Fernie et al. 2005, Balmori and Hallberg 2007, Everaert and Bauwens 2007). However, long-term studies of such exposures have been inconclusive and limited. Scientific communities have probed the extent of non-thermal exposure to low-intensity electromagnetic radiation which are thought to have adverse effect on health, reproduction and behaviour of humans and other organisms. However, evidence suggests that there is a large lacuna in research regarding the ecological effects of RF-EMF. Majority of the studies has concentrated on humans and occupational health issues, mostly based on animal model studies (e.g., mice, rats, chickens and other birds) under laboratory conditions (Cucurachi et al. 2013). Few recent studies put further insights of the effects of exposure to electromagnetic fields on populations of wild birds (Balmori 2005, Fernie et al. 2005, Balmori and Hallberg 2007; Everaert and Bauwens 2007, Rejt et al. 2007). As "*birds are candidates for being good biological indicators for low-intensity electromagnetic radiation: they have thin skulls, their feathers can act as dielectric receptors of microwave radiation, many species use magnetic navigation, they are very mobile and possible psychosomatic effects are absent*" (Balmori 2005). Balmori (2004) also stated that the urban birds that are subjected to electromagnetic contamination are more vulnerable to the negative impacts of RF-EMF.

Six species of sparrows *Passer* spp. have been reported from the Indian subcontinent (Ali et al. 1987). Out of them, the House Sparrow *Passer domesticus* and the Eurasian Tree Sparrow *Passer montanus* are chiefly associated with man-made habitats and human activities (Summers-Smith 1988). In India, the distribution of the House Sparrow is widespread; however, the Eurasian Tree Sparrow, generally a northern species, has a small resident population in the Eastern Ghats too (Grimmett et al. 1999). House Sparrow and Tree Sparrow fill similar ecological niches (Summers-Smith 1988). House sparrows usually live in urban environment, where electromagnetic contamination is comparatively higher; for this reason, sparrows may be a useful biological indicator for detecting the effects of this radiation. Successively, the recent decline of House Sparrow worldwide thought to have the possible link with electromagnetic radiation (Balmori and Hallberg 2007). Some published report anticipated that sparrows tend to avoid places with high levels of electromagnetic signals (Balmori 2003). Moreover, small organisms are especially vulnerable as they possess thinner skulls, which may facilitate radiation penetration into the brain (Hyland, 2000). However, it was also questioned, "*if the electromagnetic radiations are deleterious to birds; they should be so to a number of other animals that shares urban landscape with humans. Why must the house sparrow be vulnerable when crows, pigeons, owls, mynas, bats and geckos have not succumbed to electromagnetic radiation that is attributed telecommunication?*" (Daniels 2008).

Henceforth, in the present study we seek to understand is there any impact of electromagnetic radiation on the abundance and habitat use of sympatric House Sparrow and Tree Sparrow in the Guwahati City, India. In India, the composition of telephone subscribers using wireless form of communication is 63.27% in urban area and 33.20% in rural area (TRAI 2012). We hypothesized that if House Sparrow abundance and distribution (as hypothesized by Balmori 2004) was influenced by electromagnetic radiation that would have more or less similar consequences on Tree Sparrow too, since Tree Sparrow is ecologically similar to House Sparrow concerning body size and habitat use with highly overlapped zones within the limit of their distribution (Ali et al. 1987). Thus, we collected data on the abundance of Tree Sparrow along with House Sparrow and other associated urban bird species such as the House Crow *Corvus splendens*, Common Myna *Acridotheres tristis*, Feral Pigeon *Columba livia domestica*, Spotted Dove *Spilopelia chinensis*, Jungle Myna *Acridotheres fuscus* and Asian Pied Starling *Gracupica contra*.

Balmori and Hallberg (2007) found that when the mean field strength of electromagnetic radiation was greater than 3 volt/meter, sparrows declined drastically. Besides, they also mentioned that an apparently strong relationship between bird density and electromagnetic field strength could be conducted in a more controlled study to test the hypothesis. However, studies that have been carried out on the possible effect of electromagnetic radiation on sparrow abundance/density had not considered other ecological factors that might also influence the abundance/distribution of sparrows. Hence our specific objectives were– a) to investigate is there any impact of electromagnetic radiation on the abundance of sparrows in the presence of other ecological variables; b) to find out the association of House Crow, Common Myna, Feral Pigeon, Spotted Dove and Jungle Myna in relation to EMR; and c) to probe on the previous studies carried out on wild birds and possible effects of EMR outside laboratory condition.

Study Area

The study was carried out in Guwahati, which is the major and growing city in the north-eastern part of India (Alam, 2011). The human population of Guwahati Municipal Corporation Area in 2011 was 963,429 (Guwahati City Census 2011). The city is located on the southern bank of the Brahmaputra River, adjacent to undulating plain foothills of Meghalaya plateau, between 26°50' to 26°150' N and 91°350' to 91°550' E, and covers an area of 264 km² (Fig. 1a). Guwahati falls under the tropical monsoon climate and receives about 1,600 mm annual rainfall. The major habitat types of Guwahati comprised of forest patches (mostly hillocks), scrublands, plantations, agriculture and human settlements and Deepor beel, a Ramsar site. There are several commercial and residential nuclei (e.g., Paltan Bazar, Ganeshguri, Beltola, Sixmile, Khanapara, Maligaon) in the city. Paltan Bazar surrounded by Pan Bazar and Fancy Bazar is the central part of the city. This is the transportation hub and includes the Guwahati Railway Station, bus stations, stoppage of numerous private bus services, offices, numerous hotels and restaurants, making it one of the crowded and congested areas of the city. On the other hand, Beltola area in the eastern part of the city sharing geographic boundary with the hills of Meghalaya, has been developing in a rapid manner since 1980s and now extends up to National Highway 37 (NH-37) in the extreme south of the city. The Beltola Bazar in the central part of Beltola is a bi-weekly fruits and vegetable market, which has been place of congregation of people during the market-days since ages. It is an important traditional trade point between the people from Khasi Hills (Meghalaya) and the local people of Guwahati. Beltola area forms a gradient of urbanization scale starting from highly urbanized area such as congested market places at the road sides to residential complexes to fellow land. Additionally, the old railway quarters in Maligaon and the veterinary staff quarters in Khanapara occupy a very small area of the Guwahati city, but have Assam type traditional housing structures, with predominantly tin roofs.

Methods

Initially, we collected sparrow abundance in selected habitat gradients (highly commercial/semi-commercial city centers, residential apartments/buildings, and Assam-type houses) over a period of time (temporal) to monitor the trend. From 2013 to 2015 we visited 45 locations (Fig. 1b) on 10 occasions and collected data on the number of House Sparrow, Tree Sparrow, and other associated urban species: House Crow (HC), Feral Pigeon (FP), Common Myna (CM), Jungle Myna (JM) and Asian Pied Starling (APS). Point counts were carried out for five minutes within 30 m radius circle in the morning between 0600–0900 hrs. Simultaneously, we measured the electromagnetic radiation for each location using EMF Detector (Model-A/195, Three-Axis RF Strength meter; frequency range 50 MHz ~ 3.5 GHz). We used the radiation measurements of the maximum average for five

minutes in the V/m unit. Subsequently, we also collected microhabitat information of 12 ecologically important (see Nath et al. 2019) variables on each sample location: distance to closest green patch—delineated the boundary of nearest green patch using Google Earth and measured the closest distance of the boundary of the patch from the center of the 30 m radius circle; (ii) green cover— digitized green cover (tree + grass cover) using Google Earth; (iii) grass cover— we used handheld laser range finder and Google Earth to estimate the percent grass cover; (iv) Plant diversity— counted the number of individuals of plant species (trees and sapling) and calculated Shannon (H') diversity index (v) distance to closest marketplace— generated the center point of the open market places (open daily markets, congested areas with hotel restaurants, shopping malls, crowded places nearby bus-stops and railway station etc.) and measured the distance from the center point of 30 m radius circle; (vi) Food shops—number of hotels, restaurants, grocery shops within the 30 m radius. We also counted the (vii) number of rolling shutters people used for the front gate of shops and garage. Moreover, counted the number of (viii) single storied and (ix) multistoried house along with the roof type such as (x) tin & (xi) concrete within the 30 m radius. In addition, we also measured the (xii) area opening of drains using laser range finder, and then converted the area into percentage by dividing the area of 30 m radius circle.

Later, from November 2014 to March 2015, we also collected data on the spatial scale in the eastern part of Guwahati City, where the overlap of both sparrow species was higher compared to other parts of the city (Nath et al. 2019). A total of 168 locations were surveyed over the urban gradients and the number of House Sparrow and (avoid using ampersand in a running text, use word 'and') Tree Sparrow was counted, and the value of electromagnetic radiation was also measured using EMF Detector as mentioned above. Here, we classified the LISS-IV image (5 m resolution) of Guwahati city using *ERDAS 9.1* to get the built-up cover, green cover (tree cover + grass cover), and the proportion of each class within the 100 m radius of the sampling location using *ArcGIS 10.3*.

In addition, we presented a systematic comparative review of the published scientific studies on the potential ecological effects of electromagnetic fields on birds at the natural setup (*i.e.*, outside laboratory condition). We excluded all studies on birds that had not been conducted in field condition. Subsequently, we summarized the following: study design adopted, findings and conclusive remarks these studies delivered.

Data analysis

Pearson correlation test was performed to find out the association between EMR and abundance birds. For the temporal dataset, we conducted PCA for ecological covariates and components representing similar ecological gradients (degree of urbanization PC1: distance to nearest marketplace, number of food shops, number of rolling shutters; greenness PC2: overall green-cover, grass-cover percentage, distance to nearest green patch and plant diversity; house-type PC3: no. of single & multistoried house, no. of tin and concrete roof) (for details see Nath et al. 2019). Before performing PCA analysis, we transformed all the variables into Z-score. We used exploratory analysis such as graphs (scatter and box plots) and univariate regressions to choose the best among several indices corresponding to a single apriori hypothesis and settle on the appropriate function (linear or quadratic) before formal modeling. We built candidate regression models (Generalized linear model) using EMR and its additive and interactions with the PCA components – degree of urbanization, greenness, and house-type as an independent variable, and sparrow abundance as a dependent variable.

For the spatial dataset, we built candidate regression models with covariates –percent built-up cover and EMR, and interactions of built-up $\times$ EMR on sparrow abundance. Following Burnham and Anderson (2002), we computed Akaike-weight (W_i) of select candidate models to provide model-averaged regression coefficients, unconditional standard errors, and importance (summed Akaike-weights) of each predictor using *MuMIN* (Bartoń 2015) in program *R v 3.2.5*. Finally, we used R package “*effects*” (Fox and Hong 2009) to plot the interaction model.

Results

For the temporal habitat use dataset, both House Sparrow ($r = -0.022$, $p = 0.88$) and Tree Sparrow ($r = -0.07$, $p = 0.64$) found to have no association with EMR measures. Out of eight species of urban birds studied, significantly Spotted Dove ($r = -0.31$, $p = 0.03$) and Asian Pied Starling ($r = -0.48$, $p = 0.001$) showed negative association with increasing electromagnetic radiation (Figs. 2 & 3). The House Sparrow abundance was found to be influenced by the degree of urbanization (Table 1; S1 Table).

Electromagnetic radiation solely was not found to have any effect on the House Sparrow abundance. EMR was found to have an additive effect on House sparrow numbers when modeled with the quadratic form of degree of urbanization (not significant; see Table 2; S1 Table). A similar trend was also observed for Tree Sparrow as EMR did not influence the Tree Sparrow numbers. Interaction of greenness and house type had a positive influence, whereas the degree of urbanization had negative (see Tables 3 & 4). Among all other covariates, degree of urbanization was found to play a critical role in determining the number of sparrows in Guwahati City. House Sparrow had a quadratic relation, Tree Sparrow had a negative, whereas EMR was positively associated with the increasing urbanization (Fig. 4).

Table 1

Summary statistics [loglikelihood (LogL), degrees of freedom (df), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), Akaike weights (Wi) of candidate regression model explaining House Sparrow distribution in the presence of EMR.

Models	Wi	AICc	Δ AICc	df	logLik
(deg. of urbanization + deg. of urbanization ²)	0.387	192.6	0	4	-91.807
(deg. of urbanization + deg. of urbanization ² + EMR)	0.188	194.1	1.44	5	-91.259
(deg. of urbanization + deg. of urbanization ² + house-type)	0.14	194.7	2.04	5	-91.558
(deg. of urbanization + deg. of urbanization ² *EMR)	0.06	196.3	3.72	6	-91.063
(deg. of urbanization + deg. of urbanization ² + house-type + EMR)	0.052	196.6	4.01	6	-91.205
(deg. of urbanization + EMR)	0.05	196.7	4.09	4	-93.851
(deg. of urbanization*EMR)	0.049	196.7	4.12	5	-92.598
(deg. of urbanization)	0.049	196.7	4.13	3	-95.081
(.)	0.018	198.7	6.08	2	-97.207
EMR	0.006	201	8.36	3	-97.192
Null model shown as (.)					

Table 2

Model-averaged parameter estimates of influential habitat covariate and EMR which determines the distribution of House Sparrow

(Conditional average)	Estimate	Std. Error	Adjusted SE	z value	Pr(> z)
(Intercept)	0.5111	1.2578	1.2942	0.395	0.69289
deg. of urbanization	3.6032	1.2086	1.2447	2.895	0.00379 **
deg. of urbanization ²	-0.6517	0.2673	0.2752	2.368	0.01789 *
EMR	-0.2208	0.2195	0.2262	0.976	0.32907
<i>p</i> < 0.01*, <i>p</i> < 0.001**					

Table 3

Summary statistics [loglikelihood (LogL), degrees of freedom (df), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), Akaike weights (Wi) of candidate regression model explaining Tree Sparrow distribution in the presence of EMR.

Models	Wi	AICc	Δ AICc	df	LogLik	init.theta
(greenness*house type)	0.456	125	0	5	-56.75	0.808
(greenness*house type + deg. of urbanization)	0.189	126.8	1.76	6	-56.294	0.883
(greenness*house type + EMR)	0.143	127.4	2.32	6	-56.572	0.864
(greenness*house type*EMR)	0.091	128.3	3.22	9	-52.559	1.24
(greenness*house type + deg. of urbanization + EMR)	0.048	129.5	4.48	7	-56.248	0.907
(.)	0.045	129.7	4.61	2	-62.683	0.51
EMR	0.027	130.7	5.65	3	-62.05	0.54
Null model shown as (.)						

Table 4

Model-averaged parameters estimates coefficients (β), standard errors (S.E), significance statistics of influential habitat correlates of Tree Sparrow habitat usage in Guwahati city.

Model-averaged coefficients					
(conditional average)	β estimate	Std. Error	Adjusted SE	z value	Pr(> z)
(Intercept)	-2.0373	1.2014	1.2326	1.653	0.098356.
Green	1.9232	0.6023	0.6193	3.105	0.001900 **
House type	1.2959	0.5682	0.5855	2.213	0.026884 *
Greenness*House type	-1.0808	0.3126	0.3221	3.355	0.000794 ***
Deg. of urbanization	-0.3502	0.327	0.3372	1.038	0.299088
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Key factors influencing the habitat use using spatial dataset of sparrows are given in Tables 5 and 6. House Sparrow ($r = -0.17$, $p = 0.06$) and Tree Sparrow ($r = -0.20$, $p = 0.29$) found to have no significant association with EMR measures. We fitted model with two covariates (% built-up area and EMR) and four subset models indicating various plausible ecological hypotheses about sparrow habitat usage based on apriori expectations. The most significant predictor from the overall model was the interaction of the percent built-up area and EMR for both House Sparrow and Tree Sparrow. Built-up area has positive association with House Sparrow and negatively associated with Tree Sparrow abundance (Figs. 5 and 6).

Table 5

Summary statistics [loglikelihood (LogL), degrees of freedom (df), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), Akaike weights (Wi) of candidate regression model explaining House Sparrow distribution in the presence of EMR.

Models	(Int)	Built-up	EMR	Built-up *EMR	df	logLik	AICc	Δ AICc	Wi
(Built-up*EMR)	1.05	0.0078*	-0.3852*	0.00387*	4	-512.052	1032.3	0	0.98
(Built-up + EMR)	0.41	0.0163*	-0.1030*		3	-517.526	1041.2	8.85	0.02
(Built-up)	0.08	0.0178*			2	-525.980	1056.0	23.68	0
(EMR)	1.57		-0.1513*		2	-554.872	1113.8	81.47	0
(.)	1.23				1	-572.497	1147.0	114.67	0
Null model shown as (.) *p < 0.05									

Table 6
Summary statistics [loglikelihood (LogL), degrees of freedom (df), Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), Akaike weights (Wi) of candidate regression model explaining Tree Sparrow distribution in the presence of EMR.

Models	(Int)	Built-up	EMR	Built-up * EMR	df	logLik	AICc	Δ AICc	Wi
(Built-up * EMR)	1.64	-0.0361*	-0.352*	0.0056*	4	-246.224	500.7	0	0.791
(Built-up + EMR)	0.95	-0.0221*	-0.083		3	-249.258	504.7	3.97	0.109
Built-up	0.67	-0.0207*			2	-250.378	504.8	4.14	0.1
(.)	-0.42				1	-264.115	530.3	29.56	0
EMR	-0.37		-0.0202		2	-264.045	532.2	31.47	0
Null model shown as (.) *p < 0.05									

Our search yielded five field (outside laboratory) studies that claimed the possible impact of RF-EMF on birds. The species involved were House Sparrow, Great Tit *Parus major*, Blue Tit *Parus caeruleus*, and White Stork *Ciconia ciconia* (see Table 7). The studies claimed the possible significant effect of RF-EMF on birds' occupancy, abundance, breeding density, reproduction, and species composition. Most of these studies showed statistically significant adverse impact of RF-EMF on birds except Reijt et al. (2007) study on Tits. However, none of these studies except Tiwary et al. (2014) had taken any considerations of other environmental variables that can also influence the habitat use of these studied birds (see Table 7). We have provided a detailed on the methodology adopted, findings and conclusion drawn by the authors. Besides, we also commented and argued on the outcomes provided in relation to impact of EMR with published research works, and cite literature those who mentioned other ecological variables that could also influence the population and habitat use parameters of the studied bird species.

Table 7

Comparative analysis on the study design and findings on the impact of electromagnetic radiation on birds from field based study.

Source & Species	Study design	Frequency; Wave/ Modulation	Other ecological variable	Relationship strength	Findings	Remarks/Comments
Balmori and Hallberg (2007) House Sparrow (<i>Passer domesticus</i>)	Point transect sampling was performed at 30 points during 40 visits	1-3000 MHz; GSMtoMW	Not incorporated	$r = -0.87$; $p < 0.0001$ sparrow density had negative association with increasing electromagnetic radiation (S1 Fig).	No sparrows would be expected to be found in an area with field strength $> 4V/m$. Apparently strong dependence between bird density and field strength according to this work could be used for a more controlled study to test the hypothesis (Balmori and Hallberg 2007)	The study showed that sparrow density had a negative association with increasing electromagnetic radiation. However, published research (MacGregor-Fors et al. 2017), including our present research showed that there is a positive association of House Sparrow abundance with initial built-up habitat or urbanization index. Murgui (2009) also found out that the abundance of sparrow decreases places where urbanization reached the peak, basically a quadratic effect of urbanization on sparrows. In the present study, we found that with urbanization the number of mobile towers increases, hence EMR also increases. Hence, in areas where urbanization reached the peak have had high measures of EMR and less number of sparrows. Therefore, the studies carried out without the control setup of the urbanization effect, the negative relationship strength might not depict the actual scenario. Thus, the negative correlation strength reported by Balmori and Hallberg (2007) between sparrow density and EMR may merely attribute to sampling artifacts rather than factual causation.

Source & Species	Study design	Frequency; Wave/ Modulation	Other ecological variable	Relationship strength	Findings	Remarks/Comments
<p>Everaert and Bauwens (2007)</p> <p>House Sparrow</p>	<p>150 point locations within the six areas to examine small-scale geographic variation in the number of House Sparrow males and the strength of electromagnetic radiation from base stations.</p>	<p>925–960; GSM base station</p>	<p>Not incorporated</p>	<p>Significant variation among study areas (Chi²-tests, $P < 0.001$), and a highly significant negative effect of electric field strength on the number of House Sparrow males (Chi²-tests and AIC-criteria, $P < 0.001$; S2 Fig).</p>	<p>House Sparrow male was negatively and highly significantly related to the strength of electric fields from both the 900 and 1800MHz. The exact mechanisms of these effects are as yet poorly understood. <i>"Given the potential importance that such effects may have on aspects of biodiversity and human health, more detailed studies in both the laboratory and the field are urgently needed to corroborate our results and to uncover the underpinning mechanistic relationships"</i> (Everaert and Bauwens, 2007)</p>	<p>The breeding male of House Sparrow in general most active in the places where there are more nesting substrates nearby. Whereas, there were several studies which also concluded that over urbanized area provide less opportunity to the sparrows to place/construct nests (Nath et al. 2016). As we mentioned earlier, that EMR has a direct positive association with urbanization. Hence, the study conducted by Everaert and Bauwens (2007) without the inclusion of other ecological covariate which determines nest-site selection in sparrows couldn't be taken into account for any kind of negative association due to electromagnetic radiation.</p>

Source & Species	Study design	Frequency; Wave/ Modulation	Other ecological variable	Relationship strength	Findings	Remarks/Comments
Tiwary et al. (2014) House Sparrow	House Sparrow and other common urban species spotted on both sides of a line transect (1 km) from the 240 sub-grids comprising of 60 sampling grids, were recorded. Using single season occupancy model in program presence, they modeled occupancy as a function of the extent of preferred habitat in a grid (% urban area) and averaged EMF values.	Not mentioned	% urban area per grid sampled	Negative association with averaged EMF values (β EMF = -1.029 ± 0.19) and sparrow occupancy (S3 Fig)	Sparrow occupancy shows a positive association with its preferred habitat i.e. % urban area (β Hab = 1.58 ± 0.72). House Sparrow occupancy shows an increasing trend with the extent of % urban area while a strong negative association with averaged EMF values per grid. It lends support to the widespread speculation that high electromagnetic radiations from mobile towers and other sources may be responsible for the decline of House Sparrow population (Tiwary et al. 2014)	The study showed that the negative association between the averaged EMF values and the occupancy of House Sparrow in Delhi, India. The negative trend was based on only three data points (having EMR measures more than 5 V/m; see S3 Fig). Without these three data points, the trend line would show the opposite (i.e., positive) direction. Most likely, the negative trend of House Sparrow occupancy with EMR associated because of the high degree of urbanization. Despite that, the use of the occupancy model, which is based on the presence/absence data, may not be an appropriate method to show a cause and effect relationship.
Balmori (2005) White Stork (<i>Ciconia ciconia</i>)	For monitoring of breeding success of the white stork population, 60 nests were chosen that were exposed at very high or very low levels of electromagnetic radiation, depending on the distance from the nests to the antennas.	900–1800; GSM base station	Not incorporated	$r = -0.47$; $p < 0.0001$ (irrespective of distance from the nests to the antennas) (S4 Fig)	Significantly lower number of White Stork fledglings in nests exposed to relatively high electromagnetic radiation (2.36 ± 0.82 V/m) than in nests receiving lower levels of radiation (0.53 ± 0.82 V/m). Results suggest that electromagnetic radiation interferes with reproduction in this wild population (Balmori 2005)	The study mentioned explicitly that significantly lower number of White Stork fledglings in nests exposed to areas with relatively high electromagnetic radiation (2.36 ± 0.82 V/m) than in nests receiving lower levels of radiation (0.53 ± 0.82 V/m). However, studies also reported that White Stork populations' reproductive success is either low or highly variable throughout its breeding range (Bairlein 1991, Jovani and Tella 2004). Moreover, there were multiple factors which affect the number of

Source & Species	Study design	Frequency; Wave/ Modulation	Other ecological variable	Relationship strength	Findings	Remarks/Comments
						fledglings, including age, arrival date, breeding experience of pairs and physical fitness of parent stork, weather condition during the nestling period, nest site characteristics, and food availability which largely depends on the habitat quality (Barbraud et al. 2008, Denac 2006, Massemin-Challet et al. 2006, Nevoux et al. 2008). Hilgartner et al. 2014 found that reproductive success was significantly higher for the pairs breeding close distance to the feeding site, however, the number of fledgling per nest decreased by 8% per kilometer distance to the feeding sites. Henceforth, without considering any of these covariates mentioned above, it was hard to accomplish the fact that electromagnetic radiation affects on the hatching success of the White Stork.
Reijt et al. (2007) Great Tit (<i>Parus major</i>); Blue Tit (<i>Parus caeruleus</i>)	On the radar station area, two transects placed of 36 nest box in each. Each nest box was placed on trees, about 3m ground level. Control nest boxes were placed in other part, which was free from radar radiation.	1805–1880, 1200–3000 MHZ; GSM base station, Radar	Not incorporated	Significantly Blue tits occupied more nest boxes in high exposed areas near Radar station compared to Great Tits ($p < 0.05$).	No significant difference was noticed in the number of eggs, and number of nestling per box observed between tits occupying exposed and control nest boxes. However, they concluded that radar station generally doesn't lead to decrease of number of tits, but may cause shifts in tit species living	The study highlights that significantly Blue Tits occupied more nest boxes in high exposed areas near Radar station compared to Great Tits ($p < 0.05$) and mentioned that no significant difference was noticed in the number of eggs, and number of nestling per box observed between tits occupying exposed and control nest boxes. They also mentioned that sites where radiation level was higher were inhibited mainly by Blue Tits.

Source & Species	Study design	Frequency; Wave/ Modulation	Other ecological variable	Relationship strength	Findings	Remarks/Comments
					around the radar station (Reijt et al. 2007)	They finally concluded that radar station generally did not lead to a decrease of number of tits, but might cause shifts in tit species living around the radar station. However, the conclusion provided by Reijt et al. (2007) on the habitat shift by the tits due to the radiation is fundamentally questionable, as other studies found that Great Tits tend to be more selective in their choice of nest sites than are Blue Tits (Minot et al., 1986). Furthermore, Blue Tits occupy a broader niche and find a wider range of boxes to be suitable. On the other hand, Dhondt et al. (1979) investigated the possibility that the provision of artificial nest sites might affect the selection pressure on Great Tits to be effective competitors. However, Reijt et al. (2007) also mentioned that apart from the radiation level, micro-habitat around each nest box more likely to attract one species of tits or another.

Discussion

The present study showed that electromagnetic radiation did not show any direct effect on the abundance and habitat use of sparrows in Guwahati city. Besides, the sparrows were found to be influenced by other complex ecological variables (e.g., distance to the nearest market place, number of food shops, number of rolling shutter in shops, distance to nearest green patch, percent green cover and plant diversity, percent built-up area and percent green cover). However, the magnitudes and impacts of microhabitat variables mentioned above may vary among the specific needs of the life history traits of both the sparrow species (for details see Nath et al. 2019). It was observed that on spatial and temporal scales, ecological variables contributed significant variation to explain the habitat use of sparrows in the study area.

In general, increasing urbanization has positive association with electromagnetic radiation. The present scenario in most of the cities around the world is clear-cut— the area with higher developmental activity is also high in electromagnetic radiation because

of the growing demand for telecommunication and mobile phone services. Henceforth, the model output of our spatial data set showed a complex interaction of percent built-up and EMR since the percent built-up area partially characterizes the degree of urbanization. The interaction model (House Sparrow ~ Built-up * EMR) showed a positive association, which implies that the sampling locations with more built-up and area with high EMR measures have a large number of House Sparrow sightings (Fig. 5). Balmori and Hallberg (2007) showed that the mean density of sparrows corresponds to the lowest electromagnetic field intensity areas. Despite that, they also come up with the discordant statement that no sparrows would be expected to be found in an area with field strength > 4V/m. However, we recorded House Sparrow in the places where EMR reached up to 7.81 V/m, and even we recorded 1–17 individuals of sparrows ($5.0_{\text{Mean}} \pm 0.87_{\text{S.E}}$) within 4.00–7.81 V/m range. On the other hand, Tree Sparrow preferred habitat with minimum urbanization (Zhang and Zheng 2010), and its number was significantly influenced by greenness (% green cover, plant diversity) and type of housing structure (primarily residential apartment/building). It was found that EMR had no significant role in governing the habitat use of the Tree Sparrow; even at the different levels of EMR.

In our study, EMR was positively correlated with the degree of urbanization ($r = 0.53$, $p = 0.0001$) and negatively with greenness ($r = -0.51$, $p = 0.0002$). Subsequently, the negative association of Asian Pied Starling and Spotted Dove could be directly associated with the degree of urbanization. Both the species observed to occupy areas with low level of urbanization in the study area. Sivakumar et al. (2006) also found that the density of Asian Pied starling was more in village edge forest compared to other habitat types in Buxa Tiger Reserve, West Bengal, India. Therefore, solely based on the EMR measures the cause and effect relationship on avifaunal abundance may not be studied in the field condition. Subsequently, our analysis showed that EMR has no direct impact on the distribution and habitat use of urban birds, which collectively depending on the microhabitat needs of the species.

Previously, several studies have examined electromagnetic radiation risk on birds, but outcomes were inconsistent, and contributing factors were incoherent (Cucurachi et al., 2013). Most of the studies carried out on the effect of electromagnetic radiation on birds were laboratory investigation—on chicken (*Gallus domesticus*) and Japanese quail (*Coturnix coturnix* subsp. *japonica*). Cucurachi et al. (2013) review 113 peer-reviewed articles and concluded that two third of reviewed studies, the effects of EMR was reported at low as well as high dosages, the very low dosages can be compared with real field conditions. However, the studies lack of standardization and an inadequate number of observations bounds the prospect of generating results from an organism to an ecosystem level (Cucurachi et al. 2013). Among the 26 peer-reviewed studies on birds, 70% of them concluded possible significant adverse effects of RF-EMF (S5 Fig). However, most of these studies (60%) were carried out in the laboratory either at the embryo or egg stages of development (Cucurachi et al. 2013). On the other hand, only five field studies claim a possible significant effect of RF-EMF on birds' breeding density, reproduction, or species composition.

The study design and methods used in each of these above mentioned studies have been discussed in details in Table 7. None of these studies, considered possible interaction of electromagnetic radiation with other life history needs (ecological variables) of the studied species. Henceforth, finding out the reliable conclusion is difficult in studies without the other controlling factors (i.e. covariates). For urban birds, the sampling approach, and the intensity of urbanization and its complex association with EMR, could play a major role in the statistically significant cause and effect relationship due to sampling artifact, which has no relevance biologically. Apart from that, most of the studies were carried out in the laboratory showed significant negative impact of EMR. The duration of exposure of EMR was twice as high on average studies, which showed impact of the radiation than that of studies which did not show any effect (Cucurachi et al. 2013).

Moreover, studies that were carried out in the laboratory condition showed the significant negative impact of EMR. The duration of exposure of EMR was twice as high on average in studies, which showed the impact of the radiation than that of studies that did not show any effect (Cucurachi et al. 2013). They have also mentioned, the laboratory studies carried out in the past exposed targets to the high level of MW-EMF, which probably determined the uncontrolled rise in temperature affecting the exposed systems. The information and results on the effects of radiation gathered in laboratory studies may need to be guardedly handled due to the steep nature of the laboratory solutions adopted. The conditions applied in the laboratory studies, in fact, do not always reflect real conditions of exposure, and at times it is essential to carefully evaluate the plausibility that biological systems exposed to RF-EMF could likely translate into ecologically relevant effects.

The WHO confirms that to date the accepted health effects due to high dosage ascribable to RF-EMF are caused by temperature rise (van Deventer et al., 2011). On the contrary, in the present study in Guwahati city, and the other studies which have been carried out in the field underexposure of such a low level of EMR (< 9 V/m) were unable to generate the thermal effect. The measured electric field strength values were far below the required to produce heat as low as 0.5°C (i.e., 10 mW/cm^2 or ca. 194 V/m ; Bernhardt, 1992). However, few studies on the non-thermal effects of electromagnetic radiation provide evidence about the hypothesis of non-thermal effects of electromagnetic radiation on the brain physiology (Cucurachi et al. 2013) Subsequently, they also found that about two-thirds of the reviewed studies on the ecological effects of EMR were reported at high as well as at low dosages. The very low dosages are compatible with actual field situations and could be found under environmental conditions. However, the non-thermal effects on biological tissues still under investigation, although calcium efflux and free radical production are among the candidates of the possible mechanism responsible for the non-thermal effects of EMR. Then again, results are still not conclusive, and there is still some uncertainty about the low dosages and non-thermal effects applied in some studies which did find an effect (Cucurachi et al. 2013).

In conclusion, the studies carried out on the impact of EMR on birds in field condition, is limited. Moreover, the negative correlation strength reported by the previous studies between sparrow density and EMR may simply attribute to sampling artifacts rather than factual causation. In addition, large scale survey through questionnaire across India with the help of citizens did not able to make conclusion on any correlation in the decline of house sparrows with cellphone tower radiation (Rahmani et al. 2013). The present study also emphasized that the complexity of ecological processes involved in the cause and effect relationship should be understood in multidimensional means. Therefore, site covariates need to define and quantify along with EMR measures before concluding remarks on the impact of radiation emitted by cell phone towers.

Declarations

Acknowledgment

We are thankful to Aaranyak for providing the necessary facilities during the field surveys. We would like to thank Qamar Qureshi, Sutirtha Dutta, Sonali Ghosh and Ranjana Pal of Wildlife Institute of India in overall preparation of the manuscript. We are grateful to Minarul Haque, Samrat Sengupta, Nilutpal Mahnta for their help during the field work.

CONFLICT OF INTEREST STATEMENT

Manuscript title: Urbanization, Electromagnetic Radiation and Sparrows: a case study from Guwahati, India. The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript. Author names: Anukul Nath, Hilloljyoti Singha, Bibhuti P Lahkar.

FUNDING: The first author received fund from Aaranyak-rufford seed grant to carry out the field activity.

Financial interests: The authors declare that they have no financial interests.

AUTHOR CONTRIBUTIONS

Conceptualization: [Anukul Nath, Hilloljyoti Singha, Bibhuti P Lahkar]; Methodology: [Anukul Nath, Hilloljyoti Singha]; Formal analysis and investigation: [Anukul Nath, Hilloljyoti Singha]; Writing - original draft preparation: [Anukul Nath]; Writing - review and editing: [Hilloljyoti Singha, Bibhuti P Lahkar]; Supervision: [Hilloljyoti Singha, Bibhuti P Lahkar]

Consent to participate: We give our consent to participate in the publication process.

Consent for publication: We give our *consent* for the *publication* of submitted manuscript

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Figures

Figure 1

- a. Map showing the study area Guwahati City, Assam, India.
- b. Temporal and spatial sampling point for bird survey in Guwahati City, Assam

Figure 2

Pearson correlation among birds and Electromagnetic Radiation (EMR) of temporal point count stations.

Figure 3

Mean abundance of birds in relation to Electromagnetic radiation using temporal point count stations.

Figure 4

Relationship among sparrows and EMR with increasing degree of urbanization

Figure 5

Plot depicting probability of House Sparrow numbers at different strength of EMR measures in presence of built-up areas.

Figure 6

Plot depicting probability of Tree Sparrow numbers at different strength of EMR measures in presence of built-up areas.

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