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Avian ecological guilds determined by water quality parameters of ponds in the central plain agroclimatic zone of Punjab State

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Abstract

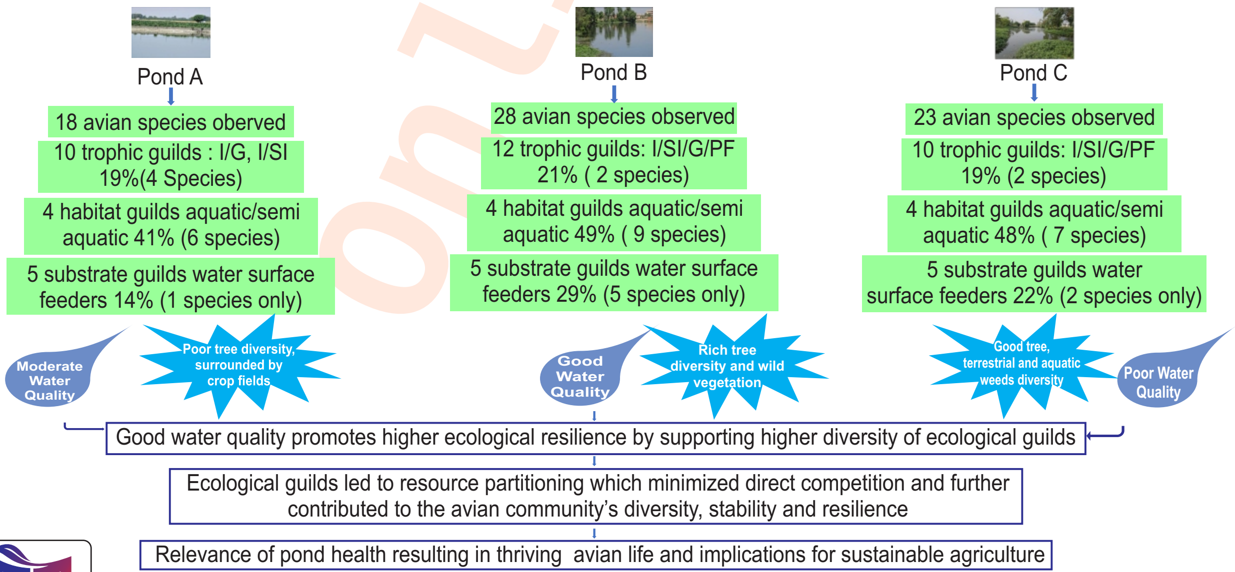
Aim: The present study investigated the relationship between avian ecological guilds and water quality parameters at three selected village ponds (namely Pond A, B and C) falling in the central plain agroclimatic zone of Punjab State.

Methodology: During the monsoon season (July-October 2022), bird populations and habitat utilization were assessed using point count/line transect methods. Water quality parameters were measured following the standard methods of APHA (2023).

Results: Twenty-eight bird species comprising of 7 orders and 15 families were identified, representing 12 trophic guilds, 4 habitat guilds and 5 substrate guilds. Pond B showed the best water quality, harbored the most semi-aquatic/aquatic species (9) and highest trophic diversity. Conversely, Pond C revealed the poorest water quality and had the lowest number of aquatic species.

Interpretation: Water quality in ponds seemed to play a crucial role in shaping avian community composition and ecological roles. This study underscores the importance of maintaining good water quality in ponds interspersed in an agroecosystem for the diversity of ecological guilds. Study findings have the potential to be extrapolated to thousands of ponds in the Indian agricultural landscape, thereby having far reaching ecological implications.

Key words: Agroclimatic zones, Birds, Diversity, Guilds, Ponds, Water quality



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Introduction

Birds play a crucial role in agro-ecosystems, contributing to the overall health and balance of agricultural environments (Kler *et al.,* 2022). Ponds create a conducive microclimate which forms a crucial attribute by providing habitat, nesting, breeding and specialized niche sites for avian fauna (Zamora-Marín *et al.,* 2021). Ponds in croplands have been considered to be containers of biodiversity, providing a range of ecosystem services (Hsu *et al.,* 2019). Survey and monitoring of avifauna provide valuable information on the ecological health and status of inland water bodies and can be used as indicators for assessing the ecological value of the pond ecosystem (Harisha, 2016). Ecological guilds of birds in pond-based ecosystems represent distinct groups of avian species that share similar feeding behaviors and ecological roles within these habitats (Sebastián-González and Green, 2014). Habitat features determining variability in habitat niches play a crucial role in shaping the predominant trophic guilds of bird populations (Mukhopadhyay and Mazumdar, 2019).

Water quality parameters, including dissolved oxygen, biological oxygen demand, and nutrient composition have a direct effect on the species richness of various animal communities in pond catchments (Castro *et al.,* 2005). Ponds in particular have been providing suitable environmental conditions for a broad spectrum of bird species, with high habitat heterogeneity known to raise overall species diversity in interconnecting pondscapes (Vad *et al.,* 2017). Many studies have reported direct association of avian species, especially breeding and migratory waterbirds with the water quality parameters that are indicative of their effects on waterbird survival and their use of habitat (Mishra *et al.,* 2023). In the pond-based ecosystems that border crop fields, a remarkable array of bird species congregates to exploit the abundant resources offered by this unique environment (Walton *et al.,* 2021). In ecological studies, understanding different patterns, factors and their inter-relations that govern faunal diversity have been found tremendously difficult to comprehend (Tucker *et al.,* 2017). Water quality parameters have profound influence in shaping the habitat suitability for various bird species (Yardi *et al.,* 2019). The village ponds, nestled adjacent to sprawling agricultural crop fields, serve as a vital nexus in shaping the intricate tapestry of avian ecosystems in agrarian Punjab State, India (Kaur *et al.,* 2018).

To date, the avian ecological guilds in pond habitats adjoining crop fields of Punjab, India have received little attention (Sidhu *et al.,* 2021; Sekhon *et al.,* 2023). Punjab State has a total geographical area of 5.03 million hectares out of which 4.20 million hectares is under cultivation (about 83%); have been identified in the agroecosystem. The present study is first of its kind in the region and has been conducted to evaluate the effect of water quality parameters on avian ecological guilds and community characteristics at ponds habitats interspersed in agricultural landscape falling in the central plain agroclimatic zone. In this context, water quality parameters, habitat guilds, substrate guilds and trophic guilds of different bird species, relationship between avian species community characteristics and water quality parameters were examined.

Materials and Methods

In the current study, avian ecological guilds and community characteristics were evaluated in relation to water quality parameters at three selected village ponds in the central plain agroclimatic zone of Punjab. The study was carried out during the monsoon season of 2022 from July to October. Selected ponds differed markedly from each other in their levels of eutrophication. The average temperature ranged from 25.1 °C to 30.6 °C and the average rainfall was 1285.25 mm during the studied season. The selected pond (Pond A) was situated on the outskirts of village Dhaipai, which was rejuvenated by the village community. Cemented boundaries along with barbed wire fencing were constructed around it. The pond edge habitat consisted of solitary tree and shrub vegetation, surrounded by agricultural fields on all sides. The pond lies at of 30° 46'25.5" N latitude; from 75° 43'10.7" E longitude and 246 m above mean sea level. In village Khandoor, the selected pond (Pond B) lies at 30° 47'58.8" N latitude; 75° 43' 19.1" E longitude and 245 m above sea level. The pond was natural low-lying area without any anthropogenic modifications.

The pond habitat comprised rich tree/ shrub diversity along the banks; bordered by agricultural fields on two sides. The third selected pond (Pond C) was situated at outskirts of village Mansuran having crop fields on one side; it had luxuriant floating aquatic weeds. Pond habitat a had moderate tree and shrub diversity along the edges. Pond showed signs of accelerated eutrophication and surface water appeared green due to algal blooms. Pond coordinates were 30° 48'23.0" N and 75° 45'12.1" E at 248 m above sea level. Intensive field observations on birds were taken to record the composition of bird species and their population numbers at studied ponds during monsoon months from July to October 2022. The point count/ line transect method (Bibby *et al.,* 1992) was employed to record the bird populations and habitat utilization niches in the studied ponds. Detailed data was recorded on all avian species including their foraging habitats/habitat guild, substrate used for foraging/substrate guild and feeding habits/trophic guilds about their preference of pond and vegetation features (MacNally, 1994). The raw count data of all birds was recorded, species wise and month-wise relative abundance (%) was calculated for each pond. Ali and Ripley (1987) and Grimmett *et al.* (2011) were followed for avifauna identification and nomenclature.

The analysis of selected pond waters for various physico-chemical quality parameters like Water Temperature (°C), Biological Oxygen Demand (BOD) in mg l^{-1}, Dissolved Oxygen (DO) in mg l^{-1}, Electrical Conductivity (EC) in dS m^{-1}, Salinity (ppt), Total Dissolved Solids (TDS) in mg l^{-1} were carried out as per APHA (2023). Water temperature was noted by using a Mercury glass thermometer. Shannon-Wiener Diversity Index (Shannon and Wiener, 1949) and the Simpson Index (Simpson, 1949) were employed to calculate the bird species richness, diversity and evenness.

Statistical Analyses: Multiple linear regression analysis was used to examine the linear relationship between a dependent variable and multiple independent variables. In this context, the dependent variable is the avian abundance and the independent variables are the various environmental parameters (predictors) such as pH, Water temperature, TDS, DO, BOD, Salinity, and Electrical Conductivity of studied ponds. In each case, the coefficients and statistical significance of the coefficients were examined to understand the strength and significance of the relationship between the dependent variable and each independent variable (level of significance at $p < 0.05$). Generalized Linear Model (GLM) is a generalization of the linear regression model that allows for a broader range of data types and distributions. It extends the linear model by incorporating a link function and assuming that the response variable follows a distribution from the exponential family. GLM was applied for the response variable of avian abundance. Tukey's HSD test is a post hoc test often used after an analysis of variance (ANOVA) or a generalized linear model (GLM). It was used to identify which group means differ from each other. The test controls the family wise error rate, allowing for the simultaneous comparison of multiple group's means. The statistical analysis was performed using IBM's Statistical Package for Social Science (SPSS v.25) software.

Results and Discussion

Observations revealed bird community with 18, 28 and 23 bird species at Pond A, Pond B and Pond C, respectively; overall a total of 28 species belonging to 7 orders and 15 families were recorded at the studied ponds (Fig.1). Overall data analysis revealed these birds exhibited 12 trophic, 4 habitat and 5 substrate guilds indicative of their diverse ecological roles (Table 1). At Pond A, water-dependent bird species exhibited a higher abundance of waterfowl such as the Common Moorhen, Indian Spot-billed Duck and Cattle egret as compared to terrestrial species. These species are depended on the pond for nesting, foraging and roosting, thus contributing significantly to the avian community. In contrast, terrestrial species such as the Brown Rock Chat and House Sparrow were present but less abundant in Pond A. Pond B showed a more balanced distribution between water-dependent and terrestrial bird species. While waterfowl such as the Little Stint, White-breasted Waterhen and Cattle Egret were present, however, their abundance was slightly lower compared to Pond A. Similarly, terrestrial species like House Crow and House Sparrow were more prevalent in Pond B, indicating a stronger association with the surrounding terrestrial habitats.

This suggest that Pond B supported a more diverse avian community with a mix of both water-dependent and terrestrial species. In Pond C, the avian community exhibited a slightly different composition, yet still emphasized the presence of water-dependent species. Birds such as the Black-winged Stilt and the Red-wattled Lapwing signified the importance of the pond's shallow water edges as foraging grounds. Moreover, the Black-headed Munia and the Plain Prinia, though not exclusively reliant on water, likely utilized the pond's vicinity for resources and habitat. Pond C supported a lower abundance of water-dependent species and a higher abundance of terrestrial species, indicating potential differences in habitat quality and resource availability among the ponds. Pond B has the highest proportion of water-dependent species with the collective relative abundance of 33.28% followed by Pond A (23.33%), while Pond C remained the lowest with 5.66% of the avian community (Fig. 1).

Depending upon the food habits of bird species, trophic guilds included insectivorous, granivorous, frugivorous, small vertebrate feeders etc., thereby revealing a broad spectrum of feeding strategies. Insectivorous species dominated across all Ponds, with substantial representation in Pond A (55.56%) and Pond B (44.44%). Granivorous birds were abundantly present in Pond A (25%), while frugivorous and omnivorous/scavenger species exhibited more localized distributions. Habitat guilds were recorded ranging from arboreal and terrestrial to semi-aquatic, indicating that birds utilized food resources from all possible niches at studied ponds. Habitat-guild wise, terrestrial bird species like House Crow and House Sparrow were noted across all ponds (Table 2-4). Ground foragers and water surface feeders showed higher prevalence among terrestrial and semi-aquatic/aquatic species, respectively, it signified the availability of abundant food resources at pond banks. Simberloff and Dayan (1991) characterized avifaunal niches based on feeding site, food type, foraging method and resource availability.

This present investigation demonstrated the concept of 'utilizing the presence of species from distinct foraging guilds as an indicator for diverse food resources' at different habitats. Accipitriformes, Anseriformes, Charadriiformes, and Passeriformes encompassed both insectivorous and granivorous trophic guilds. Arboreal habitat guilds were dominant in Accipitriformes, Coraciformes, and Psittaciformes. Arboreal species explored vegetation (trees/ shrubs) along pond banks and semi-aquatic species contributed to the habitat utilization of pond waters. Foliage foragers were recorded in Accipitriformes, Coraciformes and Passeriformes. Foliage foragers were more prevalent in Pond B (52.38%) which was in concurrence with its tree/shrub diversity. Pérez-Crespo *et al.* (2013) identified foraging habitat exploitation and techniques employed by water birds as key drivers of resource partitioning within these communities. Observations have shown the presence of water-associated species, including Common Moorhen, Little Grebe, and Little Stint at Pond A, whilst exhibiting the dominance of the Common Moorhen. Certain commensal bird species (including Rock Pigeon, House Crow, and Rose-ringed Parakeet) have been found in substantial abundance across all ponds, indicating an influence of human-modified ecosystems. Clavel *et al.* (2011) have mentioned a trend revealing the replacement of specialist species by generalists within several ecological communities. Furthermore, the varying abundance and diversity of insectivorous species, such as Plain Prinia, Black Drongo, Brown

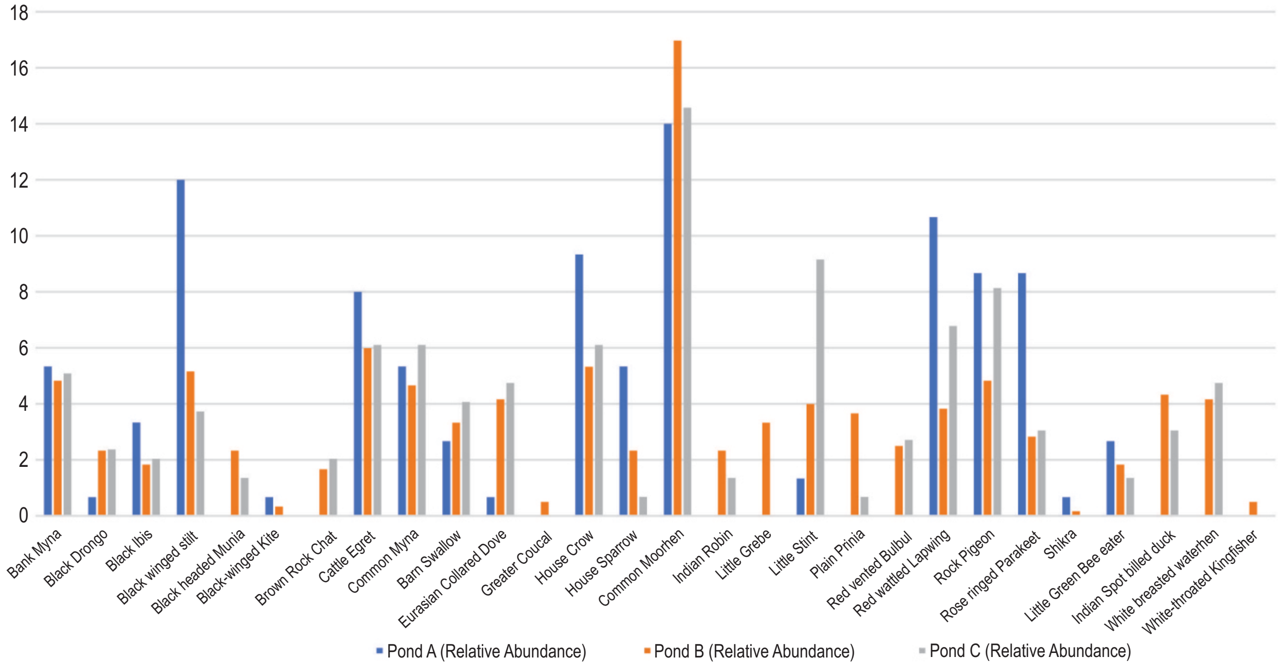

Fig. 1: Overall relative abundance (%) of bird species recorded at studied ponds.

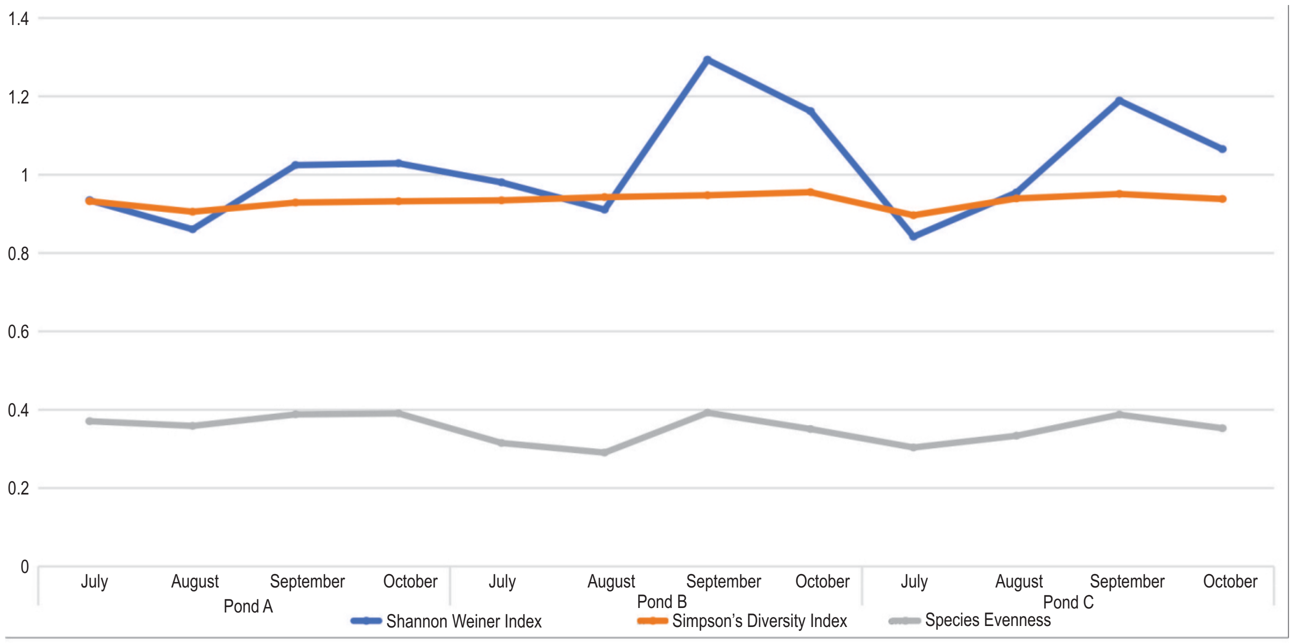

Fig. 2: Avian community characteristics at studied ponds.

Rock Chat, Indian Robin and Red-vented Bulbul across ponds underlined their ecological services in biocontrol of insects in pond habitats and in adjoining cultivated areas. Results seemed to be relevant and in concurrence with investigations into niche organization and guild structure as ecological indicators, while simultaneously serving as sensitive barometers for environmental change (Canterbury *et al.,* 2000). A higher abundance of pure insectivores along with partial insectivores in Pond C and a higher abundance of water surface feeders in Pond B bought out the Pond specific complexity of ecological guilds.

Table 1: List of avian species observed and their ecological guilds at studied village ponds

Order	Family	Common Name	Scientific Name	Trophic Guild	Habitat Guild	Substrate Guild
Accipitriformes	Accipitridae	Black-winged Kite	*Elanus caeruleus*	I/SI/SV	Arboreal	Foliage Foragers
Accipitriformes	Accipitridae	Shikra	*Accipiter badius*	I /SV	Arboreal	Foliage Foragers
Anseriformes	Anatidae	Indian Spot billed duck	*Anas poecilorhyncha*	SV/PF	Aquatic	Water Surface Feeders
Charadriiformes	Recurvirostridae	Black winged stilt	*Himantopus himantopus*	I	Semi-Aquatic	Mud Foragers
Charadriiformes	Scolopacidae	Little Stint	*Calidris minuta*	SI	Semi-Aquatic	Mud Foragers
Charadriiformes	Charadriidae	Red wattled Lapwing	*Vanellus indicus*	I/SI	Terrestrial	Ground Foragers
Columbiformes	Columbidae	Eurasian Collared Dove	*Streptopelia decaocto*	G	Terrestrial	Ground Foragers
Columbiformes	Columbidae	Rock Pigeon	*Columba livia*	G	Terrestrial	Ground Foragers
Coraciformes	Meropidae	Little Green Bee eater	*Merops orientalis*	I	Terrestrial	Foliage Foragers
Coraciformes	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	I/SV	Arboreal	Water Surface Feeders
Cuculiformes	Cuculidae	Greater Coucal	*Centropus sinensis*	I/SI/SV	Terrestrial	Ground Foragers
Gruiformes	Rallidae	Common Moorhen	*Gallinula chloropus*	I/SI/G/PF	Aquatic	Water Surface Feeders
Gruiformes	Rallidae	White breasted waterhen	*Amaurornis phoenicurus*	I/SI/G/PF	Semi-Aquatic	Water Surface Feeders
Passeriformes	Sturnidae	Bank Myna	*Acridotheres ginginianus*	I/G	Terrestrial	Ground Foragers
Passeriformes	Dicruridae	Black Drongo	*Dicrurus macrocercus*	I	Arboreal	Foliage Foragers
Passeriformes	Estrildidae	Black headed Munia	*Lonchura atricapilla*	I/G	Terrestrial	Foliage Foragers
Passeriformes	Muscicapidae	Brown Rock Chat	*Oenanthe fusca*	I	Terrestrial	Foliage Foragers
Passeriformes	Sturnidae	Common Myna	*Acridotheres tristis*	I/G	Terrestrial	Ground Foragers
Passeriformes	Hirundinidae	Barn Swallow	*Hirundo rustica*	I	Semi-Aquatic	Aerial Feeders
Passeriformes	Corvidae	House Crow	*Corvus splendens*	O/S	Terrestrial	Ground Foragers
Passeriformes	Passeridae	House Sparrow	*Passer domesticus*	I/G	Terrestrial	Ground Foragers
Passeriformes	Muscicapidae	Indian Robin	*Saxicoloides fulicata*	I	Terrestrial	Ground Foragers
Passeriformes	Cisticolidae	Plain Prinia	*Prinia inornata*	I	Terrestrial	Foliage Foragers
Passeriformes	Pycnonotidae	Red vented Bulbul	*Pycnonotus cafer*	I/PF/F	Terrestrial	Foliage Foragers
Pelecaniformes	Threskiornithidae	Black Ibis	*Pseudibis papillos*	I/G	Semi-Aquatic	Mud Foragers
Pelecaniformes	Ardeidae	Cattle Egret	*Bubulcus ibis*	I/SI	Semi-Aquatic	Mud Foragers
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	I/SI/SV	Aquatic	Water Surface Feeders
Psittaciformes	Psittaculidae	Rose ringed Parakeet	*Psittacula krameri*	F/PF/G	Arboreal	Foliage Foragers

Abbreviations: I- Insectivorous; G-Granivorous; SI-Soil invertebrate; SV-Small Vertebrate Feeders; O-Omnivorous; S-Scavenger; PF-Plant feeders; F-Frugivorous

The collective presence of 9 semi-aquatic/aquatic species in Pond B was in concurrence with good quality of water physico-chemical parameters.

The measured physico-chemical parameters in Ponds A, B, and C revealed significant variations in the water quality of studied ponds. Dissolved oxygen (DO) levels indicated moderate oxygen levels in Pond A (6.2-6.71 mg l^{-1}), while Pond B exhibited higher DO levels (6.93-7.67 mg l^{-1}) and Pond C had lower DO levels (3.51-4.24 mg l^{-1}). Lower DO levels suggested oxygen deficiency due to eutrophication. Biochemical oxygen demand (BOD) values reflected the presence of higher organic matter in Pond C (12.59-13.02 mg l^{-1}), compared to Ponds A and B. Total dissolved solids (TDS) were highest in Pond C (1720.58-1786.34 mg l^{-1}) followed by Pond A and lowest in Pond B, indicating varying concentrations of dissolved substances. Salinity levels also followed a similar trend with Pond C having the highest values (0.95-1.02 ppt) signifying the influence of anthropogenic factors. Water temperature ranges were relatively consistent (25.2-30.4°C) across all Ponds, while electrical conductivity was slightly higher in Pond A. The pH values indicated a slightly alkaline environment in Pond C (8.15-8.41) and more neutral conditions in Ponds A and B (Table 2). The water quality parameters highlighted eutrophication stress due to anthropogenic factors along with different physico-chemical conditions in Pond C as compared to other Ponds. Water quality parameters at Pond C measured during specific periods exceeded the permissible limits as per BIS (2012). This deterioration is likely attributable to the combined influence of surrounding urbanization, agricultural activity, anthropogenic stresses and sewage effluents of resident houses. While eutrophication may pose a significant threat to aquatic ecosystems, it can offer increased food availability for specific bird species, consequently boosting their population.

This phenomenon can cause a shift in the environmental conditions driven by nutrient enrichment. However, at high densities, waterbird populations themselves can significantly amplify eutrophication processes, creating a complex feedback loop (Amat and Green, 2010). Yetis *et al.* (2021) concluded that anthropogenic activities can significantly amplify natural processes, thereby accelerating their impact on water quality and indirectly on the waterbird communities residing there. Chatterjee

Table 2: Physico-chemical parameters of Pond water A, B and C in Agroclimatic Zone of Punjab State

	Pond A			Pond B			Pond C		
Physico-chemical parameters	**Min**	**Max**	**Mean±SE**	**Min**	**Max**	**Mean±SE**	**Min**	**Max**	**Mean±SE**
DO (mg l^{-1})	6.2	6.71	6.45375±0.14924	6.93	7.67	7.305±0.2256	3.51	4.24	4±0.25894
BOD (mg l^{-1})	6.75	7.89	7.245±0.41451	4.55	5.25	4.91625±0.30095	12.59	13.02	12.74125±0.14512
TDS (mg l^{-1})	1105.63	1210.05	1156.32875±36.25012	612.51	671.33	642.285±20.24824	1720.58	1786.34	1749.7225±23.21019
Salinity (ppt)	0.58	0.67	0.62±0.02825	0.3	0.343278212	0.33±0.01361	0.95	1.02	0.97±0.02176
Water temperature (°C)	25.2	29.7	26.6875±1.74745	25.6	29.4	26.725±1.67909	25.6	30.4	27.775±1.73475
Electrical Conductivity (dS m^{-1})	1.24	1.356393258	1.293±0.0395	0.688213483	0.754303371	0.723±0.0223	1.92	2.007124	1.960±0.0296
pH	7.29	7.88	7.71875±0.17968	7.42	7.59	7.5225±0.05471	8.15	8.41	8.31125±0.08099

et al (2020b) had compared waterbird community of two sub-Himalayan wetlands which were found differing in bird densities dependent on habitat management, invasive species and unregulated tourist activities. Hamza and Selmi (2018) found out that the wetland preferences of waterbirds were influenced by a suite of environmental factors. These included the physico-chemical composition of water, diversity and abundance of aquatic plants, prevalence of invertebrate fauna and physical characteristics of the habitat (Gaget *et al.,* 2020). Species richness and abundance are affected to a large extent by water availability and the structural complexity of habitat types (Hadjikyriakou *et al.,* 2022).

Trophic guild analysis revealed insectivores as a common and substantial component across all ponds, although their relative abundance values and species diversity values varied. Pond A had the highest representation of insectivores (38%), with both generalists and specialized feeders, alongside omnivores/scavengers and frugivorous/plant feeder/granivorous guilds, indicating a varied resource utilization strategy (Table 3). Pond B exhibited a higher trophic diversity, with insectivores again dominant (20%), but with a more specialized foraging strategy evident in the presence of insectivorous/soil invertebrate/small vertebrate feeders and insectivorous/soil invertebrate feeders. Pond C also had a significant insectivore population (36%) but with a higher species diversity (seven) and additional complexity in the trophic structure due to guilds like insectivorous/soil invertebrates/granivorous/plant feeders and soil invertebrate feeders. In the present study, selected pond habitats supported a greater number of insectivorous species as compared to study conducted in zero till wheat and direct seeded paddy crops in Ludhiana district (Kaur *et al.,* 2017). The distinct trophic guild compositions across ponds have bought out the influence of water quality parameters on shaping avian communities and maintaining a trophic balance, similar to observations by Meerhoff *et al.* (2003) in wetlands. Pond A was dominated by ground-dwelling/terrestrial birds (48%), reflecting abundant food sources in the terrestrial environment. A noteworthy point was that 27% of the avian community belonged to semi-aquatic species, indicating suitable aquatic foraging niches within pond ecosystems (Table 4). Pond B showed a more balanced distribution across foraging habitats, with prominent terrestrial species (45%) but also significant contributions from arboreal and semi-aquatic guilds. The presence of aquatic species (25%) further emphasized the importance of water bodies in shaping the avian community (Table 3). Pond C seemed similar to Pond A, with terrestrial birds comprising 47% of the population and semi-aquatic and aquatic species also contributing substantially. However, arboreal species were less prevalent in Pond C compared to other ponds, suggesting potential differences in the availability of tree-dwelling niches or suitable resources for this guild. These findings were aligned with studies highlighting the indicator species for monitoring ecosystem health and integrity (Ahmed, 2016), and they also resonated with the trophic guild structure and niche organization of waterbird communities as observed by Chatterjee *et al.* (2020a).

In Pond A, ground foragers dominated (45%), indicating a strong preference for terrestrial substrates. Mud foragers and foliage foragers also contributed significantly, suggesting diverse substrate utilization. The presence of water surface feeders pointed to the exploitation of aquatic substrates (Table 3). Pond B exhibited a more balanced distribution across substrate guilds, with prominent ground foragers (33%) alongside substantial contributions from foliage foragers and water surface feeders. The presence of aerial feeders indicated the portion of the community engaged in mid-air feeding. Pond C resembled Pond A with ground foragers dominating (39%) and foliage foragers and mud foragers contributing to the overall substrate diversity. Aerial

Table 3: Trophic guilds of avian species and their relative abundance at studied ponds

Ecological guilds	Different types of guilds	Pond A		Pond B		Pond C	
		Relative abundance	Species richness	Relative abundance	Species richness	Relative abundance	Species richness
Trophic guilds	Insectivorous/Granivorous	19.33	4	15.97	5	15.25	5
	Insectivorous	18.00	4	20.30	7	15.59	7
	Insectivorous/Soil invertebrate/ Small Vertebrate Feeders	0.67	1	4.16	3	0.00	0
	Insectivorous/Soil Invertebrate Feeders	18.67	2	9.82	2	12.88	2
	Granivorous	9.33	2	8.99	2	12.88	2
	Omnivorous/Scavenger	9.33	1	5.32	1	6.10	1
	Insectivorous/Soil Invertebrates/ Granivorous/Plant feeders	14.00	1	21.13	2	19.32	2
	Soil Invertebrate Feeder	1.33	1	3.99	1	9.15	1
	Insectivorous/Plant feeder/ Frugivorous	0.00	0	2.50	1	2.71	1
	Frugivorous/Plant Feeder/ Granivorous	8.67	1	2.83	1	3.05	1
	Insectivorous/Small Vertebrate Feeders	0.67	1	0.67	2	0.00	0
	Small Vertebrates Feeder/Plant feeder	0.00	0	4.33	1	3.05	1
Habitat guilds	Terrestrial (Ground- Dwelling)	48.00	8	44.76	14	47.12	14
	Arboreal (Tree-Dwelling)	10.67	4	6.16	5	5.42	2
	Semi-Aquatic	27.33	5	24.46	6	29.83	5
	Aquatic	14.00	1	24.63	3	17.63	2
Substrate guilds	Ground Foragers	45.33	7	32.78	9	38.9831	9
	Foliage Foragers	13.33	5	17.64	9	13.5593	7
	Mud Foragers	24.67	4	16.97	4	21.0169	4
	Aerial Feeders	2.67	1	3.33	1	4.0678	1
	Water Surface Feeders	14.00	1	29.28	5	22.3729	2

feeders and water surface feeders were also present, highlighting a multifaceted foraging approach. Overall, the investigation revealed distinct patterns in avian ecological guild composition and resource utilization across three ponds. The findings have found support in existing studies on indicator species and niche organizations in avian communities, providing valuable insights into the complex interplay between environmental factors and ecological dynamics (Chatterjee *et al.,* 2020a).

The analysis of temporal variations in biodiversity indices, including the Shannon-Wiener Index (H'), Simpson's Diversity Index (D), and Species Evenness (E) revealed variations across Ponds A, B, and C (Fig 2). In Pond A, the Shannon-Wiener Index (H') exhibited a fluctuating pattern, reaching its highest point in September. This showed a peak in species diversity during that month, due to resource abundance and habitat suitability fluctuations. Conversely, Simpson's Diversity Index (D), remained relatively constant, suggesting a consistent dominance of certain species throughout the observed period. Species Evenness (E) showed some variations, with a notable increase in August. This indicated a more equitable distribution of species abundance compared to other months. Pond B showed a similar trend to Pond A as the Shannon-Wiener Index (H') followed a trend with a peak in September, implying a temporary rise in biodiversity. Both Simpson's Diversity Index (D) and Species Evenness (E) exhibited stability, suggesting consistent species dominance and a relatively balanced distribution. Pond C displayed different temporal dynamics. While the Shannon-Wiener Index (H') also peaked in September, indicating a potential diversity increase. Simpson's Diversity Index (D) and Species Evenness (E) showed fluctuation. It suggested varying levels of dominance and evenness among species throughout the observed period.

A Multiple Linear Regression (MLR) model was used to investigate the relationship between various water physico-chemical parameters and bird abundance at three ponds. While the model at Pond A showed a strong positive association (R-squared=0.955) between predictors and bird abundance, the overall model wasn't statistically significant (F-statistic=3.572, p-value=0.384), suggesting further analysis (Table 4). The Generalized Linear Model (GLM) identified salinity (M6) as the

Table 4: Effect of variance in the dependent variable based on the predictors and Model selection using Alkaike Information Criterion (AIC) at Pond A

Dependent Variable	R	R^2	Adjusted R^2	S.E.	F-Statistic	Sig.
Bird Abundance	0.977a	0.955	0.688	2.127	3.572	0.384
Predictors[a]: DO, BOD, TDS, Salinity, Water Temp, Electrical Cond, pH (Constant)						
Model	**Variable**	**logLik**	**AICc**	**ΔAICc**	**Relative likelihood**	**wi**
M1	Water temperature	-23.081	52.561	0.200	0.905	0.145
M2	Dissolved Oxygen	-23.244	52.888	0.527	0.768	0.123
M3	Biochemical Oxygen Demand	-23.064	52.527	0.166	0.920	0.148
M4	Total Dissolved Solids	-23.155	52.709	0.348	0.840	0.135
M5	Electrical Conductivity	-23.127	52.564	0.203	0.903	0.145
M6	Salinity	-22.981	52.361	0.000	1.000	0.160
M7	pH	-23.088	52.576	0.215	0.898	0.144

Table 5: Effect of variance in the dependent variable based on the predictors and Model selection using Alkaike Information Criterion (AIC) at Pond B

Dependent Variable	R	R^2	Adjusted R^2	S.E.	F-Statistic	Sig.
Bird Abundance	1.00a	1	0.998	0.968	752.351	0.028
Predictors[a]: DO, BOD, TDS, Salinity, Water Temp, Electrical Cond, pH (Constant)						
Model	**Variable**	**logLik**	**AICc**	**ΔAICc**	**Relative likelihood**	**wi**
M1	Water temperature	-34.975	76.350	3.224	0.199	0.146
M2	Dissolved Oxygen	-40.768	87.935	14.809	0.001	0.000
M3	Biochemical Oxygen Demand	-33.363	73.126	0.000	1.000	0.734
M4	Total Dissolved Solids	-40.073	86.546	13.420	0.001	0.001
M5	Electrical Conductivity	-41.307	89.014	15.888	0.000	0.000
M6	Salinity	-41.228	88.977	15.851	0.000	0.000
M7	pH	-35.196	76.792	3.666	0.160	0.117

most influential variable at Pond A. Similarly, MLR at Pond B indicated a perfect fit (adjusted R-squared=1) with statistically significant relationship (F-statistic and p-value both significant) between predictors and bird abundance. However, GLM highlighted BOD (M3) as the most important factor influencing bird abundance at Pond B (Table 5).

At Pond C, MLR showed a highly significant relationship (R-squared=0.998, adjusted R-squared=0.989) with low standard error (1.259), but also suggested multicollinearity among predictors (F-statistic and p-value both marginally significant). Again, GLM analysis revealed BOD (M3) as the most influential variable for bird abundance at Pond C (Table 6). Overall, while MLR provided initial insights, GLM with AIC selection identified specific water quality parameters like salinity (Pond A), BOD (Ponds B and C) as key factors influencing bird abundance across the ponds, highlighting the importance of considering multiple environmental factors and their complex interplay within the ecosystem. Thus, these water physico-chemical parameters have a pivotal role in shaping bird population and driving the ecosystem dynamics. Several studies have pointed correlation of water quality parameters with avian population. Variations in wetland water quality have had a significant influence on the population composition and distribution patterns of birds, both resident and migratory, across various seasons and even years (Zhang *et al.,* 2017). Boros *et al* (2023) studied nutrient cycling and transport waterbird guilds in inland saline waters of Central Asia and found waterbird guilds closely linked to twelve environmental attributes. Toth et al. (2023) analyzed four years of data from the Homoród stream in Transylvania and found that the presence and number of various migratory waterbird species were correlated with seasonal variations in water quality.

The richness of waterbird species has been associated with multiple factors, including water quality, flora-fauna diversity, geographic region, waterbird population density, and migration routes (Babbitt and Tanner, 2012). Sulai *et al.* (2015) also

Table 6: Effect of variance in the dependent variable based on the predictors and Model selection using Alkaike Information Criterion (AIC) at Pond C

Dependent Variable	R	R^2	Adjusted R^2	S.E.	F-Statistic	Sig.
Bird Abundance	0.999a	0.998	0.989	1.259	102.587	0.075

Predictors[a]: DO, BOD, TDS, Salinity, Water Temp, Electrical Cond, pH (Constant)

Model	Variable	logLik	AICc	ΔAICc	Relative likelihood	wi
M1	Water temperature	-30.105	66.610	4.142	0.126	0.053
M2	Dissolved Oxygen	-28.498	63.395	0.927	0.629	0.264
M3	Biochemical Oxygen Demand	-28.034	62.468	0.000	1.000	0.420
M4	Total Dissolved Solids	-29.318	65.036	2.568	0.277	0.116
M5	Electrical Conductivity	-29.542	65.484	3.016	0.221	0.093
M6	Salinity	-30.410	67.221	4.753	0.093	0.039
M7	pH	-31.406	69.212	6.744	0.034	0.014

Table 7: Analysis of Post-hoc with Tukey HSD test to highlight significant differences in bird abundance and species richness between ponds

Variable	Comparison	Mean Difference	Lower CI	Upper CI	p-value
Bird Abundance	Pond A vs. B	-111.88	-131.91	-91.84	0.000
	Pond A vs. C	-31.12	-51.16	-11.09	0.002
	Pond B vs. C	80.75	60.71	100.79	0.000
Species Richness	Pond A vs. B	-12.13	-14.9	-9.35	0.000
	Pond A vs. C	-6	-8.77	-3.23	0.000
	Pond B vs. C	6.13	3.35	8.9	0.000

identified electrical conductivity as a factor influencing waterbird species richness. Similarly, a positive relationship between water temperature and waterbird population size was reported by Thapa and Saund (2012). Haileselasie (2024) reported that species richness of aquatic bird species was positively correlated with surface area and limnological characteristics of water reservoirs in Northern Ethiopia. Mishra *et al* (2024) found that higher water bird abundance and diversity were related to lowland emergent vegetation during winter across Khajuha wetland in Uttar Pradesh, India. These findings underscored the need for targeted conservation efforts for waterbirds in the wetlands and water reservoirs. The use of multiple linear regression (MLR) in this study indicated a strong positive association between physico-chemical water quality parameters and the avian community characteristics at various ponds. Tukey's Honestly Significant Difference (HSD) test was used to identify significant pairwise differences among the studied ponds (Table 7). The comparison of bird abundance and species richness across the Ponds A, B and C revealed significant differences in both metrics. In terms of bird abundance, Pond A exhibited significantly lower levels compared to both Pond B (Mean Difference = -111.88, $p < 0.001$) and Pond C (Mean Difference =-31.12, $p = 0.002$). Conversely, Pond B demonstrated significantly higher bird abundance than Pond C (Mean Difference=80.75, $p < 0.001$). Similarly, species richness followed a similar trend with Pond A having significantly lower richness compared to both Pond B (Mean Difference = -12.13, $p < 0.001$) and Pond C (Mean Difference = -6.00, $p < 0.001$). Additionally, Pond B exhibited slightly higher species richness than Pond C (Mean Difference = 6.13, $p < 0.001$). These findings have suggested distinct ecological characteristics and different habitat qualities across the studied ponds. Collectively, the Tukey's HSD results highlighted the importance of local environmental factors in shaping avian diversity and abundance.

The water quality parameters of these ponds emerged as pivotal determinants influencing the composition and dynamics of avian species ecological guilds further supporting the harmonious coexistence between water and farmland in pond habitats. A wide spectrum of ecological niches utilized by avian community has bought about the contribution of pond habitats for strengthening avian ecological services in farmlands. This study has suggested that resource partitioning along the trophic axis among terrestrial, semi-aquatic and aquatic birds minimized direct competition which further contributed to the community's organization into distinct trophic guilds. The findings of this study has furthered the understanding of guild-specific avian foraging habitats in each location for developing tailored strategies to preserve their ecological niches via site-specific habitat conservation and management, thereby ensuring the long-term sustainability of avian communities. By maintaining pond habitats coupled with water quality, we may promote ecological resilience and the coexistence of bird species with varying feeding behaviors and roles within agricultural ecosystems. Integration of ecological indicators into policies and regulations should be advocated for monitoring the health and integrity of diverse ecosystems including village ponds and wetlands in agricultural landscapes.

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