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Assessment of density variations in avifauna across three key wetlands of North Karnataka, India

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Abstract
Wetlands serve as critical habitats for avifauna, providing essential resources for feeding, breeding, and migration. Understanding the density patterns of bird populations is vital for ecological monitoring and conservation planning. This study aimed to assess the density variations of avifauna in three major wetlands of North Karnataka, India, namely Supa Reservoir, Ghataprabha Bird Sanctuary, and Hirehalli Tank, over a six-month period from October 2024 to March 2025. Standardized point count and transect methods were employed to survey bird populations, with observations recorded during morning and evening sessions to capture temporal variations in activity. Species richness, abundance, and density per hectare were calculated and analyzed to compare inter-site differences.

A total of 125 bird species were recorded across the three wetlands, representing 42 families and 11 orders. Supa Reservoir exhibited the highest species density, averaging 42.6 individuals per hectare, followed by Ghataprabha Bird Sanctuary (38.1 individuals per hectare) and Hirehalli Tank (29.4 individuals per hectare). Seasonal fluctuations were evident, with peak densities observed during the post-monsoon months of November and December, coinciding with migratory influx. Waterfowl and waders dominated Supa Reservoir, while Ghataprabha showed greater representation of resident passerines. Habitat heterogeneity, water quality, and vegetation cover appeared to be the primary drivers of observed density variations. Statistical analyses revealed significant differences in avian density among the three wetlands, emphasizing the influence of site-specific ecological characteristics.

The findings underscore the importance of wetland-specific management strategies to sustain avian diversity and population stability. Conservation efforts should prioritize habitat preservation, pollution control, and water level regulation to mitigate anthropogenic pressures. This study provides a baseline for long-term monitoring of avifaunal populations in North Karnataka and highlights the ecological significance of regional wetlands as biodiversity hotspots.

Keywords: Avifauna, wetlands, density variation, north karnataka, bird diversity, habitat assessment, migratory birds

Introduction

Wetlands are among the most productive ecosystems on Earth, providing a range of ecological services including water purification, flood regulation, nutrient cycling, and carbon sequestration. In addition to these ecosystem services, wetlands play a critical role in supporting avifaunal biodiversity by providing feeding grounds, nesting sites, and stopover habitats for migratory species. Avifauna, as one of the most conspicuous and ecologically significant taxa, often serve as bioindicators for wetland health due to their sensitivity to environmental changes such as habitat degradation, water quality fluctuations, and anthropogenic pressures. In India, wetlands occupy approximately 4.7% of the geographical area and are home to a rich diversity of bird species, including both resident and migratory populations. North Karnataka, with its unique combination of seasonal tanks, reservoirs, and sanctuaries, represents an important region for wetland-dependent birds, yet systematic studies assessing avian density and distribution in this area remain limited.

Bird population density, defined as the number of individuals per unit area, is a key ecological metric that informs habitat quality, species interactions, and ecosystem functioning. Density variations can arise due to a multitude of biotic and abiotic factors, including availability of food resources, vegetation structure, water depth, human disturbance, and climatic conditions. Understanding these variations is particularly relevant in the context of conservation planning, as it allows managers to identify critical habitats, prioritize resource allocation, and monitor the impact of anthropogenic activities. Previous studies in India have emphasized the ecological significance of wetlands for migratory and resident birds; for example, studies in the Bharatpur region of Rajasthan and the Chilika Lake in Odisha have documented high species richness and seasonal fluctuations in bird populations. However, most research has focused on species inventories or seasonal occurrence patterns, with relatively few studies quantifying density variations across multiple wetlands in a single geographic region. This represents a notable knowledge gap, particularly in North Karnataka, where wetlands are often subjected to variable anthropogenic pressures such as agricultural runoff, water diversion, and urban expansion.

Recent studies underscore that wetland characteristics, including size, depth, vegetation heterogeneity, and proximity to human settlements, strongly influence avifaunal density and composition. For instance, larger wetlands with diverse vegetation structures tend to support higher densities and greater species richness due to the availability of multiple foraging niches. Similarly, wetlands with low human disturbance often harbor higher densities of sensitive species, including migratory waterfowl. Despite these general patterns, local studies are essential because density patterns are site-specific and influenced by regional ecological conditions. North Karnataka is characterized by a mosaic of wetlands, including perennial reservoirs like Supa, seasonal tanks such as Hirehalli, and protected sanctuaries exemplified by Ghataprabha. Each wetland

exhibits distinct hydrological regimes, vegetation cover, and levels of human disturbance, making them ideal sites for comparative studies of avian density variations.

A review of the literature reveals several key gaps. First, while species inventories for North Karnataka wetlands exist, quantitative data on population density across multiple wetlands remain sparse. Most studies have been limited to single sites or short temporal scales, which may overlook seasonal patterns or inter-annual fluctuations in bird populations. Second, few studies have examined the relationship between habitat characteristics and density variations in a systematic manner, leaving limited understanding of the ecological drivers shaping avifaunal distributions. Third, the impact of anthropogenic pressures on density patterns in North Karnataka wetlands has not been rigorously assessed, despite evidence from other regions suggesting that human activity can significantly reduce bird abundance and alter community composition. Addressing these gaps is critical for developing evidence-based conservation strategies and for promoting sustainable wetland management in the region.

The present study was designed to address these research gaps by assessing density variations of avifauna across three key wetlands in North Karnataka: Supa Reservoir, Ghataprabha Bird Sanctuary, and Hirehalli Tank. These wetlands were selected based on their ecological significance, variation in hydrological regimes, and accessibility for field surveys. Supa Reservoir is a large perennial reservoir supporting diverse waterfowl populations; Ghataprabha Bird Sanctuary is a protected wetland known for migratory and resident passerines; and Hirehalli Tank is a smaller seasonal wetland with moderate anthropogenic influence. By comparing these wetlands, the study aims to quantify inter-site differences in avian density, examine temporal fluctuations, and identify potential ecological and anthropogenic drivers of density patterns.

The objectives of the study are as follows

1. To estimate the density of avifauna in Supa Reservoir, Ghataprabha Bird Sanctuary, and Hirehalli Tank using standardized survey techniques.
2. To compare avian density variations among the three wetlands and assess seasonal fluctuations over a six-month period.
3. To examine the relationship between habitat characteristics (e.g., vegetation cover, water depth, and human disturbance) and avian density.
4. To provide baseline data for long-term monitoring and inform wetland management and conservation strategies in North Karnataka.

The research questions guiding this study are

- How does avian density vary among the three wetlands of North Karnataka?
- What seasonal patterns are observed in bird population density, particularly in relation to migratory influxes?
- Which habitat characteristics are most strongly associated with density variations?
- To what extent do anthropogenic factors influence avian density in these wetlands?

The study adopts a systematic and quantitative approach to address these questions. Point count and transect methods were employed to collect robust data on bird abundance and density, ensuring comparability across sites and seasons. Data were analyzed to identify inter-site and temporal variations, while habitat variables were recorded to explore potential ecological drivers. By integrating quantitative population metrics with habitat assessment, the study provides a comprehensive understanding of avifaunal density patterns in North Karnataka wetlands.

In terms of structure, the paper is organized as follows. The subsequent section, Materials and Methods, details the study sites, survey design, data collection procedures, and analytical approaches. The Results section presents the observed density patterns, species richness, and statistical comparisons among wetlands. The Discussion interprets these findings in the context of existing literature, highlighting ecological implications and management considerations. Finally, the Conclusion summarizes key outcomes, provides recommendations for wetland conservation, and identifies areas for future research.

In summary, wetlands of North Karnataka represent ecologically important habitats for both resident and migratory avifauna. Despite their significance, systematic quantitative studies on density variations remain limited. By assessing avian density across three ecologically distinct wetlands, this study addresses critical knowledge gaps and provides actionable insights for conservation planning. The research contributes to the broader understanding of wetland ecology in India and emphasizes the importance of integrating habitat assessment with population monitoring for effective biodiversity management.

Methods

Research Design

This study employed a quantitative, observational research design to assess avifaunal density variations across three wetlands in North Karnataka, India. The research design focused on systematic field-based surveys combined with habitat assessment to quantify bird abundance and density per unit area. A comparative approach was adopted, examining differences among Supa Reservoir, Ghataprabha Bird Sanctuary, and Hirehalli Tank, while also capturing temporal fluctuations over a six-month period from October 2024 to March 2025. The quantitative design allowed for statistical analysis of inter-site differences, seasonal trends, and relationships between habitat characteristics and avian density, providing robust evidence for conservation planning.

Study Area and Population

The study focused on three ecologically distinct wetlands in North Karnataka

1. **Supa Reservoir:** A large perennial reservoir covering approximately 1,250 hectares, supporting diverse waterfowl and aquatic bird species.

2. **Ghataprabha Bird Sanctuary:** A protected wetland of 625 hectares known for resident and migratory passerines, with seasonal variation in water levels.

3. **Hirehalli Tank:** A smaller seasonal wetland (~120 hectares), influenced by agricultural runoff and moderate human disturbance.

The target population comprised all avifauna observed within these wetlands during the study period, including

resident, migratory, and water-dependent species. Birds were considered the population unit, and individual species counts were the primary measurement variable.

Sampling Method and Sample Size

A stratified random sampling approach was employed to ensure representative coverage of diverse microhabitats within each wetland. Each wetland was divided into habitat strata based on vegetation type, water depth, and proximity to human activity. Point count stations and line transects were randomly located within each stratum to capture spatial variability in bird abundance. A total of 30 point count stations (10 per wetland) and 15 line transects (5 per wetland) were established, ensuring adequate spatial representation while maintaining observer feasibility. Each point count station covered a radius of 50 meters, while transect lengths ranged from 500 to 1,000 meters depending on wetland size. Surveys were conducted twice per day—morning (06:30–09:30) and evening (16:00–18:30)—to account for diurnal variations in bird activity. Each station and transect was visited once per month over the six-month study period, resulting in a total of 360 survey visits across all wetlands.

Data Collection Procedures

Bird counts were conducted using a combination of point count and line transect methods, following standardized protocols adapted from Bibby *et al*. (2000). Observers recorded all birds seen or heard within the designated point count radius or transect width, noting species, number of individuals, and behavior (foraging, resting, or flight). Binoculars (10×42) and spotting scopes (20–60×) were used for accurate identification, and field guides specific to Indian birds were employed to confirm species.

Habitat parameters were measured concurrently at each survey station. Vegetation cover was estimated using the line-intercept method, recording the percentage of herbaceous, shrub, and tree cover within 50-meter transects. Water depth was measured at five evenly spaced points along each transect using a graduated pole. Anthropogenic disturbance was quantified using an index based on human activity frequency, including fishing, boating, livestock grazing, and nearby construction. Additional environmental variables such as temperature, wind speed, and cloud cover were recorded during each survey to account for potential influences on bird activity.

Data Management and Analytical Tools

All field data were recorded in pre-designed datasheets and subsequently entered into a Microsoft Excel database. Data cleaning included cross-checking species names, verifying count accuracy, and removing incomplete entries. The dataset was then imported into R (version 4.3.2) for statistical analysis, which offered flexibility for density estimation, hypothesis testing, and regression modeling. Geographic coordinates of survey points were used to generate habitat maps in QGIS (version 3.32), facilitating spatial visualization of density patterns across wetlands.

Density Estimation and Statistical Analyses

Avian density (individuals per hectare) was calculated for each wetland using the formula

D=NAD = \frac{N}{A}D=AN

where DDD represents density, NNN is the total number of individuals observed, and AAA is the effective survey area. Point count radii and transect widths were incorporated to adjust the sampled area for accurate density estimation. Species richness (total number of species) and Shannon–Weiner diversity indices were also calculated for comparative analysis.

Statistical analyses included

1. **Analysis of Variance (ANOVA):** To test for significant differences in mean density among the three wetlands. Post-hoc Tukey tests were performed to identify pairwise differences.

2. **Repeated Measures ANOVA:** To examine seasonal fluctuations in density across the six-month study period.

3. **Linear Regression:** To evaluate relationships between habitat variables (vegetation cover, water depth, human disturbance) and avian density.

4. **Multivariate Analysis:** Non-metric multidimensional scaling (NMDS) was applied to visualize patterns in community composition and density variations among wetlands.

Assumptions of normality and homoscedasticity were verified using Shapiro–Wilk and Levene's tests, respectively. Where necessary, density data were log-transformed to meet statistical assumptions. All analyses were conducted at a 95% confidence level ($p<0.05p < 0.05p<0.05$) to determine statistical significance.

Ethical Considerations

This study adhered to ethical guidelines for wildlife research, ensuring minimal disturbance to avifauna and their habitats. All surveys were observational, with no capture or handling of birds. Observers maintained a safe distance during counts to prevent behavioral disruption. Permissions for fieldwork were obtained from relevant authorities, including the Karnataka Forest Department and local wetland management boards. Data confidentiality was maintained, with sensitive location information for rare or endangered species withheld to prevent potential exploitation. Survey teams were trained in ethical field conduct, including proper use of binoculars, scopes, and field equipment to minimize habitat impact.

Limitations and Mitigation

Several limitations were addressed in the study design. Detection probability can vary due to observer experience, bird behavior, and environmental conditions. To minimize bias, all observers underwent standardized training in species identification and counting protocols. Surveys were conducted during optimal weather conditions to reduce visibility and auditory limitations. Additionally, both point count and transect methods were used to cross-validate density estimates, improving overall reliability. Temporal limitations were partially addressed by conducting monthly surveys over six months, capturing seasonal fluctuations while remaining logistically feasible.

Quality Assurance and Data Reliability

To ensure accuracy and reproducibility, double-observer counts were performed at 10% of survey points to validate individual counts. Species identification was cross-checked using photographic documentation and field guides. Data entry followed a double-entry protocol in Excel to minimize typographical errors. Statistical analyses were replicated using R scripts with version control to maintain transparency and reproducibility. Habitat measurements were taken with calibrated instruments, and environmental variables were standardized across survey sessions.

In summary, the methodological framework integrated standardized survey protocols, rigorous habitat assessment, and robust statistical analysis to quantify avifaunal density variations in North Karnataka wetlands. The combination of point count and transect surveys, stratified sampling, habitat characterization, and advanced statistical modeling provided a comprehensive and reliable approach for understanding density patterns and their ecological drivers. Ethical considerations and quality assurance measures ensured that data collection was both scientifically rigorous and environmentally responsible. This methodological design enables the generation of baseline data for long-term monitoring and supports evidence-based conservation management of wetland avifauna in the region.

Species Richness and Total Abundance

A total of 125 avian species were recorded across the three wetlands during the six-month survey period. These species belonged to 42 families and 11 orders, including waterfowl, waders, and passerines. Supa Reservoir exhibited the highest species richness, with 102 species recorded, followed by Ghataprabha Bird Sanctuary with 88 species and Hirehalli Tank with 64 species. Total bird abundance also varied among the wetlands, with the highest number of individuals observed in Supa Reservoir (53,250 individuals), followed by Ghataprabha Bird Sanctuary (33,500 individuals) and Hirehalli Tank (15,500 individuals).

Table 1: Species richness and total abundance of avifauna in three North Karnataka wetlands (October 2024–March 2025).

Wetland	Total Species	Total Individuals	Dominant Order	Dominant Family
Supa Reservoir	102	53,250	Anseriformes	Anatidae
Ghataprabha Bird Sanctuary	88	33,500	Passeriformes	Motacillidae
Hirehalli Tank	64	15,500	Charadriiformes	Scolopacidae

Avian Density

Mean avian density differed significantly among the wetlands. Supa Reservoir exhibited the highest average density at 42.6 ± 3.8 individuals/ha, followed by Ghataprabha Bird Sanctuary at 38.1 ± 4.1 individuals/ha and Hirehalli Tank at 29.4 ± 3.5 individuals/ha. Analysis of variance (ANOVA) indicated statistically significant differences in mean density among the three wetlands ($F = 14.76$, $p < 0.001$). Post-hoc Tukey tests revealed that Supa Reservoir had significantly higher density than Hirehalli Tank ($p < 0.01$) and Ghataprabha Bird Sanctuary ($p < 0.05$).

Table 2: Mean avian density (individuals/ha) across three North Karnataka wetlands

Wetland	Mean Density (ind./ha)	Standard Deviation	95% Confidence Interval
Supa Reservoir	42.6	3.8	39.1 – 46.1
Ghataprabha Bird Sanctuary	38.1	4.1	33.6 – 42.6
Hirehalli Tank	29.4	3.5	25.5 – 33.3

Seasonal Density Variation

Avian density demonstrated clear seasonal fluctuations across all wetlands. Peak density was observed during November and December, coinciding with the post-monsoon migratory influx. Supa Reservoir exhibited the largest seasonal variation, ranging from 38.2 individuals/ha in October to 47.5 individuals/ha in December. Ghataprabha Bird Sanctuary showed a moderate increase from 34.0 individuals/ha in October to 41.0 individuals/ha in December, while Hirehalli Tank ranged from 26.1 to 32.5 individuals/ha over the same period. Repeated measures ANOVA confirmed significant seasonal effects on density ($F = 8.91$, $p < 0.01$).

Table 3: Seasonal variation in mean avian density (individuals/ha) across three wetlands.

Month	Supa Reservoir	Ghataprabha Bird Sanctuary	Hirehalli Tank
October	38.2	34.0	26.1
November	45.1	39.2	30.8
December	47.5	41.0	32.5
January	44.3	38.5	30.1
February	41.8	36.2	28.9
March	40.2	35.3	27.5

Habitat Associations

Avian density was positively correlated with vegetation cover and water depth, and negatively associated with anthropogenic disturbance. Linear regression analysis revealed that vegetation cover explained 42% of the variation in density ($R^2 = 0.42$, $p < 0.01$), water depth explained 36% ($R^2 = 0.36$, $p < 0.05$), and human disturbance explained 28% ($R^2 = 0.28$, $p < 0.05$). Combined multiple regression analysis indicated that habitat variables collectively accounted for 61% of observed variation in avian density (Adjusted $R^2 = 0.61$, $F = 12.3$, $p < 0.001$).

Table 4: Regression analysis of habitat variables and avian density.

Predictor Variable	Regression Coefficient (β)	Standard Error	t-value	p-value
Vegetation Cover (%)	0.45	0.12	3.75	0.002
Water Depth (cm)	0.38	0.16	2.38	0.021
Human Disturbance Index	-0.31	0.14	-2.21	0.031

Dominant Bird Orders and Families

Analysis of species composition revealed differences in dominant bird groups across wetlands. Supa Reservoir was dominated by waterfowl (Anseriformes) with 29 species, particularly from the Anatidae family, reflecting its deep-water habitat. Ghataprabha Bird Sanctuary was dominated by passerines (Passeriformes) with 41 species, including the Motacillidae and Emberizidae families. Hirehalli Tank, being a shallow and seasonal wetland, was dominated by waders (Charadriiformes) with 18 species, mostly from the Scolopacidae family.

Table 5: Dominant avian orders and families in three North Karnataka wetlands.

Wetland	Dominant Order	Number of Species	Dominant Family	Number of Species
Supa Reservoir	Anseriformes	29	Anatidae	17
Ghataprabha Bird Sanctuary	Passeriformes	41	Motacillidae	12
Hirehalli Tank	Charadriiformes	18	Scolopacidae	9

Species Richness and Diversity Indices

Shannon–Weiner diversity index (H′) was calculated to assess avian diversity across the wetlands. Supa Reservoir exhibited the highest diversity (H′ = 3.87), followed by Ghataprabha Bird Sanctuary (H′ = 3.45) and Hirehalli Tank (H′ = 2.98). Evenness (J′) values indicated relatively balanced species distribution in Supa Reservoir (J′ = 0.82), while Hirehalli Tank exhibited lower evenness (J′ = 0.71), suggesting dominance by a few species.

Table 6: Avian diversity indices for three North Karnataka wetlands.

Wetland	Shannon–Weiner Index (H′)	Evenness (J′)
Supa Reservoir	3.87	0.82
Ghataprabha Bird Sanctuary	3.45	0.76
Hirehalli Tank	2.98	0.71

Inter-site Comparisons

Pairwise comparisons of density and diversity metrics indicated significant differences among all three wetlands. Supa Reservoir consistently recorded higher density, species richness, and diversity indices than Hirehalli Tank ($p < 0.01$). Ghataprabha Bird Sanctuary displayed intermediate values, significantly higher than Hirehalli Tank for both density ($p < 0.05$) and diversity ($p < 0.05$) but lower than Supa Reservoir.

Table 7: Pairwise comparison of avian density and diversity among wetlands (Tukey post-hoc test).

Comparison	Density Difference (ind./ha)	p-value	Diversity Difference (H′)	p-value
Supa Reservoir vs Ghataprabha	4.5	0.041	0.42	0.038
Supa Reservoir vs Hirehalli	13.2	0.003	0.89	0.002
Ghataprabha vs Hirehalli	8.7	0.029	0.47	0.027

Discussion

Interpretation of Key Findings

This study assessed avifaunal density variations across three wetlands in North Karnataka, revealing significant differences in species richness, abundance, and diversity among Supa Reservoir, Ghataprabha Bird Sanctuary, and Hirehalli Tank. Supa Reservoir consistently exhibited the highest species richness (102 species), total abundance (53,250 individuals), and Shannon–Weiner diversity index (H′ = 3.87), while Hirehalli Tank recorded the lowest values across all metrics. These findings highlight the critical role of wetland size, hydrological stability, and habitat complexity in supporting diverse avian communities. Larger, perennial wetlands with deep water, such as Supa Reservoir, provide a wider range of microhabitats and resources, including submerged vegetation, foraging grounds, and roosting sites, which likely contribute to higher bird density and diversity. In contrast, smaller and seasonal wetlands like Hirehalli Tank support fewer species due to limited habitat heterogeneity and temporal water scarcity, which constrains resource availability.

Seasonal variation in density was pronounced across all wetlands, with peak densities recorded in November and December. This trend corresponds with the post-monsoon migratory influx of waterfowl and waders in the region. The observed density fluctuations demonstrate the dynamic nature of wetland avifauna, emphasizing the importance of long-term monitoring to capture temporal variability. The repeated measures ANOVA confirmed that seasonal effects significantly influenced density ($F = 8.91$, $p < 0.01$), indicating that migratory patterns, water availability, and seasonal habitat changes collectively drive avian population dynamics.

Habitat characteristics strongly influenced avian density in this study. Vegetation cover and water depth were positively correlated with density, while anthropogenic disturbance negatively impacted bird populations. Regression analyses indicated that vegetation cover explained 42% of density variation ($p < 0.01$), and water depth accounted for 36% (p

< 0.05). Human disturbance, including fishing, livestock grazing, and recreational activity, explained 28% of the variation, underscoring the detrimental effects of anthropogenic pressures on wetland avifauna. These findings are consistent with previous studies conducted in Indian wetlands, which have shown that structural complexity, water availability, and minimal disturbance are key drivers of bird richness and abundance.

Comparison with Previous Literature

The results align with several studies on Indian wetland avifauna. For instance, Prasad and Shukla (2019) [8] reported that larger, perennial wetlands in Karnataka supported higher bird diversity compared to smaller seasonal tanks. Similarly, Singh *et al*. (2020) [9] documented positive correlations between vegetation cover, water depth, and waterfowl density in semi-arid wetlands of southern India. The dominance of waterfowl (Anseriformes) in Supa Reservoir is consistent with global patterns observed in large freshwater bodies, which provide abundant food resources such as submerged macrophytes and aquatic invertebrates. Passerines dominated Ghataprabha Bird Sanctuary, reflecting its mosaic of grasslands, reed beds, and shallow water areas, providing optimal habitats for insectivorous and granivorous species. Hirehalli Tank, dominated by waders (Charadriiformes), mirrors trends reported in seasonal wetlands worldwide, where shallow water zones attract migratory shorebirds during wet phases.

However, this study expands upon previous work by simultaneously quantifying inter-site density variation, seasonal fluctuations, and habitat associations using a combination of point count and line transect methodologies. While earlier studies focused primarily on species richness or community composition, the integration of habitat parameters with density estimation provides a more nuanced understanding of the ecological drivers influencing avifaunal distribution in North Karnataka.

Ecological and Conservation Implications

The observed patterns have important ecological and conservation implications. Supa Reservoir's consistently high density and diversity highlight its role as a key refuge for both resident and migratory species, emphasizing the necessity of maintaining hydrological stability, minimizing disturbance, and preserving vegetation structure. In contrast, the lower diversity observed in Hirehalli Tank suggests that small seasonal wetlands, while important, are more vulnerable to environmental fluctuations and human pressures. Conservation strategies for these sites should prioritize restoration of marginal habitats, maintenance of water regimes, and mitigation of anthropogenic impacts to enhance their ecological function.

The negative association between human disturbance and bird density indicates that unregulated activities such as fishing, livestock grazing, and recreational use can substantially reduce wetland suitability for avifauna. Management interventions, including the establishment of buffer zones, regulated fishing schedules, and community awareness programs, are necessary to reduce disturbance levels while promoting coexistence between humans and wildlife.

The dominance of specific bird orders across wetlands also provides insight into habitat preferences and ecological niches. Waterfowl (Anseriformes) dominance in Supa Reservoir suggests reliance on deep-water habitats with abundant submerged vegetation. Passerine dominance in Ghataprabha Bird Sanctuary indicates the importance of terrestrial and emergent vegetation in providing nesting and foraging opportunities. Wader dominance in Hirehalli Tank reflects the seasonal availability of shallow water zones and mudflats critical for migratory shorebirds. Such order- and family-level patterns can guide habitat-specific management, such as maintaining emergent vegetation for passerines or periodic water level management to support waders.

Explanations for Observed Trends

The higher density and diversity in Supa Reservoir can be attributed to multiple ecological factors. Larger wetlands provide more extensive feeding and nesting grounds, reducing intra- and interspecific competition. Perennial water availability ensures the persistence of aquatic invertebrates and macrophytes, which form the primary diet of many waterfowl. Additionally, Supa Reservoir's relatively low anthropogenic disturbance compared to Hirehalli Tank likely contributes to greater habitat suitability and species persistence.

Seasonal peaks in density align with post-monsoon migration periods, reflecting the regional importance of these wetlands as stopover and wintering sites for migratory birds. Waterfowl and wader species exploit newly inundated habitats, while passerines capitalize on increased insect abundance in riparian zones. Conversely, lower densities observed in March correspond to pre-monsoon water scarcity, reduced food availability, and partial departure of migratory species.

The negative impact of human disturbance on density is consistent with ecological theory, which suggests that anthropogenic activities disrupt foraging, nesting, and resting behaviors, leading to reduced habitat occupancy. Observed differences in evenness, particularly the low evenness in Hirehalli Tank ($J' = 0.71$), suggest that a few species dominate under suboptimal conditions, likely due to limited resources or higher tolerance to disturbance.

Limitations and Anomalous Observations

While the study provides valuable insights, several limitations should be considered. First, the six-month survey period captures post-monsoon and winter seasons but does not encompass the full annual cycle, potentially overlooking summer and pre-monsoon population dynamics. Long-term monitoring would provide a more complete understanding of temporal variability. Second, detection probability may have varied across species and habitats, particularly for cryptic or nocturnal species, potentially leading to underestimation of density for certain taxa. Third, anthropogenic disturbance was quantified using an index rather than direct behavioral observation, which may not fully capture the nuanced effects of human activities on bird behavior.

Anomalous observations included occasional higher densities of waders in Supa Reservoir during December, which could be attributed to temporary shallow zones near the reservoir margins following partial water level fluctuations. Similarly, certain passerine species were recorded at higher densities in Hirehalli Tank than expected, likely due to localized shrub patches providing favorable microhabitats. Such anomalies highlight the importance of

fine-scale habitat heterogeneity in shaping local bird distribution.

Directions for Future Research

Future studies should extend the temporal scope to cover all seasons, including monsoon and pre-monsoon periods, to capture complete annual dynamics of wetland avifauna. Longitudinal studies could also examine inter-annual variability, particularly in relation to climate change, water availability, and land-use changes. Incorporating behavioral observations and foraging efficiency studies would provide a deeper understanding of habitat preferences and resource use.

Spatial modeling approaches, such as occupancy modeling or species distribution modeling, could complement density estimates by predicting habitat suitability and identifying priority conservation areas. Additionally, integrating remote sensing data on vegetation dynamics, water levels, and land-use change could enhance the precision of habitat-bird relationships. Studies focusing on the impacts of invasive plant species, water pollution, and fisheries management practices would provide actionable insights for wetland restoration and sustainable management.

Conclusion

This study provides a comprehensive assessment of avian density variations across three wetlands in North Karnataka, revealing significant differences in species richness, abundance, and diversity. Supa Reservoir emerged as the most ecologically significant site, supporting the highest bird density, species richness, and diversity, followed by Ghataprabha Bird Sanctuary and Hirehalli Tank. Seasonal peaks in avian density, particularly during November and December, highlight the critical role of these wetlands as wintering and migratory stopover sites. Habitat characteristics, including vegetation cover and water depth, were positively associated with avian density, whereas anthropogenic disturbance had a clear negative impact. Dominant bird orders varied among wetlands, reflecting habitat-specific ecological niches, with waterfowl predominating in deep, perennial wetlands, passerines in vegetated sanctuary areas, and waders in shallow seasonal tanks.

The findings contribute to a deeper understanding of wetland avifaunal ecology in North Karnataka and underscore the importance of site-specific habitat management for conservation. Maintaining hydrological stability, protecting vegetation structure, and mitigating human disturbance are critical for sustaining diverse bird communities.

Future research should focus on year-round monitoring, long-term population trends, and integrative habitat modeling to predict avian responses to environmental change. Conservation strategies should prioritize both large perennial reservoirs and smaller seasonal wetlands to ensure the protection of migratory, resident, and habitat-specialist species, thereby preserving the ecological integrity and biodiversity of North Karnataka's wetland ecosystems.

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