Impacts of Artificial Lighting on Avian Biodiversity: A Case Study of Udaipur (Rajasthan), India

Raghvendra Mishra[1], Lavina Soni[1], Sunil Dutt Shukla[1]

1 Government Meera Girls College

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Abstract

The pervasive presence of artificial light in urban environments significantly affects biodiversity. This study investigates the impact of light pollution on avian biodiversity in Udaipur, India. Excessive artificial lighting alters natural habitats, disrupts ecosystems, and affects the behaviour and abundance of various avian species.

The study was conducted in Udaipur from December 2019 to March 2023, utilizing Visible Infrared Imaging Radiometer Suite (VIIRS) DNB Free Cloud Composite Imagery and field surveys. The research spanned rural and urban landscapes, employing methods such as timed species counts and point counts to assess avian fauna. The Shannon-Wiener Diversity Index was used to measure biodiversity, with ANOVA and Tukey's post-hoc tests for statistical analysis.

VIIRS data analysis revealed three light pollution clusters: dark, moderately dark, and bright areas. Avian diversity varied across these clusters, with significantly higher diversity observed in dark areas. Daytime and night time observations also showed variations, with higher biodiversity observed at night. Common species exhibited significantly higher abundance in brighter areas, while moderately dark and dark areas supported greater diversity.

Artificial lighting has profound effects on avian biodiversity in Udaipur. Bright areas exhibit reduced biodiversity, while dark areas support richer ecosystems. This study underscores the importance of managing light pollution to preserve avian diversity and maintain ecological balance in urban environments.

Raghvendra Mishra, **Lavina Soni**, and **Sunil Dutt Shukla***

Department of Zoology, Government Meera Girls College, Udaipur 313001, India

*Corresponding Author: shuklasd@gmail.com

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Introduction

Since light is ubiquitous on our planet, it is apparently linked to the life of all biota and it would be therefore expected, that excess lighting would impact all life-forms. Studies carried out by different workers have supported this assumption. Today the night skies in the cities are hundred times brighter than that in nature therefore, it is difficult to see the stars and other celestial bodies in a brightly lit city. Changes in ambient temperature due to heat dissipated from excessive lighting can bring about subtle environmental changes with more profound long-term consequences. Another aspect of these environmental changes is an increase in the production of greenhouse gases, which are considered responsible for profound environmental degradation. Light pollution entails wastage of energy, since a large part of energy (electricity) production involves burning of fossil fuels, it leads to the addition of greenhouse gases (e.g., carbon dioxide) to the environment without serving any useful purpose. Thus, greenhouse gas production runs parallels to light pollution as serious light pollution may also potentially contribute directly to greenhouse pollution by raising ambient temperatures locally.

Light pollution makes nighttime look like daytime, which can drastically impact nocturnal animals. Light pollution may adversely affect the survival of a particular species in a food chain and indirectly impact the survival of another species that feeds on it, thus disturbing the ecological balance of that area [1][2]. Analogous consequences would result if artificial lighting creates an environment conducive to better survival and breeding of a species. Predators use light to hunt, and darkness is a safety cover for the prey [3][4]. A range of behavioral changes have been attributed to light pollution in different animals, e.g., attraction of moths to artificial light at night; the moths attract bats, in turn. Many moths are eaten up by bats, and some get killed by the heat of the light source. Thus, light pollution has the potential to decrease the population of moths and increase that of bats. Migratory birds are known to be disoriented by bright lights, and light pollution may make them migrate too early or too late, so that they may miss the ideal time for nesting and other breeding behavior, affecting their population [5][6][7]. Advanced onset of dawn song has been reported in songbirds due to light pollution [8]. Light pollution has led sea-turtle hatchlings to migrate away from the sea and consequently die, resulting in a serious drop in the population of this species [9][10][11][12][13]. Amphibian inhabitants of wetlands indulge in nighttime croaking – a breeding ritual to attract their mates. Light pollution inhibits this behavior, and the amphibians are not able to breed normally, leading to a decline in their population [14][15][16]. On a larger scale, the species-specific changes may also alter community dynamics and even the ecological balance of the area. Excessive artificial lighting has been suggested to be responsible for disturbing delicate ecological balances and environmental parameters. Light pollution in the form of sky glow, glare, clutter, and light trespass has adversely impacted the environment [17]. Other types of pollution, like dust and smoke, may amplify light pollution by light scattering. The most obvious effect of light pollution is sky glow, which obscures our view of the true night sky.

The present study explores the relationship between light pollution and avian diversity, considering birds as bioindicators of ecosystem health. By employing transect surveys and biodiversity indices, the research seeks to elucidate how varying levels of artificial light impact the abundance, richness, and composition of avian communities in different urban settings.

Furthermore, the investigation delves into the potential interactions between light pollution and species-specific traits, such as habitat preferences and activity patterns. Understanding how different species respond to artificial light is crucial for designing effective conservation strategies and mitigating the negative impacts of light pollution on biodiversity.

Overall, this study contributes in giving valuable insights of the complex interplay between urbanization, light pollution, and biodiversity conservation. By elucidating the ecological consequences of excessive artificial lighting, the resultant findings can be used in policy-making, urban planning, and environmental management practices aimed at promoting sustainable coexistence between human activities and natural ecosystems.

Materials and Methods

Study Area: The study was conducted in Udaipur city, situated within the Aravalli Range of mountains in the state of Rajasthan, western India. Udaipur is renowned for its natural and man-made lakes, earning it the epithet "City of Lakes." The study area encompasses both the historic "Walled City" and the contemporary "Outer City," each with distinct characteristics and urban layouts.

Data Collection Period: The research spanned from December 2019 to March 2023, totalling to 40 months. Data was presented for 39 months, excluding July 2022 due to data unavailability. The study period coincided with the COVID-19 pandemic, during which a lockdown was imposed, affecting data collection procedures. The total lockdown duration was 68 days, during which field recordings were collected during designated relaxation hours from 7:00 pm to 10:00 pm.

VIIRS Data Collection: VIIRS-DNB Free Cloud Composite Imagery, obtained from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), was utilized for light pollution analysis. Filtering techniques were applied to selected images to remove short-term events, with image processing methods used to distinguish stationary illumination from transient sources.

Study Limitations: Limitations of the study include data unavailability for July 2022 and the impact of the COVID-19 lockdown on data collection efforts. Additionally, the coarse spatial resolution and limited dynamic range of satellite imagery may have affected the accuracy of light pollution assessments.

Figure 1. Area Under Study (Image Source Google Earth)

Table 1. Locations Studied and their Coordinates

Location	Longitude	Latitude
Ayad Pulia (Ashok Nagar)	73.711	24.586
Balicha Choraha	73.673	24.524
Celebration Mall	73.702	24.613
Chetak Circle	73.69	24.591
Dakan Kotda	73.741	24.504
Delhi Gate	73.695	24.586
Fatehpura Circle	73.689	24.609
Goverdhan Vilas	73.788	24.537
Gulab Bagh	73.692	24.574
Hiran Magri	73.729	24.567
Jagdish Chowk	73.684	24.58
Kaladwas Industrial Area	72.762	25.568
Machhala Magra Peak	73.689	24.565
Machhala Magra (Kacchi Basti)	73.692	24.561
Madri Industrial Area	73.7448	24.571
Pratapnagar	73.737	24.588
Shilpgram	73.661	24.611
Sukehar Choraha	73.712	24.634
Surajpole	73.697	24.58
Udiapole	73.7	24.576

Effects of artificial lighting on Biodiversity

Artificial night lighting affects various ecosystems. Almost all groups of animals are directly or indirectly affected, especially birds and nocturnal insects. To demonstrate the consequences of artificial lighting, we studied rural and urban landscapes in and around Udaipur. Appropriate methods were used to measure biodiversity, including timed species counts and point counts, along with intermittent sampling to measure avian fauna. The line transect method was used to observe amphibian/reptile and mammalian diversity.

We used the walking line transect method. A transect walk involves walking in a straight line for a pre-determined distance, recording geographical coordinates every fifty meters or so, and writing down environmental characteristics around that point. The total distance covered was 385 km. Each transect was covered once in the morning (05:00 to 09:30 h) and once in the evening (17:00 h to 19:30 h) each week from 2019 to 2023. Similar recordings were also made during the day and night time, for comparing the avian diversity between to contrast time periods. The distance of the animal's location from the transect line (or road) was recorded using a rangefinder (15 to 180 m range) at 10 m square intervals.

Data Analysis

The VIIRS data was subjected to K Means clustering. Based on the presence or absence of similar patterns data is divided into 3 clusters namely Bright Area, Moderately Dark Area and Dark Area.

Descriptive Statistics was applied to avian diversity data and following were calculated Minimum values, Lower boundaries, Quartile values (Q1, Median, Q3), Upper boundaries, Maximum values, Interquartile ranges (IQR), Mean values, Skewness, Excess kurtosis and Outliers. The Avian diversity during the study period was measured using the Shannon-Wiener Diversity Index. Data were further subjected to ANOVA and followed by Multiple Comparisons (Tukey's Posthoc) to assess the significance level. All the data was analysed using Microsoft Excel.

Results

VIIRS Studies

The data was divided into 3 clusters (k=3). The percentage of variance explained by the clustering solution with k=3 is 86.98%. This indicates how well the clusters represent the variability in the data. The SSE (total variance within each cluster) is 128.2248. The SSG (the variance between the cluster centroids) is 856.4728. The SST (total variance in the data) is 984.6977. The centroids (centers) of the clusters are given as 5.69 (dark area), 17.984 (moderately dark area), and 25.71 (bright area) respectively. These represent the average values of the data points within each cluster along each dimension.

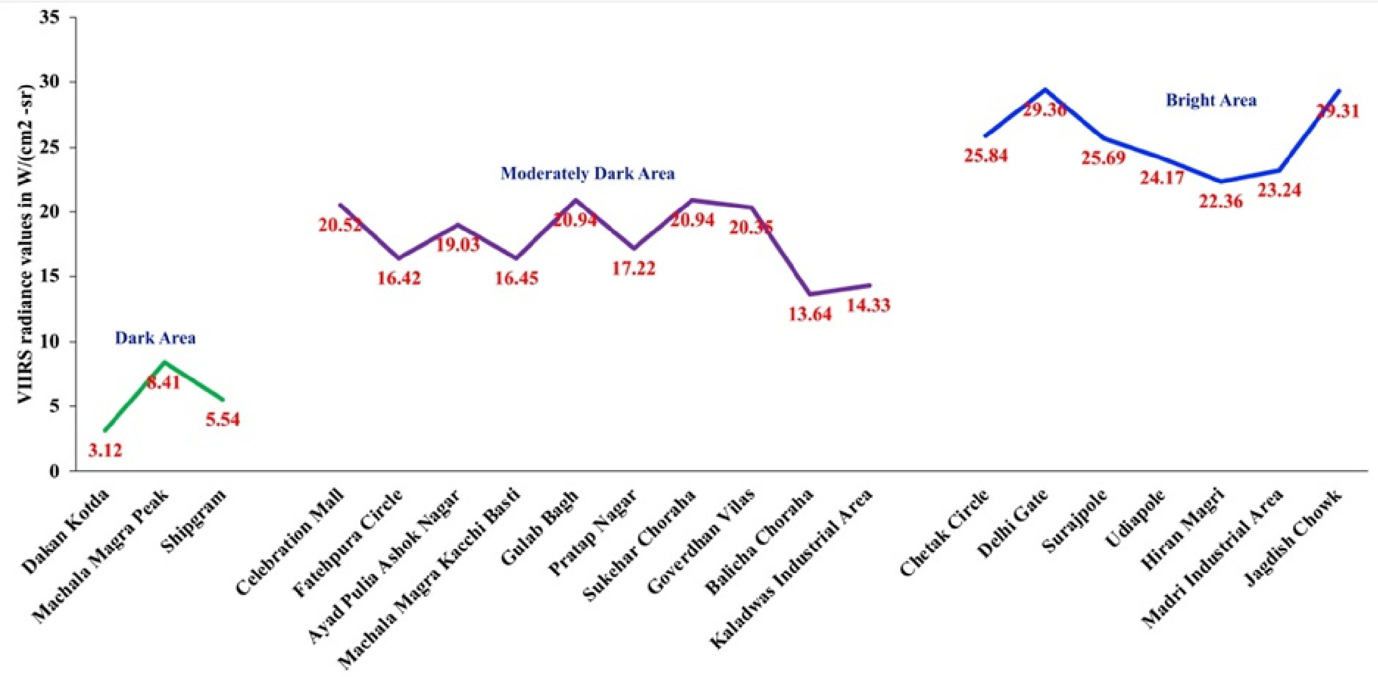

Figure 2. K-value Clusters as observed for VIIRS Values

Table 2. K-Value Cluster Centres as observed for VIIRS Values

	Initial Cluster		
	Dark Area	Moderately Dark Area	Bright Area
VIIRS radiance values in W/(cm^2 - sr)	3.12	14.33	29.36
	Final Cluster		
	5.69	17.98	25.71

Table 3. Analysis of Variance (ANOVA) Results for comparison of VIIRS Value Between Bright Area, Moderately Dark Area and Dark Area

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
VIIRS radiance values in W/(cm^2 - sr)	428.407	2	7.544	17	56.785	.000

Results indicate that there is a statistically significant difference among the VIIRS radiance ($F(2, 17) = 428.407$, $p < 0.001$) across the clusters, as the F value is 56.785 with a very low p-value of.000, suggesting strong evidence against the null hypothesis of equal means.

Diversity Studies with reference to effect of light

Descriptive statistics for all three groups revealed the minimum values for all three groups (Bright, Moderately Dark and Dark Area) are 1, and the lower boundaries are -28.375 for Bright Area, -26.5 for Moderately Dark Area, and -15.75 for Dark Area. The Q1 values are 2 for Bright Area, 2 for Moderately Dark Area, and 3 for Dark Area. The medians are 8 for Bright Area, 7 for Moderately Dark Area, and 8 for Dark Area. The Q3 values are 22.25 for Bright Area, 21 for Moderately Dark Area, and 15.5 for Dark Area. The upper boundaries are 52.625 for Bright Area, 49.5 for Moderately Dark Area, and 34.25 for Dark Area. The maximum values are 60 for Bright Area, 58 for Moderately Dark Area, and 57 for Dark Area. The IQR values are 20.25 for Bright Area, 19 for Moderately Dark Area, and 12.5 for Dark Area. The mean values are 14.7568 for Bright Area, 13.5682 for Moderately Dark Area, and 13.5 for Dark Area. The skewness values are 1.5204 for Bright Area, 1.5219 for Moderately Dark Area, and 1.7593 for Dark Area, indicating asymmetrical and right/positive skewness for all three groups. The excess kurtosis values are 1.5324 for Bright Area, 1.5921 for Moderately Dark Area, and 2.2576 for Dark Area, indicating leptokurtic distributions with long heavy tails for all three groups. The outliers for Bright Area are 59, 58, and 60, for Moderately Dark Area are 52, 53, and 58, and for Dark Area are 49, 39, 55, 55, and 57.

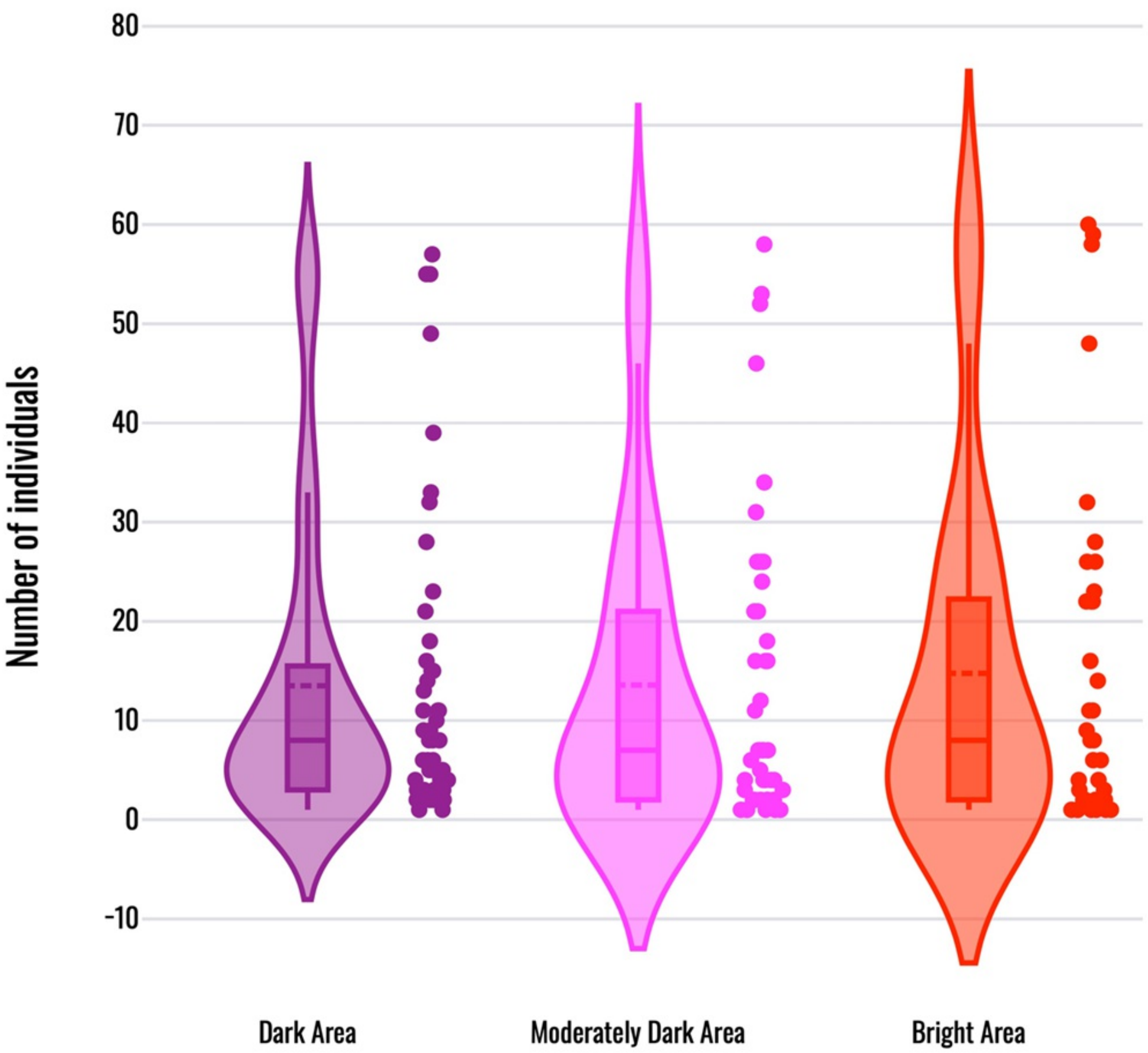

Figure 3. Violin Plot Representing Avian Diversity Observed in Bright, Moderately Dark and Dark Area

The descriptive statistics for night and for day time exhibits the minimum values for both groups are 1, and the lower boundaries are -74.5 for night time and -99 for day time. The Q1 values are 5 for night time and 7.5 for day time, while the medians are 14.5 and 22.5, respectively. The Q3 values are 58 for night time and 78.5 for day time, and the upper boundaries are 137.5 and 185, respectively. The maximum values are 173 for night time and 225 for day time. The IQR values are 53 for night time and 71 for day time, while the mean values are 35.82 for night time and 48.3958 for day time. The skewness values are 1.7327 for night time and 1.6745 for day time, indicating positive skewness for both groups. The excess kurtosis values are 2.4866 for night time and 2.2633 for day time, indicating leptokurtic distributions with long heavy tails. The outliers for night time are 160, 166, and 173, while the outliers for day time are 208, 216, and 225.

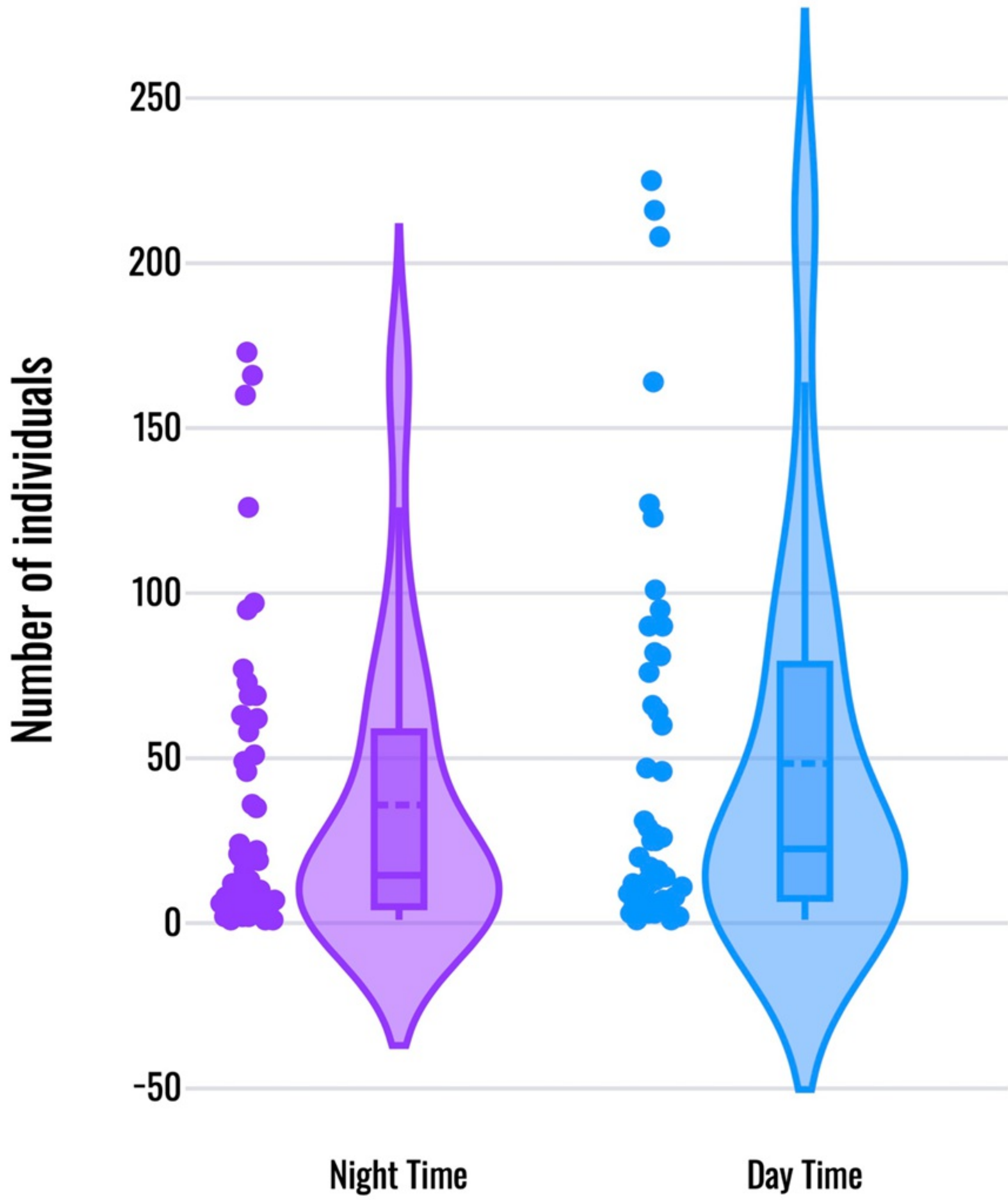

Figure 4. Violin Plot Representing Avian Diversity Observed During the Night and Day Time

The Shannon-Wiener Index data reveals varying degrees of biodiversity across different environmental settings. In the bright area, the diversity index stands at 3.023, indicative of a moderately diverse ecosystem hosting 37 observed species and 546 individuals. Moving to moderately dark areas, the diversity index slightly increases to 3.238, suggesting a marginally richer biodiversity with 44 species and 597 individuals recorded. Dark areas exhibit even greater biodiversity, as evidenced by a diversity index of 3.375, supported by observations of 48 species and 648 individuals. Night time environments showcase a similar level of diversity, with a diversity index of 3.274, corresponding to 50 species and a significantly higher count of 1791 individuals. Conversely, daytime environments display a slightly lower diversity index of

3.258 despite the observation of 48 species, possibly due to higher human activity influencing the ecosystem. These findings underscore the dynamic nature of biodiversity across different times of the day and varying light intensities, highlighting the importance of understanding and conserving ecosystems under diverse environmental conditions.

Table 4. Avian Species Observed During the Study Period

Family	Scientific Name	Common Name
Strigidae	*Athena brama*	Spotted Owlet
Caprimulgidae	*Caprimugus asiaticus*	Indian Nightjar
Accipitridae	*Elanus caeruleus*	Black-Winged Kite
Accipitridae	*Milvus migrans*	Black Kite
Accipitridae	*Accipiter badius*	Shikra
Phasianidae	*Pavo cristatus*	Indian Peafowl
Charadriidae	*Vanellus indicus*	Red-Wattled Lapwing
Columbidae	*Columba Livia*	Rock Pigeon
Columbidae	*Streptopelia tranquebarica*	Red Collared Dove
Psittaculidae	*Psittacula krameri*	Rose-Ringed Parakeet
Cuculidae	*Eudynamys scolopacea*	Asian Koel
Cuculidae	*Centropus sinensis*	Greater Coucal
Apodidae	*Apus affinus*	House Swift
Alcedinidae	*Halcyon smyrnensis*	White-Throated King Fisher
Alcedinidae	*Ceryle rudis*	Pied Kingfisher
Meropidae	*Merop orientalis*	Green Bee-Eater
Coraciidae	*Coracias benghalensis*	Indian Roller
Upupidae	*Upupa epops*	Common Hoopoe
Bucerotidae	*Ocyceros birostris*	Indian Grey Hornbill
Megalaimidae	*Megalaima haemacephala*	Coppersmith Barbet
Hirundinidae	*Hirundo smithii*	Wire-Tailed Swallow
Sturnidae	*Sturnia pagodarum*	Brahminy Starling
Sturnidae	*Acridotheres trisis*	Common Myna
Sturnidae	*Acridotheres ginginianus*	Bank Myna
Dicruridae	*Dicrurus macrocercus*	Black Drongo
Dicruridae	*Dendrocitta vagabunda*	Rufous Treepie
Corvidae	*Corvus splendens*	House Crow
Corvidae	*Corvus macrorhynchos*	Large-Billed Crow
Pycnonotidae	*Pycnonotus cafer*	Red-Vented Bulbul
Leiothrichidae	*Turdoldes caudatus*	Common Babbler
Leiothrichidae	*Turdoides malcolmi*	Large Grey Babbler
Cisticolidae	*Prinia socialis*	Ashy Prinia
Cisticolidae	*Orthotomus sutorius*	Common Tailorbird

Muscicapidae	*Copsychus saularis*	Oriental Magpie Robin
Muscicapidae	*Saxicoloides fulicata*	Indian Robin
Muscicapidae	*Cercornela fusca*	Brown Rock Chat
Matacillidae	*Anthus rufulus*	Paddyfield Pipit
Matacillidae	*Motacilla alba*	White Wagtail
Matacillidae	*Motacilla madaraspatensis*	White-Browed Wagtail
Matacillidae	*Motacilla flays*	Yellow Wagtail
Nectariniidae	*Nectarinia asiatica*	Purple Sunbird
Passeridae	*Passer domesticus*	House Sparrow
Ardeidae	*Andes cinerea*	Grey Heron
Ardeidae	*Ardeola grayli*	Indian Pond Heron
Ardeidae	*Bubulcus ibis*	Cattle Egret
Ardeidae	*Mesophoyx intermedia*	Intermediate Egret
Ardeidae	*Egretta garzetta*	Little Egret
Ardeidae	*Ardea purpurea*	Purple Heron
Threskiornithidae	*Threskiornis melanocephalus*	Black-Headed Ibis
Threskiornithidae	*Pseudibis papillosa*	Black Ibis

Effect of light on bird diversity with reference to their abundance

There were significant differences in mean bright area observations across the three abundance levels of the species (Common, Moderately common or Less common) (p = 0.000). Post-hoc tests showed common species abundance had significantly higher mean bright area observations compared to moderately dark common and less common abundance levels. There was no significant difference between moderately common and not-common abundance levels.

There were significant differences in mean moderately dark area observations across abundance levels (p = 0.001). Post-hoc tests showed common abundance had significantly higher mean moderate observations compared to moderately common and less common. There was no significant difference between moderately common and not-common.

There were significant differences in mean dark area observations across abundance levels (p = 0.002). Post-hoc tests showed common abundance had significantly higher mean dark observations compared to moderately common and less common. There was no significant difference between moderately common and less common.

Table 5. Analysis of Variance (ANOVA) Results for Species Abundance (Common, Moderately Common, and Less common Species) Across Light Conditions

		Sum of Squares	df	Mean Square	F	Sig.
Bright Area	Between Groups	9058.46	2	4529.23	54.28	.001
	Within Groups	3921.21	47	83.43		
	Total	12979.68	49			
Moderately Dark Area	Between Groups	4734.72	2	2367.36	17.05	.001
	Within Groups	6524.09	47	138.81		
	Total	11258.82	49			
Dark Area	Between Groups	2699.58	2	1349.79	7.43	.002
	Within Groups	8534.33	47	181.58		
	Total	11233.92	49			

Table 6. Tukey's Posthoc (Multiple Comparisons) Test Results Across Light Conditions for Common, Moderately Common, and Less common Species

Dependent Variable	(I) Abundance	(J) Abundance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Bright Area	Common Species	Moderately Common Species	30.78*	3.34	.001	22.68	38.89
		Less common Species	34.40*	3.57	.001	25.74	43.06
	Moderately Common Species	Common Species	-30.78*	3.34	.001	-38.89	-22.68
		Less common Species	3.61	2.97	.450	-3.57	10.81
	Less common Species	Common Species	-34.40*	3.57	.001	-43.06	-25.74
		Moderately Common Species	-3.61	2.97	.450	-10.81	3.57
Moderately Dark Area	Common Species	Moderately Common Species	19.49*	4.31	.001	9.04	29.94
		Less common Species	26.42*	4.61	.001	15.25	37.59
	Moderately Common Species	Common Species	-19.49*	4.31	.001	-29.94	-9.04
		Less common Species	6.93	3.83	.178	-2.35	16.21
	Less common Species	Common Species	-26.42*	4.61	.001	-37.59	-15.25
		Moderately Common Species	-6.93	3.83	.178	-16.21	2.35
Dark Area	Common Species	Moderately Common Species	12.62*	4.93	.036	.66	24.57
		Less common Species	20.33*	5.27	.001	7.56	33.10
	Moderately Common Species	Common Species	-12.62*	4.93	.036	-24.57	-.66
		Less common Species	7.71	4.38	.195	-2.90	18.33
	Less common Species	Common Species	-20.33*	5.27	.001	-33.10	-7.56
		Moderately Common Species	-7.71	4.38	.195	-18.33	2.90

**. The mean difference is significant at the 0.05 level.*

Effect of light on bird diversity with reference to their habit

The analysis of variance (ANOVA) was conducted on habitat types—diurnal, nocturnal, and both—across different brightness areas. For the Bright Area, while the between-groups comparison yielded an F-value of 2.25, suggesting some difference between habitat types, the p-value of 0.116 was not significant. Similarly, for the moderately dark area, the between-groups F-value was 3.03 with a p-value of 0.058. The dark area displayed a similar trend, with an F-value of 2.92 and a p-value of 0.06. Subsequent Tukey's post-hoc tests aimed to discern specific differences between habitat types. While some pairwise comparisons revealed notable mean differences, the associated p-values were non-significant.

Table 7. ANOVA Analysis of Habitat Preference Among Diurnal, Nocturnal, and Both time active Species

		Sum of Squares	df	Mean Square	F	Sig.
Bright Area	**Between Groups**	1137.78	2	568.89	2.25	.116
	Within Groups	11841.90	47	251.95		
	Total	12979.68	49			
Moderately Dark Area	**Between Groups**	1286.84	2	643.42	3.03	.058
	Within Groups	9971.97	47	212.17		
	Total	11258.82	49			
Dark Area	**Between Groups**	1242.52	2	621.26	2.92	.06
	Within Groups	9991.40	47	212.58		
	Total	11233.92	49			

Table 8. Tukey's Posthoc Multiple Comparisons Among Diurnal, Nocturnal, and Both time active Species

Dependent Variable	(I) Habit	(J) Habit	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Bright Area	Diurnal	Nocturnal	13.30	11.50	.485	-14.53	41.13
		Both	11.55	6.14	.156	-3.32	26.42
	Nocturnal	Diurnal	-13.30	11.50	.485	-41.13	14.53
		Both	-1.75	12.54	.989	-32.11	28.61
	Both	Diurnal	-11.55	6.14	.156	-26.42	3.32
		nocturnal	1.75	12.54	.989	-28.61	32.11
Moderately Dark Area	Diurnal	Nocturnal	13.47	10.55	.415	-12.06	39.01
		Both	12.47	5.64	.080	-1.17	26.12
	Nocturnal	Diurnal	-13.47	10.55	.415	-39.01	12.06
		Both	-1.00	11.51	.996	-28.86	26.86
	Both	Diurnal	-12.47	5.64	.080	-26.12	1.17
		nocturnal	1.00	11.51	.996	-26.86	28.86
Dark Area	Diurnal	Nocturnal	11.45	10.56	.529	-14.11	37.01
		Both	12.70	5.64	.073	-0.96	26.36
	Nocturnal	Diurnal	-11.45	10.56	.529	-37.01	14.11
		Both	1.25	11.52	.994	-26.64	29.14
	Both	Diurnal	-12.700	5.64	.073	-26.36	0.96
		Nocturnal	-1.250	11.52	.994	-29.14	26.64

Effect of night and day observations on bird diversity with reference to their abundance

There were significant differences in mean night observations across the abundance groups (Common Species, Moderately Common Species or Less common Species) (p = 0.00). There were significant differences in mean day observations across the habit groups (p = 0.00).

Table 9. ANOVA Analysis of Abundance Across Day and Night for Common, Moderately Common, and Less common Species

		Sum of Squares	df	Mean Square	F	Sig.
Night	Between Groups	45663.95	2	22831.97	20.16	.001
	Within Groups	53215.42	47	1132.24		
	Total	98879.38	49			
Day	Between Groups	78106.48	2	39053.24	20.32	.001
	Within Groups	90315.93	47	1921.61		
	Total	168422.42	49			

Table 10. Multiple Comparisons (Tukey's Posthoc) Across Day and Night for Common, Moderately Common, and Less common Species

Dependent Variable	(I) Abundance	(J) Abundance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Night	Common Species	Moderately Common Species	62.90*	12.33	.001	33.04	92.75
		Less common Species	81.16*	13.17	.001	49.26	113.06
	Moderately Common Species	Common Species	-62.90*	12.33	.001	-92.75	-33.04
		Less common Species	18.26	10.95	.228	-8.24	44.77
	Less common Species	Common Species	-81.16*	13.17	.000	-113.06	-49.26
		Moderately Common Species	-18.26	10.95	.228	-44.77	8.24
Day	Common Species	Moderately Common Species	82.27*	16.06	.001	43.38	121.16
		Less common Species	106.14*	17.16	.001	64.59	147.70
	Moderately Common Species	Common Species	-82.27*	16.06	.001	-121.16	-43.38
		Less common Species	23.87	14.27	.226	-10.66	58.41
	Less common Species	Common Species	-106.14*	17.16	.001	-147.70	-64.59
		Moderately Common Species	-23.87	14.27	.226	-58.41	10.66

**. The mean difference is significant at the 0.05 level.*

Effect of night and day observations on bird diversity with reference to their habit

There were no significant differences in mean night observations across the habit groups (Diurnal, Nocturnal or Both) (p = 0.063). There were no significant differences in mean day observations across the habit groups (p = 0.052), but it was close to the significance threshold (0.05).

Table 11. ANOVA Analysis of Habitat Preference Among Diurnal, Nocturnal, and Both time Species

		Sum of Squares	df	Mean Square	F	Sig.
Night	Between Groups	10970.40	2	5485.20	2.93	.063
	Within Groups	87908.97	47	1870.40		
	Total	98879.38	49			
Day	Between Groups	19872.94	2	9936.47	3.14	.052
	Within Groups	148549.47	47	3160.62		
	Total	168422.42	49			

Table 12. Multiple Comparisons (Tukey's Posthoc) Among Diurnal, Nocturnal, and Both time Species

Dependent Variable	(I) Habit	(J) Habit	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Night	Diurnal	Nocturnal	38.22	31.33	.448	-37.6126	114.06
		Both	36.72	16.74	.083	-3.8119	77.26
	Nocturnal	Diurnal	-38.22	31.33	.448	-114.0626	37.61
		Both	-1.50	34.19	.999	-84.2456	81.24
	Both	Diurnal	-36.72	16.74	.083	-77.2619	3.81
		nocturnal	1.50	34.19	.999	-81.2456	84.24
Day	Diurnal	Nocturnal	56.40	40.73	.357	-42.1833	154.98
		Both	48.02	21.77	.081	-4.6700	100.72
	nocturnal	Diurnal	-56.40	40.73	.357	-154.9833	42.18
		Both	-8.37	44.44	.981	-115.9382	99.18
	Both	Diurnal	-48.02	21.77	.081	-100.7200	4.67
		Nocturnal	8.37	44.44	.981	-99.1882	115.93

In general, the common abundance level had significantly higher bright, moderate, and dark observations compared to the other two abundance levels across all light conditions. However, moderately common and less common abundance levels did not differ significantly in their observations under any light conditions. The habit (diurnal, nocturnal, or both) did not significantly affect the night or day observations based on this analysis.

Discussion

The descriptive statistics and violin plots reveal variations in avian diversity across three groups and two time periods. The data shows positive skewness and leptokurtosis, indicating extreme values and long tails. Interquartile range (IQR) values indicate higher variability in Bright Area and nighttime. Mean values suggest slightly higher avian diversity in Bright area and daytime. Outliers indicate extreme values across all groups and time periods.

The Shannon-Wiener Index data provides valuable insights into the biodiversity of different artificial light settings, ranging from bright areas to dark areas and spanning both day and night. This index is popularly used to assess the species diversity and evenness within an ecosystem. Both the number of species present (species richness) and their relative abundances (species evenness) are considered by this index.

Urban environments homogenize animal communities and this results into the omnipresence of avian species[18]. Udaipur is rich in avian biodiversity. Udaipur city harbours 46 terrestrial and 42 aquatic bird species, belonging to 24 and 14 families respectively [19]. However certain birds prefer typical habitat, but maximum have shown the habituation to presence of light and urban settlements.

We observed distinct patterns across the various lighting conditions. Bright areas, characterized by higher levels of light intensity, exhibit a diversity index of 3.023. We observed 37 bird species and 546 individuals and this contributes to the overall richness of Bright Area. This suggests that although these areas support a relatively diverse variety of species, there may be some variation in the abundance of these species, which may affect the evenness of the ecosystem. In cities, urbanization tends to reduce species richness [20]. Artificial lights affect the stopover habitat use by inland migrating birds, which avoid bright areas [21].

We observed a slight increase in the diversity index to 3.238 in moderately dark areas, indicating a slightly richer biodiversity compared to bright areas. A total of 44 species and 597 individuals were observed in these areas. The display of an increased number of species and individuals in these areas may be attributed to the transitional nature of light availability, which can support a variety of flora and fauna.

The highest level of biodiversity was observed in the dark areas during the study, displaying a diversity index of 3.375, with the total number of observed species being 48 and the number of individuals being 648. This indicates dark environments may provide more stable conditions for certain species (nocturnal or crepuscular), leading to higher species richness and evenness than bright and moderately dark environments. Light pollution constitutes a major threat to biodiversity by decreasing habitat quality and landscape connectivity for nocturnal species because contact between dark areas is a vital element for the species [22]. In contrast, slow fliers (gleaners) or nocturnal butterfly eaters (e.g.,*Barbastella barbastellus*, *Myotis nattereri, and M. bechsteinii*) are more sensitive to lighting and prefer complete darkness[23].

Nighttime environments also demonstrated a diversity index of 3.274 with 50 species and 1791 individuals being observed. This indicates the adaptability of organisms to avoid bright light conditions, as well as the potential for nocturnal species to thrive in these environments.

Conversely, daytime environments exhibit a slightly lower diversity index of 3.258, despite the observation of 48 species. This is probably due to increased human activity during the day, which disturbs natural habitats and impacts the composition of species.

The results obtained from the analysis of avian diversity in Udaipur in terms of species abundance levels under different light conditions are very insightful. Across the spectrum of lighting conditions, namely bright, moderate and dark, there appears to be a consistent pattern as the observations indicate, hence validating the fact that bird diversity is influenced by lighting levels.

Under bright conditions, avian diversity and the mean value of commonly found species were significantly higher than in areas with moderately dark areas. This pattern persisted even in medium and dark conditions. These findings suggest that areas with higher abundance levels tend to host a greater number of avian species, regardless of light intensity.

Furthermore, the post-hoc Tukey's HSD test and homogeneous subsets analysis reinforced the significance of these findings by highlighting the distinctiveness of the common abundance level of species in each light condition. Conversely, no significant differences were observed between moderately common and less common abundance levels of species, indicating a potential threshold effect wherein once avian abundance reaches a certain level, further increases do not significantly impact observed diversity.

In contrast to the influence of light on abundance levels, the analysis revealed that the habits of birds, whether diurnal, nocturnal, or exhibiting both, were non-significant during either night or day observations. While diurnal habits displayed higher average observations than nocturnal habits, this was still not statistically significant. However, it is worth noting that the descriptive statistics still provide valuable insights into potential patterns, with diurnal habits consistently exhibiting higher mean observations across both night and day conditions.

Artificial illumination has the potential to alter birds' perception of day length, thereby impacting their circadian and circannual rhythms. Additionally, it can serve as a beacon, attracting nocturnally migrating bird populations to urban environments [24][25]. Sleep, a crucial animal behaviour for stress alleviation, memory consolidation, and energy preservation, can be disrupted by artificial light at night, as evidenced by studies [26][27].

The presence of artificial lighting also influences bird nesting and roosting habits. For instance, certain species, like the Black-tailed godwits (*Limosa limosa*), exhibit a tendency to avoid well-lit areas[28]. In areas brightly lit by street lamps, birds are likely to be active longer than in unilluminated areas [29].

These findings have important implications for understanding bird diversity patterns under different light conditions in urban environments like Udaipur. First, they underline the importance of abundance levels in shaping bird communities, with areas of higher abundance consistently displaying greater diversity across different light conditions. Second, while habits did not emerge as a significant factor in this analysis, the trend toward higher observations in diurnal habitats suggests that, at least in the context of this study, diurnal activities compared to nocturnal behaviour Birds may play a more prominent role in diversity.

Many bird species exhibit abilities to adapt to human-altered environments. While some birds do indeed have preferences for specific habitats. A significant number of bird species have shown a tendency for habituation to the presence of light and urban settlements.

Availability of resources, as urban environments provide a consistent and abundant food source for birds in the form of food scraps, insects attracted towards lights and feeds provided by humans to birds as religious practices. In addition to buildings, windowsills and other structures which mimic natural cliff faces or tree hollows are used by the birds as nesting sites. Some birds have also shown change in their feeding pattern to take the advantage of artificial lights attracting insects during the night. Habituation can lead to reduced stress levels and better tolerance for urban environments. This is evident by the bold behaviour. But this is not true for all the species, some species fails to do so and they struggle to find suitable resources or are more sensitive to disturbances.

Conclusion

To conclude, these findings contribute in providing valuable knowledge to the field of urban avian ecology, emphasizing the complex interplay between environmental factors such as abundance, habits, and different light conditions. Understanding these dynamics is essential for conservation strategies and promoting biodiversity in urban landscapes.

Further research exploring the interplay between abundance, habits and light conditions may provide deeper insights into the mechanisms driving avian diversity dynamics.

Statements and Declarations

Contributions

- RM: Experimentation and data collection, Writing- Original draft preparation.
- LS: Writing, Reviewing and Editing of the Manuscript.
- SDS: Conceptualization, Writing- Reviewing and Editing and Supervision.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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