

7-26-2023

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[10.11609/jott.8467.15.7.23472-23486](https://doi.org/10.11609/jott.8467.15.7.23472-23486)

Nima, P., Timsina, M., Jamtsho, T., & Khandu, P. (2023). Babesa sewage treatment plant as a vital artificial wetland habitat for a multitude of avian species. *Journal of Threatened Taxa*, 15(7), 23472-23486. <https://doi.org/10.11609/jott.8467.15.7.23472-23486>

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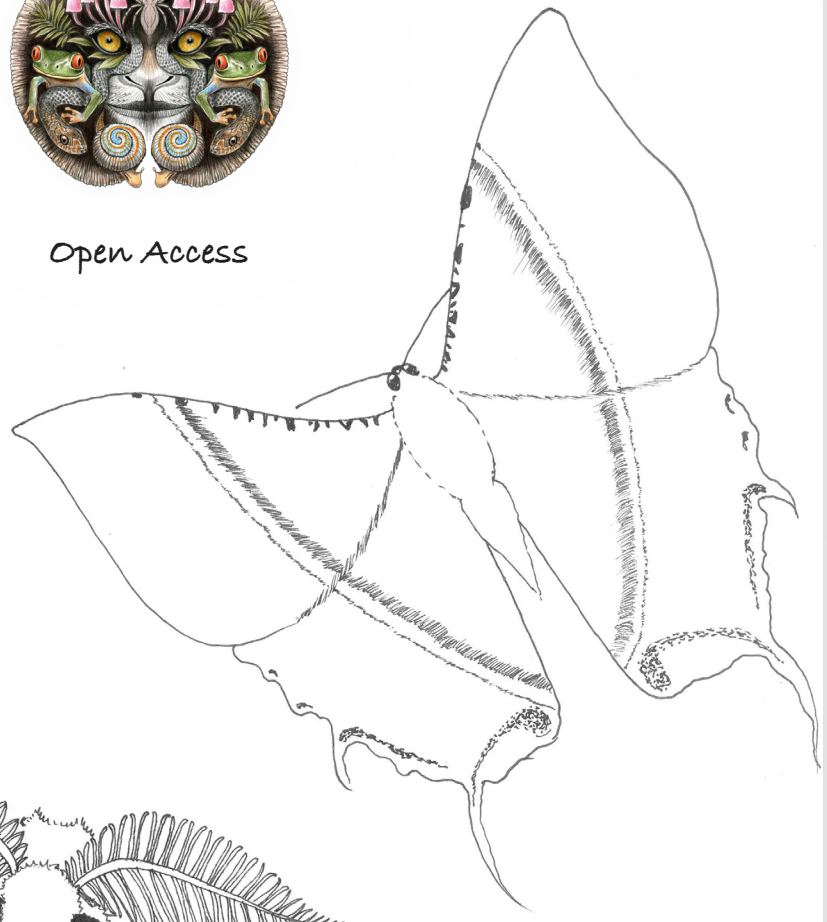
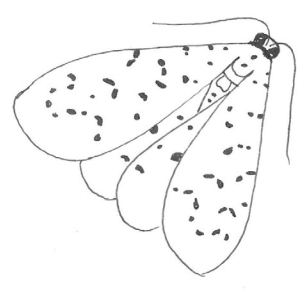
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# Journal of Threatened Taxa



Open Access



10.11609/jott.2023.15.7.23463-23630  
[www.threatenedtaxa.org](http://www.threatenedtaxa.org)

26 July 2023 (Online & Print)  
15(7): 23463-23630  
ISSN 0974-7907 (Online)  
ISSN 0974-7893 (Print)



ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher  
**Wildlife Information Liaison Development Society**  
www.wild.zooreach.org

Host  
**Zoo Outreach Organization**  
www.zooreach.org

43/2 Varadarajulu Nagar, 5<sup>th</sup> Street West, Ganapathy, Coimbatore, Tamil Nadu 641006, India  
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Cover: Celebrating the unsung heroes—moths, our nocturnal pollinators. © Priyanka Iyer.



## Babesa Sewage Treatment Plant as a vital artificial wetland habitat for a multitude of avian species

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**Abstract.** This study aimed to glean basic ecological aspects on diversity and abundance, temporal variation and guild composition of the birds at Babesa Sewage Treatment Plant (STP). The line transect method was used as the sampling technique from November 2021 to October 2022. A total of 80 species belonging to 58 genera, 29 families, and 11 orders were detected, of which three, namely, River Lapwing *Vanellus duvaucelii*, Falcated Duck *Mareca falcata*, and Ferruginous Duck *Aythya nyroca*, are 'Near Threatened' with the remaining being 'Least Concern'. The highest species richness was recorded in the winter (6.29), the highest species diversity in the spring (2.73), and the highest evenness in the summer (0.76). There was not any statistically significant difference between non-waterbirds and waterbirds, or between feeding guilds. However, based on a permutational multivariate analysis of variance (PERMANOVA), the bird composition was significantly different among seasons. Subsequently, pairwise comparisons revealed a significant difference between autumn & winter ( $P = 0.006$ ), autumn & summer ( $P = 0.006$ ), autumn & spring ( $P = 0.018$ ), winter & summer ( $P = 0.006$ ), winter & spring ( $P = 0.006$ ) as well as spring & summer ( $P = 0.006$ ). The non-metric multidimensional scaling (NMDS) biplot showed most bird species overlap occurred between autumn and spring as well as summer and spring, respectively. Taken together, the present results suggest that the Babesa STP holds significant potential as a habitat for diverse avian populations and underscores the ecological significance of artificial wetlands.

**Keywords:** Artificial wetland, avian population, feeding guilds, non-waterbirds, species diversity, waterbirds.

**Editor:** H. Byju, Coimbatore, Tamil Nadu, India.

**Date of publication:** 26 July 2023 (online & print)

**Citation:** Nima, P., M. Timsina, T. Jamtsho & P. Khandu (2023). Babesa Sewage Treatment Plant as a vital artificial wetland habitat for a multitude of avian species. *Journal of Threatened Taxa* 15(7): 23472–23486. <https://doi.org/10.11609/jott.8467.15.7.23472-23486>

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**Funding:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Competing interests:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Author contributions:** PN conceived the study design, carried out field study, data collection, data tabulation, statistical analysis and prepared the whole manuscript. MT carried out field study, data collection, data tabulation and helped in revision. TJ provided critical comments on the whole manuscripts and helped in revision. PK critically commented and revised the whole manuscript, and provided comments on statistical analysis. All authors read and approved the final manuscript.

**Acknowledgements:** All authors remain indebted to IDEA WILD for the grant of the equipment (Police Binocular).



## INTRODUCTION

Accumulating evidence suggest that wetlands are indispensable for the conservation of many waterbirds and migratory species as well as for mammals, fishes, invertebrates, reptiles and amphibians (Airoldi et al. 2008; Kedleck & Wallace 2008; Engle 2011). This is because wetlands are primarily considered to be abundant in food (Rajpar et al. 2010) and water resources that sustain various lifeforms. Particularly for waterbirds, they are thought to provide breeding, stopover and wintering sites for diverse migratory species (Rendon 2008; Ma et al. 2009), and have been shown to help in the accumulation of critical energy reserves (Catry et al. 2022; Liu et al. 2022), which is inevitable for the wetland-dependent birds to complete a long migration (Alerstam et al. 2003). Wetlands are also considered to enhance landscape biodiversity, control floods, provide recreation (Hansson et al. 2005) and remove pollutants (Vymazal 2010).

However, due to the burgeoning human population, wetlands have been imperilled (Zedler & Kercher 2005). For example, anthropogenic-induced pressures such as water pollution, surplus use of pesticides in adjoining agricultural habitats and human settlements have caused 50% of natural wetlands to be degraded and altered globally (Mitsch & Gosselink 2015). Likewise, human dependence on wetlands for various ecosystem services has intensified and mounted pressures on these ecologically delicate ecosystems (Molur et al. 2011), which may further deteriorate in the future.

Consequently, it has placed wetland inhabitants in a perilous state (Soderquist et al. 2021) often culminating in fewer resources for wetland-dependent species such as waterbirds (Forcey et al. 2011). As a result, avifaunal diversity has diminished. Thus, waterbirds have become progressively reliant on alternative and artificial wetlands (Murray & Hamilton 2010) such as small agricultural ponds, paddy fields and water treatment plants to meet their needs (Lawler 2001; Sebastián-González et al. 2010; Hsu et al. 2011).

Though artificial wetlands cannot fully replace the operationality of natural wetland habitats (Li et al. 2013), wastewater treatment ponds have been reported to increasingly play an important role in supporting regional population of waterbirds (Kalejta-Summers et al. 2001) mainly due to abundance of food resources such as zooplankton (Hamilton et al. 2005). Further, such artificial wetland habitats have been reported to form key staging sites and breeding grounds for migratory bird species (Donahue 2006). Indeed, Breed et al. (2020) showed that

wastewater treatment plant is a crucial refuge site for several species of ducks and waders. Similarly, several other studies have also shown that sewage treatment plant (STP) provide habitat supplements and occasional alternative sanctuaries for waterbirds (Attuquayefio & Gbogbo 2001; Gbogbo 2007; Harebottle et al. 2008; Murray & Hamilton 2010). As a consequence, attempts have been made globally to safeguard the wetlands of significance (Tiéga 2011; Ibrahim & Aziz 2012), several of which encompass artificial wetlands (Zedler & Kercher 2005). For instance, a few sewerage habitats, such as Phakalane sewage lagoons in Botswana and Samra sewage in Jordan, are internationally acknowledged as an important bird area (Orlowski 2013).

However, despite the global recognition of STPs as valuable habitat for many bird species, studies pertaining to it are limited (Murray & Hamilton 2010). As such, there is not a single report from Bhutan regarding the role of STP in bird conservation, and in general, studies concerning bird diversity and conservation are sparse and limited only to protected areas (Gyeltshen et al. 2020; Dendup et al. 2021), non-protected areas (Norbu et al. 2021) and freshwater ecosystems (Passang 2018; Nima & Dorji 2022). Therefore, there is a paucity of information and a knowledge gap concerning the role of STPs on the conservation of waterbirds in Bhutan.

To this end, the present systematic study aimed to glean basic ecological aspects on i) diversity and abundance, ii) temporal variation and iii) guild composition of the birds found in Thimphu's only STP. This study will also provide the opportunity to form a basis for formulating national and local policies for the conservation of waterbird species (Wang et al. 2018) and proper management of their essential habitats such as the STP. Documenting the avian diversity of this habitat will advance our understanding of the utilization of sewerage treatment plants by the different avian communities.

## MATERIALS AND METHODS

### Study site

The present study was conducted at Babesa STP (27.4367°N, 89.6521°E) (Figure 1), Thimphu, Bhutan. The study site spans an area of 13 acres of land with the design capacity of 1.75 million l/day and 325 mg/l five-day biological oxygen demand (BOD<sub>5</sub>) removal (Phuntsho et al. 2016). There are three ponds with varying areas and depth. The first one, anaerobic pond covers 1.85



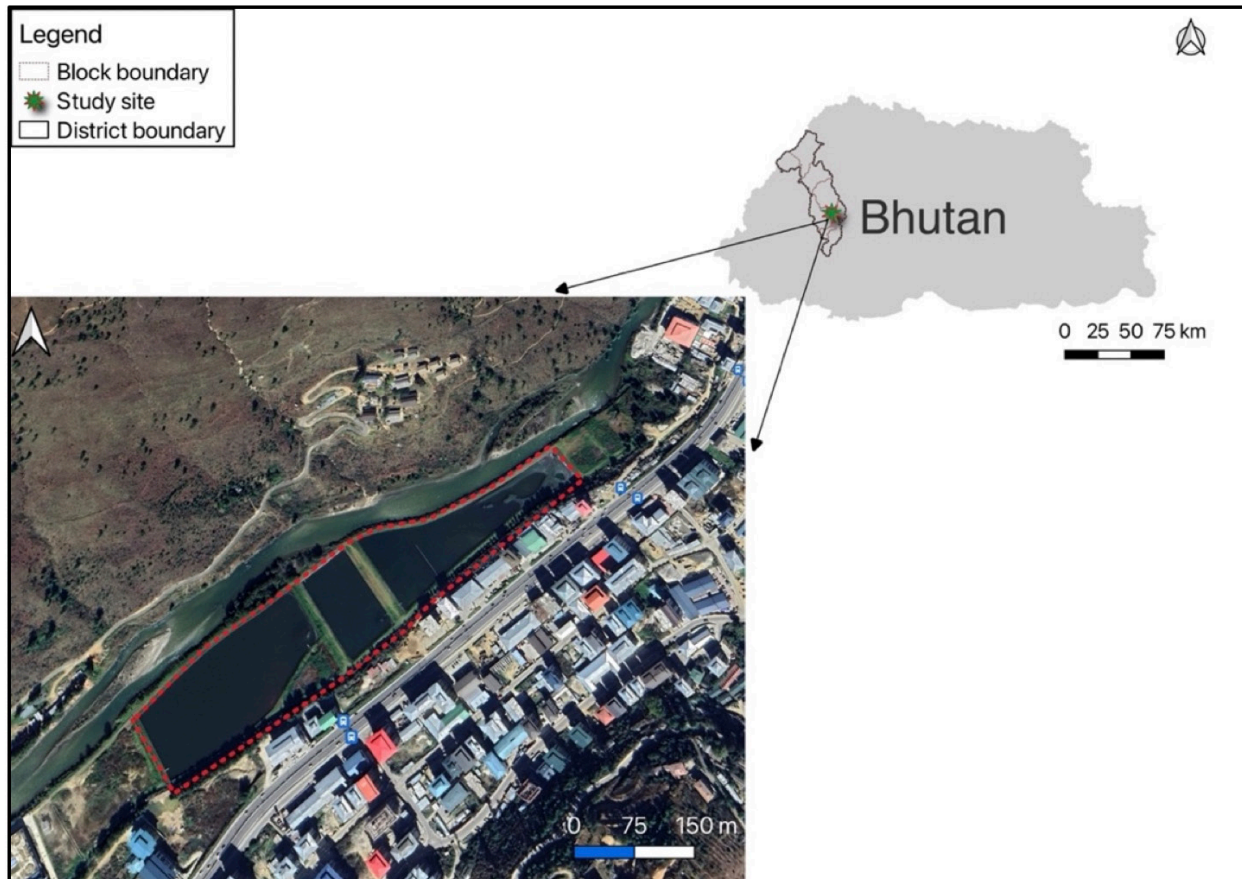


Figure 1. Map showing the location of the study site. The boundary of the STP is marked with red dotted lines.

ha with a depth of 3 m, while the second, facultative pond covers 0.71 ha with a depth of 2 m, and the third, maturation pond covers 1.71 ha with a depth of 1.5 m, respectively. The banks of all the three ponds have flat upper surfaces lined with rocks, mostly covered by *Cynodont dactylon*, and features steep vertical slopes approximately measuring 0.45 m. Other sparsely populated herb species such as *Rumex nepalensis* is also found along the edges of the pond. The surrounding vegetation is mostly dominated by tree species such as *Salix babylonica*, sparsely populated *Silax* and *Populus* species along with the shrub *Rosa brunonii* and the herb *Fagopyrum* species.

It is situated about 40 m away from Babesa-Thimphu expressway and lies to the immediate south of Wangchhu (chhu = river) while heading towards the main town. The nearest human settlement is about 15 m away from the study site. The site has moderate summer, cool spring and autumn, and a cold winter season with an annual average temperature of 13.8°C, and an annual average rainfall of 48.3 mm (NCHM 2013). The STP uses wastewater stabilization ponds alone (Phuntsho et al. 2016).

### Bird counts

A reconnaissance study was carried out in the last week of October 2021 to identify vantage points and a suitable position for a transect lines. The actual study commenced from the first week of November 2021, considered to be the ideal time for studying wintering and resident birds in the sub-Himalayan region (Salewski et al. 2003; Mazumdar et al. 2007), through to the end of October 2022.

We divided the time of the day into two intervals: 0800–1000 h in the morning and 1500–1700 h in the evening for 23 bird count surveys along the 650-m transect line. So, in a day we traversed for four hours along the 1,300 m transect line. For the remaining 14 bird surveys, in a day we surveyed the birds only once for 2 h in the evening along the 650 m transect line. Altogether, we spent 120 h surveying the birds along the 39,000 m of transect line. All the surveys were performed on weekends.

Prior to entering the designated study site, we observed and recorded all the birds sighted in the open sewerage pond from a vantage point to make a quick estimate of the actual birds present and help validate

the counts made from the line transect. Before we traversed the preset transect line by foot and recorded the sightings, we spent about 10 min to settle so that the birds did not feel disturbed and stressed. Concurrently, care was taken to maintain a proper distance between the observer and birds. At a certain randomly identified points marked along the transect, we stopped for about 15 min and recorded additional visible species and estimated the number of each species (Webb et al. 2010). We included all the observed bird species either wandering on the bank or resting on the bank or trees as long as they were within 50 m radius from the transect (Hutto et al. 1986). We did not consider flying birds in order to avoid repeated counting of the same individuals. Moreover, to reduce the impact of inclement weather on results of sightings, observations were not taken during snowfall or rainfall.

Birds were recorded using direct observations with the help of binoculars namely Police (7 x 50, Steiner, Germany), and Nikon (7 x 50), and immediately noted in the field journal. Where a bird species could not be confirmed, photos were taken using Canon 7d Mark II paired with Tamron G2 telephoto zoom lens (150–600 mm) and Nikon D850 paired with Nikkor telephoto zoom lens (200–500 mm) for further identification.

#### Bird identification, nomenclature, feeding guild, and conservation status

We followed Grimm et al. (2019) for avifauna identification and nomenclature. Further, birds were categorized as per their residency pattern as Altitudinal Migrant (AM), Passage Migrant (PM), Resident (R), Summer Visitor (SV), Vagrant (V), and Winter Visitor (WV) (Ali et al. 1996; Feijen & Feijen 2008; Grimm et al. 2019). Likewise, feeding guilds were ascribed based on the observation made in the field (Kumar & Sharma 2018; Singh et al. 2020). Additionally, we followed Ali & Ripley (1987) to assign the feeding guild: granivorous if they fed on grains, omnivorous if they fed on both plants and animals, insectivorous if they fed on insects, carnivorous if they fed on non-insects' invertebrates and vertebrates, frugivorous if they fed on fruits and nectarivorous if they fed on floral nectar. Birds were also categorized as water and non-waterbirds. The conservation status of the identified bird species was categorized as per International Union of Conservation for Nature (IUCN 2022).

#### Species accumulation curve

Species accumulation curve as a function of sampling adequacy was performed to determine if the probability

of sighting new species increased with increase in sampling days. The function 'specaccum' from R package 'vegan' (Oksanen et al. 2019) was employed to discover the expected species accumulation curve by means of sample-based rarefaction (Chiarucci et al. 2008).

#### Bird abundance and rank abundance curve

We followed Bull (1974) to describe the bird abundance. If more than 1,000 individuals were seen in a day, it was classed as very abundant (VA), those between 201–1,000 individuals as abundant (A), between 51–200 individuals as very common (VC) and those between 21–50 as common (C). Likewise, those between seven to 20 were classed as fairly common (FC) and between one to six as uncommon (UC). For birds with one to six individuals per season, it was classed as rare (Ra) and those with infrequent occurrence as very rare (VR) species.

The season-wise rank abundance curve was graphed with abundance rank and relative abundance. For interpretation purpose, a horizontal rank abundance indicated a community with a complete even distribution, whereas a steeper slope indicated a community with a less even distribution of species (Akinnesi 2010). Subsequently, a rank abundance curve was plotted to analyse dominance patterns and species evenness across different seasons.

#### Data analysis

The relative diversity (RDi) of families was computed following La Torre-Cuadros et al. (2007), where:

$$RDi = \frac{\text{Number of species in a family}}{\text{Total number of species}} * 100.$$

For species evenness (E), we followed Pielou's index (Pielou 1966):

$$E = \frac{H'}{\ln S}$$

Where:

E: Pielou's index

H': Shannon diversity index

Ln: natural logarithm

S: number of species observed

If E is close to 0, species evenness is considered low and if E is close to 1, evenness is considered to be relatively uniform.

For richness index (R), we followed Margalef's equation (Margalef 1968):

$$R = \frac{(S-1)(1)}{\ln(N)}$$

Where:

R: index of species richness.

S: number of species observed.

N: number of individuals of all species observed.

Ln: natural logarithm.

If  $R < 2.5$ , the species richness is considered low, medium if  $R > 2.5$  but  $< 4$  and high if  $R > 4$ .

For species diversity, Shannon-Weaver index ( $H'$ ) (Shannon & Weaver 1949) was used as follows:

$$\text{Shannon - Weaver index } (H') = - \sum_{i=1}^n P_i \ln P_i$$

Where:

$H'$ : Shannon-Weaver diversity index.

n: number of individual species.

$P_i$ : proportion of individual species belonging to the  $i^{\text{th}}$  species of the total number of individuals.

If  $H' < 1$ , the diversity index is considered low, medium if  $H' > 1$  but  $< 3$  and high if  $H' > 4$ .

Data was checked for normality using Shapiro-Wilk test. As it did not conform to a normal distribution, a non-parametric Kruskal-Wallis test was performed to evaluate the statistical significance in the feeding guilds of the birds. Likewise, to assess the statistical significance between waterbirds and non-waterbirds, a Mann-Whitney test was computed. Waterbirds included Anatidae, Ardeidae, Charadriidae, Ciconiidae, Icthyophaga, Motacillidae (White Wagtail *Motacilla alba*, White-browed Wagtail *Motacilla maderaspatensis*, Water Pipit *Anthus spinoletta*, Citrine Wagtail *Motacilla citreola*), Muscicapidae (White-capped Redstart *Phoenicurus leucocephalus*, Plumbeous Redstart *Phoenicurus fuliginosus*), Podicipedidae, Phalacrocoracidae, Rallidae, and Scolopacidae.

NMDS was applied to visualize and compare species composition across seasons using the function 'ordihull' in vegan (Tojo 2015) and the results were presented as two-dimensional plots. The function 'ordihull' creates neat and convex outlines to further depict group segregation for visual clarity (Moskowitz et al. 2020).

We removed species whose frequency of observation was only once. NMDS is an ordination technique that uses rank-order dissimilarity of multivariate data to ordinate sites and species, in which similar communities are placed closer together (Duchardt et al. 2018). To this end, we used Bray-Curtis dissimilarity, which factors in species abundance, using vegan package (Bray & Curtis 1957).

The statistical difference in species composition across seasons was computed by PERMANOVA using 'adonis' function from the vegan package (Oksanen

et al. 2020). Subsequently, to evaluate which seasons significantly differed from each other, pairwise 'adonis' function in R with Bonferroni correction was used (Arbizu 2020). Abundance values were square root-transformed to lower the influence of abundant species on rare species prior to executing multivariate analysis method (Zar 2010).

All analyses were performed by using R Statistical Computing Software, version 4.0.2.  $P < 0.05$  was considered statistically significant for all analyses.

## RESULTS

### Sampling adequacy and Species composition

Sampling adequacy was tested based on the number of bird species sighted during the study period, which indicated that an asymptote was not reached. Hence, it is plausible that a greater number of unrecorded bird species might be present at the site (Figure 2).

During a period spanning from November 2021 to October 2022, the present study recorded a total of 7661 individual birds belonging to 80 species, 58 genera, 29 families and 11 orders (Table 1). The greatest number of bird species detected were from order Passeriformes (52.50%) with 42 species, followed by Anseriformes (18.75%) with 15 species, Charadriiformes (7.5%) with six species, Gruiformes (5%) with four species, Pelecaniformes (3.75%) with three species, Accipitriformes, Columbiformes, Coraciiformes, Podicipediformes with two species (2.50%) each, and Bucerotiformes and Suliformes with only one species (1.25%) each.

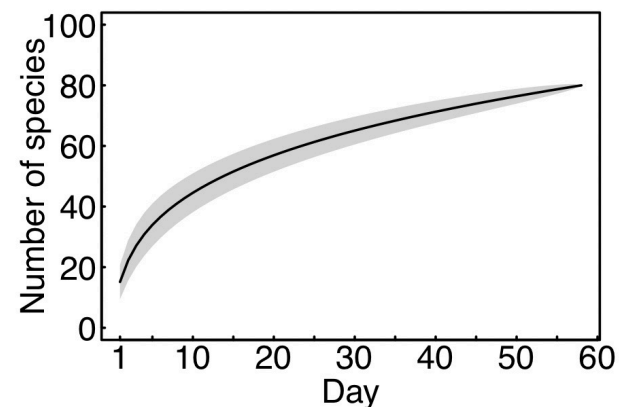


Figure 2. Species accumulation as a function of number of sampling days. The grey shade indicates the 95% confidence interval.



Table 1. Family, order and species recorded from November 2021 to October 2022 from the study site.

Family	Order	Common name	Scientific name
Muscicapidae	Passeriformes	Plumbeous Redstart	<i>Phoenicurus fuliginosus</i>
	Passeriformes	Hodgson's Redstart	<i>Phoenicurus hodgsoni</i>
	Passeriformes	Aberrant Bush-warbler	<i>Horornis flavolivaceus</i>
	Passeriformes	White-capped Redstart	<i>Phoenicurus leucocephalus</i>
	Passeriformes	Slaty-backed Flycatcher	<i>Ficedula erithacus</i>
	Passeriformes	Common Stonechat	<i>Saxicola maurus</i>
	Passeriformes	Chestnut-bellied Rock-Thrush	<i>Monticola rufiventris</i>
Motacillidae	Passeriformes	Verditer Flycatcher	<i>Eumyias thalassinus</i>
	Passeriformes	White Wagtail	<i>Motacilla alba</i>
	Passeriformes	Olive-backed Pipit	<i>Anthus hodgsoni</i>
	Passeriformes	White-browed Wagtail	<i>Motacilla maderaspatensis</i>
	Passeriformes	Grey Wagtail	<i>Motacilla cinerea</i>
	Passeriformes	Water Pipit	<i>Anthus spinoletta</i>
	Passeriformes	Rosy Pipit	<i>Anthus roseatus</i>
Leiothrichidae	Passeriformes	Citrine Wagtail	<i>Motacilla citreola</i>
	Passeriformes	Chestnut-crowned Laughingthrush	<i>Trochalopteron erythrocephalum</i>
	Passeriformes	Rufous Sibia	<i>Heterophasia capistrata</i>
	Passeriformes	Red-billed Leiothrix	<i>Leiothrix lutea</i>
Corvidae	Passeriformes	Chestnut-tailed Minla	<i>Chrysominla strigula</i>
	Passeriformes	Large-billed Crow	<i>Corvus macrorhynchos</i>
Turdidae	Passeriformes	House Crow	<i>Corvus splendens</i>
	Passeriformes	Blue Whistling-thrush	<i>Myophonus caeruleus</i>
	Passeriformes	Black-throated Thrush	<i>Turdus atrogularis</i>
	Passeriformes	Alpine Thrush	<i>Zoothera mollissima</i>
	Passeriformes	White-collared Blackbird	<i>Turdus albocinctus</i>
Zosteropidae	Passeriformes	Red-throated Thrush	<i>Turdus ruficollis</i>
	Passeriformes	Indian White-eye	<i>Zosterops palpebrosus</i>
Paridae	Passeriformes	Whiskered Yuhina	<i>Yuhina flavicollis</i>
	Passeriformes	Green-backed Tit	<i>Parus monticolus</i>
Passeridae	Passeriformes	Coal Tit	<i>Periparus ater</i>
	Passeriformes	Eurasian Tree Sparrow	<i>Passer montanus</i>
Phylloscopidae	Passeriformes	Russet Sparrow	<i>Passer cinnamomeus</i>
	Passeriformes	Common Chiffchaff	<i>Phylloscopus collybita</i>
Pycnonotidae	Passeriformes	Sulphur-bellied Warbler	<i>Phylloscopus griseolus</i>
Aegithalidae	Passeriformes	Himalayan Black Bulbul	<i>Hypsipetes leucocephalus</i>
Cettiidae	Passeriformes	Rufous-fronted Bushtit	<i>Aegithalos iouschistos</i>
Emberizidae	Passeriformes	Aberrant Bush Warbler	<i>Horornis flavolivaceus</i>
Fringillidae	Passeriformes	Little Bunting	<i>Emberiza pusilla</i>
Cinclidae	Passeriformes	Yellow-breasted Greenfinch	<i>Chloris spinoides</i>
Laniidae	Passeriformes	Brown Dipper	<i>Cinclus pallasi</i>
Prunellidae	Passeriformes	Grey-backed Shrike	<i>Lanius tephronotus</i>
Anatidae	Passeriformes	Rufous-breasted Accentor	<i>Prunella strophiata</i>
	Anseriformes	Ruddy Shelduck	<i>Tadorna ferruginea</i>
	Anseriformes	Common Shelduck	<i>Tadorna tadorna</i>
	Anseriformes	Common Merganser	<i>Mergus merganser</i>
	Anseriformes	Mallard	<i>Anas platyrhynchos</i>
	Anseriformes	Red-crested Pochard	<i>Netta rufina</i>
	Anseriformes	Eastern Spot-billed Duck	<i>Anas zonorhyncha</i>
	Anseriformes	Common Teal	<i>Anas crecca</i>
	Anseriformes	Falcated Duck	<i>Mareca falcata</i>
	Anseriformes	Northern Pintail	<i>Anas acuta</i>
	Anseriformes	Northern Shoveler	<i>Spatula clypeata</i>
	Anseriformes	Gadwall	<i>Mareca strepera</i>
	Anseriformes	Eurasian Wigeon	<i>Mareca penelope</i>
	Anseriformes	Ferruginous Duck	<i>Aythya nyroca</i>
Anseriformes	Tufted Duck	<i>Aythya fuligula</i>	
Anseriformes	Garganey	<i>Spatula querquedula</i>	
Alcedinidae	Coraciiformes	Crested Kingfisher	<i>Megaceryle lugubris</i>
	Coraciiformes	Common Kingfisher	<i>Alcedo atthis</i>
Charadriidae	Charadriiformes	River Lapwing	<i>Vanellus duvaucelii</i>
	Charadriiformes	Long-billed Plover	<i>Charadrius placidus</i>
	Charadriiformes	Grey-headed Lapwing	<i>Vanellus cinereus</i>
Scolopacidae	Charadriiformes	Common Sandpiper	<i>Actitis hypoleucos</i>
	Charadriiformes	Green Sandpiper	<i>Tringa ochropus</i>

Family	Order	Common name	Scientific name
Ibidorhynchidae	Charadriiformes	Ibisbill	<i>Ibidorhyncha struthersii</i>
Columbidae	Columbiformes	Oriental Turtle-dove	<i>Streptopelia orientalis</i>
	Columbiformes	Rock Pigeon	<i>Columba livia</i>
Accipitridae	Accipitriformes	Long-legged Buzzard	<i>Buteo rufinus</i>
	Accipitriformes	Himalayan Buzzard	<i>Buteo refectus</i>
Rallidae	Gruiformes	Eurasian Coot	<i>Fulica atra</i>
	Gruiformes	Eurasian Moorhen	<i>Gallinula chloropus</i>
	Gruiformes	White-breasted Waterhen	<i>Amaurornis phoenicurus</i>
	Gruiformes	Black-tailed Crake	<i>Zapornia bicolor</i>
Ardeidae	Pelecaniformes	Indian Pond-Heron	<i>Ardeola grayii</i>
	Pelecaniformes	Cattle Egret	<i>Bubulcus ibis</i>
	Pelecaniformes	Little Egret	<i>Egretta garzetta</i>
Podicipedidae	Podicipediformes	Black-necked Grebe	<i>Podiceps nigricollis</i>
	Podicipediformes	Great Crested Grebe	<i>Podiceps cristatus</i>
Phalacrocoracidae	Suliformes	Great Cormorant	<i>Phalacrocorax carbo</i>
Upupidae	Bucerotiformes	Common Hoopoe	<i>Upupa epops</i>

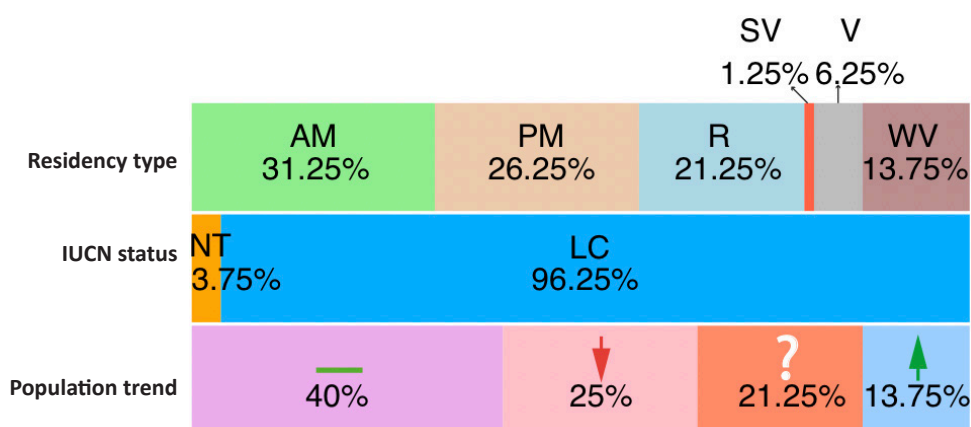


Figure 3. Graph showing residential status, IUCN status and population trend of the species in percentage: AM—Altitudinal Migrant | PM—Passage Migrant | R—Resident | SV—Summer Visitor | V—Vagrant | WV—Winter visitor | NT—Near Threatened | LC—Least Concern. — Stable | ↓—Decreasing | ?—Unknown | ↑—Increasing.

### Global population trends and residential status

Of the 80 recorded bird species, only three birds namely River Lapwing, Falcated Duck, and Ferruginous Duck were ‘Near Threatened’ species classified based on the IUCN Red List category. The remaining birds were species of ‘Least Concern’. Further, the present study found out that sewerage treatment plant hosted 32 species (40%) of birds known to have a stable population trend, 11 increasing (13.75%), 20 decreasing (25%) and 17 (21.25%) unknown on the global population trends as per the IUCN. The study also recorded the residential status of the birds and found 31.25% (AM), 26.25% (PM), 21.25% (R), 1.25% (SV), 6.25% (V), and 13.75% (WV), respectively (Figure 3).

### Relative diversity, Bird abundance, and Rank abundance

Table 2 shows the relative diversity of the bird families. Subsequently, Anatidae (15 species, RDi = 18.75) was found to be the most dominant of the total 29 families followed by Muscicapidae (eight species, RDi = 10), Motacillidae (seven species, RDi = 8.75), Turdidae (five species, RDi = 6.25), Leiothrichidae and Rallidae (four species each, RDi = 5), Ardeidae and Charadriidae (three species each, RDi = 3.75), Accipitridae, Alcedinidae, Columbidae, Corvidae, Paridae, Passeridae, Phylloscopidae, Podicipedidae, Scolopacidae and Zosteropidae (two species each, RDi = 2.50). The poorly represented families were Ibidorhynchidae, Aegithalidae, Cettiidae, Cinclidae, Emberizidae, Fringillidae, Laniidae, Phalacrocoracidae, Prunellidae, Pycnonotidae and Upupidae (one species each, RDi =

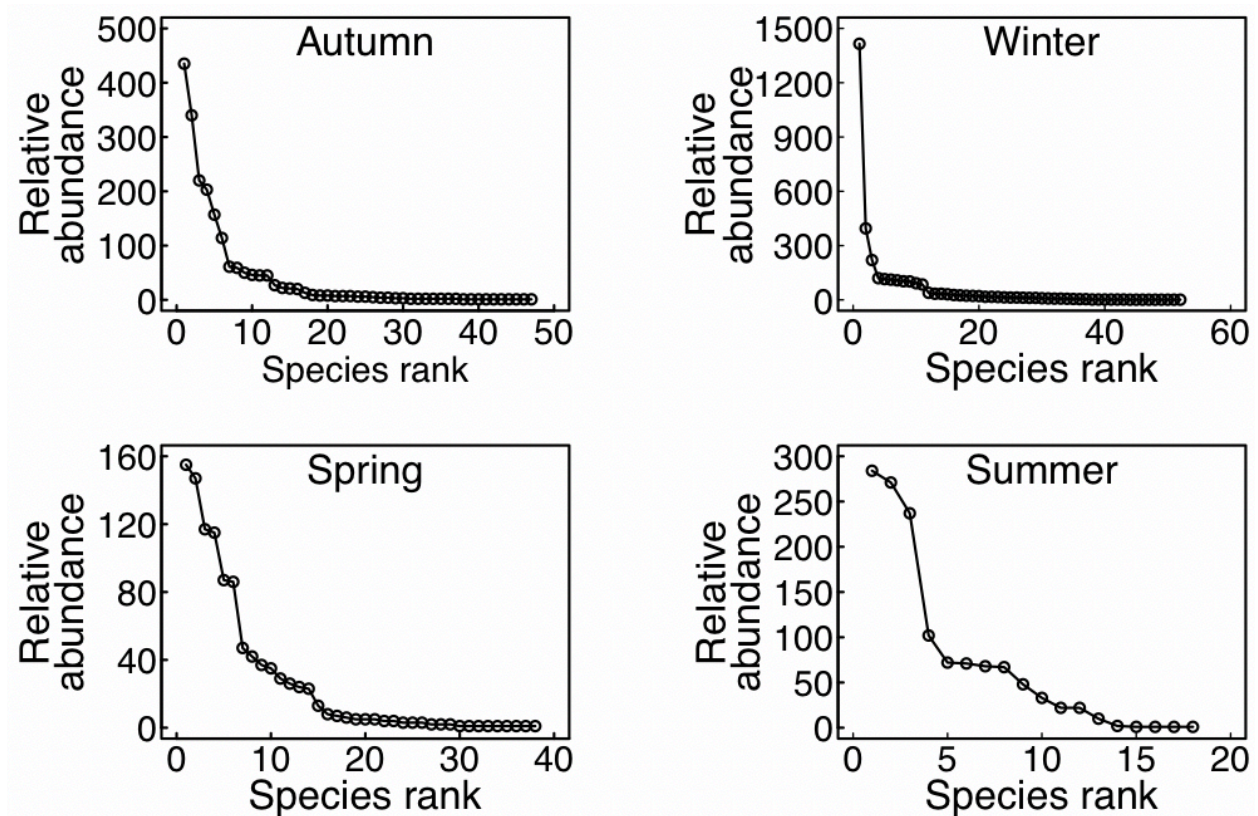


Figure 4. Rank abundance curve for bird species in autumn, winter, spring and summer.

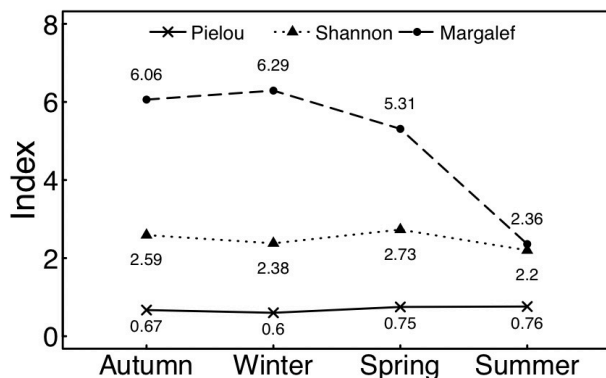


Figure 5. Seasonal variation in Pielou's evenness, Shannon-Weaver diversity index and Margalef's richness index.

1.25). Assessment of the bird abundance showed that three species were VC, eight species (C), 12 species (FC), eight species (UC), 13 (Ra) and 36 species (VR).

The rank-abundance curve had a steep gradient for winter, autumn and spring season, respectively, denoting low evenness of bird species (Figure 4). During winter, Ruddy Shelduck *Tadorna ferruginea* ranked first followed by White Wagtail, Common Merganser *Mergus merganser*, Common Sandpiper *Actitis hypoleucos*, and

River Lapwing *Vanellus duvaucelii*. In the autumn season, White Wagtail ranked first followed by Ruddy Shelduck, Oriental Turtle-Dove *Streptopelia orientalis*, River Lapwing, and Common Sandpiper. Spring season had White Wagtail ranked first followed by River Lapwing, Oriental Turtle-Dove, House Crow *Corvus splendens* and Common Sandpiper. By contrast, the curve for summer season was shallower in comparison to the other seasons. Subsequently, summer witnessed higher even distribution of the birds with Oriental Turtle-dove ranked first followed by River Lapwing, White Wagtail, Himalayan Black Bulbul *Hypsipetes leucocephalus* and Eurasian Hoopoe *Upupa epops*. Moreover, the curve length of summer and autumn season are shorter compared to the winter and spring season.

#### Richness index and Species diversity

Figure 5 shows season-wise Margalef's richness index (R), Shannon-Weaver diversity index ( $H'$ ) and Pielou's evenness index. Winter had the highest species richness (6.29), followed by autumn (6.06), spring (5.31) and summer (2.36), respectively. Similarly, the highest species diversity was recorded for the spring season (2.73), followed by autumn (2.59), winter (2.38) and

summer (2.20), respectively. The highest evenness was recorded for summer (0.76), followed by spring (0.75), autumn (0.67) and winter (0.60), respectively.

**Feeding guilds of birds and difference between waterbirds and non-waterbirds**

Figure 6 shows the abundance of birds in different feeding guilds. A non-parametric Kruskal-Wallis test was carried out to check for statistically significant difference between the guilds. Result revealed that there was no statistically significant difference between the feeding guilds ( $\chi^2 = 2.14$ ,  $df = 3$ ,  $P = 0.543$ ). However, insectivores were higher (median = 17.0,  $Q1-Q3 = 1.0-45.0$ ) than granivores (median = 12.0,  $Q1-Q3 = 8.5-126.5$ ), omnivores (median = 8.5,  $Q1-Q3 = 1.0-40.25$ ) and carnivores (median = 4.0,  $Q1-Q3 = 1-7.00$ ).

Likewise, Figure 7 shows the relative abundance of waterbirds and non-waterbirds. A Mann-Whitney test found that there was no statistically significant difference between the relative abundance of waterbirds and non-waterbirds ( $Z = -0.2769$ ,  $P = 0.78$ ), although non waterbirds were higher (median = 10.0,  $Q1 - Q3 = 1-42.50$ ) than the waterbirds (median = 7.0,  $Q1-Q3 = 2-41.0$ ).

**Comparisons of bird species composition across seasons**

The NMDS analysis revealed a stress value of 0.146 and suggested a good fit (Clarke & Warwick 2001). The NMDS biplot showed that most bird species overlap occurred between autumn and spring seasons as well as summer and spring, respectively. However, the overlap did not occur between winter and spring, winter and summer as well as between autumn and summer (Figure 8).

To check for statistically significant difference in the bird species composition across seasons, a PERMANOVA test was computed and found that there was a statistically significant difference ( $F_{3, 56} = 16.732$ ,  $P = 0.001$ ).

Subsequently, pairwise comparisons revealed a statistically significant difference between autumn and winter ( $R^2 = 0.347$ ,  $P = 0.006$ ,  $df = 1$ ), autumn and summer ( $R^2 = 0.242$ ,  $P = 0.006$ ,  $df = 1$ ), autumn and spring ( $R^2 = 0.148$ ,  $P = 0.018$ ,  $df = 1$ ), winter and summer ( $R^2 = 0.706$ ,  $P = 0.006$ ,  $df = 1$ ), winter and spring ( $R^2 = 0.502$ ,  $P = 0.006$ ,  $df = 1$ ) as well as spring and summer ( $R^2 = 0.197$ ,  $P = 0.006$ ,  $df = 1$ ), respectively.

**Table 2. The number of species in each avian family and their relative diversity.**

Avian families	Number of species	Relative diversity (RDi)
Accipitridae	2	2.50
Aegithalidae	1	1.25
Alcedinidae	2	2.50
Anatidae	15	18.75
Ardeidae	3	3.75
Cettiidae	1	1.25
Charadriidae	3	3.75
Cinclidae	1	1.25
Columbidae	2	2.50
Corvidae	2	2.50
Emberizidae	1	1.25
Fringillidae	1	1.25
Ibidorhynchidae	1	1.25
Laniidae	1	1.25
Leiothrichidae	4	5.00
Motacillidae	7	8.75
Muscicapidae	8	10.00
Paridae	2	2.50
Passeridae	2	2.50
Phalacrocoracidae	1	1.25
Phylloscopidae	2	2.50
Podicipedidae	2	2.50
Prunellidae	1	1.25
Pycnonotidae	1	1.25
Rallidae	4	5.00
Scolopacidae	2	2.50
Turdidae	5	6.25
Upupidae	1	1.25
Zosteropidae	2	2.50

**DISCUSSION**

To our knowledge, this is the first study that reported on the avifaunal composition concerning species diversity, relative abundance, feeding guilds and temporal variation from the Babesa STP, Bhutan. Despite the rapid urban sprawl over the years, a substantial number of avian species was observed at the study site.

In total, 80 species of birds, representing about 12.05% of the country’s total bird species, belonging to 58 genera, 29 families and 11 orders were detected accounting for a total of 7661 individuals. The most notable and the relatively abundant bird species



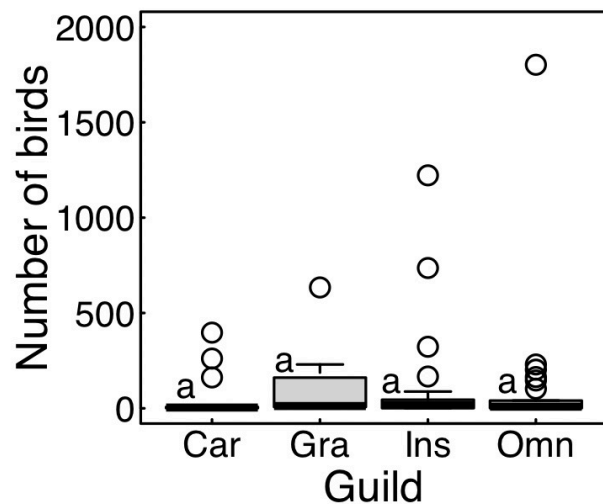


Figure 6. Relative abundance of the birds based on the various feeding guilds. The horizontal black lines in the box indicates the median. The top and bottom edges of each box represent the 75th and 25th percentiles, respectively. The whiskers of the box plot encompass the data within a range of 1.5 times the interquartile range, spanning the upper and lower quartiles. Outliers are indicated by open circles. Identical letters on the box plot signify statistical significance was not found based on non-parametric Kruskal-Wallis test.

Car—Carnivorous | Gra—Granivorous | Ins—Insectivorous | Omn—Omnivorous.

were Ruddy Shelduck (Anatidae), followed by White Wagtail (Motacillidae), River Lapwing (Charadriidae), Oriental Turtle-dove (Columbidae), Plumbeous Redstart (Muscicapidae) and Common Sandpiper (Scolopacidae). The findings imply that the site is relatively rich in avian diversity and richness as evidenced by the detection of birds that belonged to various migration status. Therefore, the Babesa STP holds great potential as a habitat for a diverse population of birds including vagrant, resident and migratory waterbird species.

The family Anatidae, which includes wintering birds such as Ruddy Shelduck, Common Shelduck *Tadorna tadorna*, Common Merganser, Mallard *Anas platyrhynchos*, Red-crested Pochard *Netta rufina*, Eastern Spot-billed Duck *Anas zonorhyncha*, Common Teal *Anas crecca*, Falcated Duck *Mareca falcata*, Northern Pintail *Anas acuta*, Northern Shoveler *Spatula clypeata*, Gadwall *Mareca strepera*, Eurasian Wigeon *Mareca penelope*, Ferruginous Duck *Aythya nyroca*, Tufted Duck *Aythya fuligula*, and Garganey *Spatula querquedula*, was found to have the highest RDi value, as previously reported by Tak et al. (2010) and Kumar et al. (2016), which reported a high abundance of the Anatidae family among wetland avifauna communities.

These findings further support the significance of the study site as an important area for avian biodiversity.

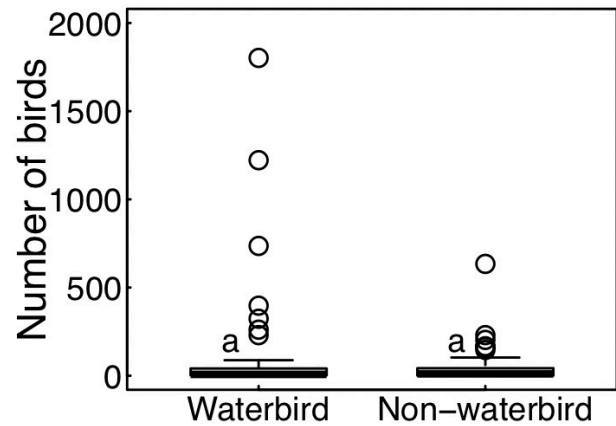


Figure 7. Relative abundance of waterbird and non-waterbird found at the study site. The horizontal black lines in the box indicates the median. The top and bottom edges of each box represent the 75th and 25th percentiles, respectively. The whiskers of the box plot encompass the data within a range of 1.5 times the interquartile range, spanning the upper and lower quartiles. Outliers are indicated by open circles. Identical letters on the box plot signify statistical significance was not found based on non-parametric Mann-Whitney test.

In the present study, the wintering ducks were mostly seen to inhabit open water and avoided thick vegetation presumably because of limited space and minimal foraging scope (King & Wrubleski 1998; Benoit & Askins 1999).

We observed a large flock of Ruddy Shelduck foraging, resting and roosting at the study site. We also observed Common Merganser foraging in the treatment plant twice. Some conceivable reasons for the substantial number of wintering ducks could be the availability of food resources and size of the wetland (Afdhal et al. 2012; Murray 2014), minimal interference, physical features of wetland habitats (Chatterjee et al. 2020), lack of hunting zones and predators (Kloskowski et al. 2009) at the study site. However, we cannot dismiss the role that the fresh water ecosystem might have played in attracting these birds, especially Ruddy Shelduck, given its close proximity to the STP, or vice versa, as we observed them shuttling between the two during our field visits.

Further, high invertebrate production has also been suggested as one of the key drivers for the occurrence and abundance of waterbirds (Augustin et al. 1999), which could have provided favorable foraging opportunities. Similarly, shorebirds and waders such as Common Sandpiper, Green Sandpiper *Tringa ochropus*, River Lapwing, Grey-headed Lapwing *Vanellus cinereus* and Long-billed Plover *Charadrius placidus* were seen confined to the edges of the STP and on the banks either

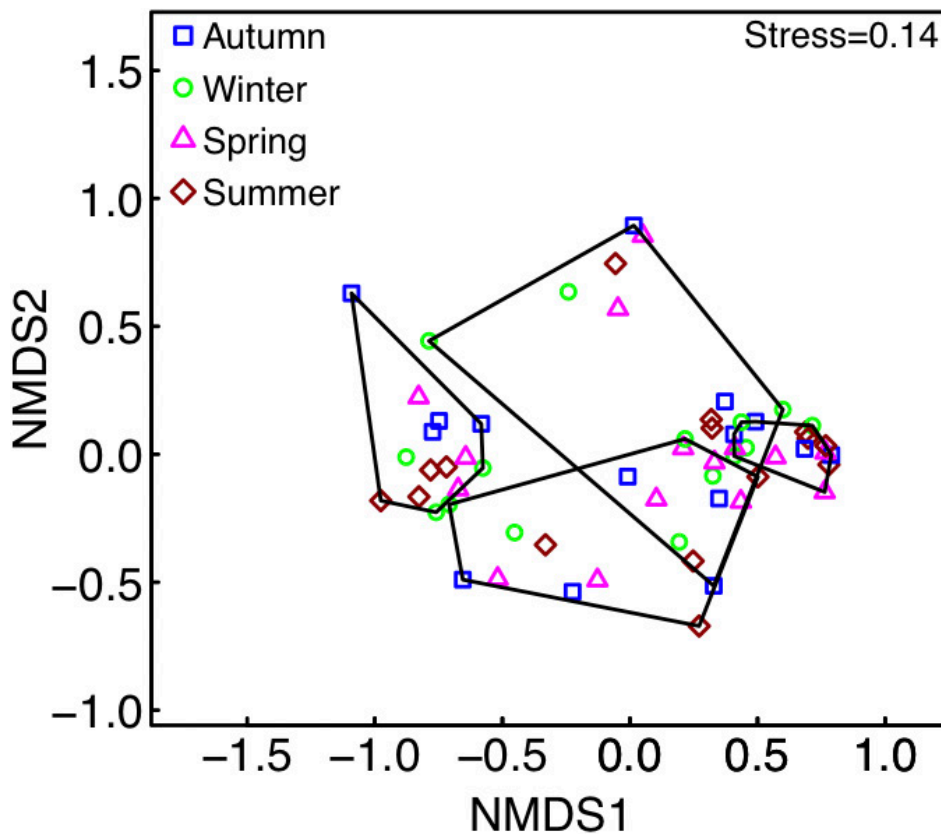


Figure 8. Non-metric multidimensional scaling (NMDS) plot showing dissimilarity in bird species composition across autumn, winter, spring and summer based on the Bray-Curtis dissimilarity matrix of species abundance data with square root transformation. Stress = 0.14.

resting or exploring food resources such as insects, invertebrates, worms and seeds.

The aforementioned findings are in congruence with previous literatures (Muhammad et al. 2018; Luo et al. 2019; Holbech & Cobbinah 2021). Taken together, the results highlights that the Babesa STP is a critical stopover ground and wintering site for many migratory birds which spends as long as six months at the site prior to their summer migration. Perhaps, artificial wetlands have been acknowledged as important migration routes for numerous diving ducks (Kennedy & Mayer 2002). Altogether, that the artificial wetlands hold potential value and can be of importance for migratory waterbird species was reported by Giosa et al. (2018).

Moreover, three ‘Near Threatened’ waterbird species, namely River Lapwing, Falcated Duck, and Ferruginous Duck, occurred at the study site. The River Lapwing occurred throughout the study period while the Falcated and Ferruginous ducks occurred only during winter (February) and spring (March) months. This indicates that constructed wetlands such as Babesa STP play an indispensable role in conservation and provide important sanctuaries even for threatened species.

Regarding the non-waterbirds, the richness and diversity could be attributed to resources, surrounding habitat and cover along with availability of food (van Biervliet et al. 2020). Indeed, on many occasions we observed non-waterbirds, especially Grey-backed Shrike *Lanius tephronotus* and Common Stonechat *Saxicola maurus*, feed on insects, seeds and fruits, and Eurasian Hoopoe *Upupa epops* forage on edges of the STP as it afforded easy availability of prey.

Likewise, availability of the trees and plants within the vicinity of the study site could have been central to their large assemblages because we observed many of them roost on the branches of the trees and plants. Consistent with this, plant diversity has been shown to exert a positive influence on the bird richness and diversity (Fontana et al. 2011) as it affords microhabitats for roosting, nesting and feeding (Canterbury et al. 1999; Soderstrom & Part 1999).

Interestingly, despite the large avian assemblage there was not any statistically significant difference observed between non-waterbirds and waterbirds, which implies that it might afford a suitable habitat for a large number of avian species. The presence of

vegetation for roosting and nesting, open water for foraging and swimming as well as the large occurrence of food resources makes the site attractive for the birds. Taken together, the findings suggest that the study site may function as an important ecological niche for various bird species, including both waterbirds and non-waterbirds.

In contrast, the current study observed statistically significant difference in bird composition between the seasons, in agreement with the findings of Kopij & Paxton (2018). Particularly, the largest differences in bird composition were observed between winter and summer, and between winter and spring. These findings indicate that the dissimilarities in bird compositions across seasons are particularly conspicuous between the dry and monsoon seasons, as well as between the dry and pre-monsoon seasons.

Further, spring and autumn were found to have the highest avian diversity while winter and autumn had the highest species richness compared to spring and summer, respectively. This may be due to seasonal changes in food and resource availability, competition among related species, and predator avoidance strategies (Morin 2011), which may lead to birds utilizing different food sources that vary in quantity and accessibility over time. Additionally, the allocation of resources over time may aid in the coexistence of avian species by allowing for the exploitation of shared resources at different times (Kopij & Paxton 2018). Also, variations in the population and peak abundance of birds across seasons may suggest the migratory patterns of the birds and reveal the direction of migration (Nisbet 1957).

With regard to the feeding guilds, there was no statistically significant difference between the guilds. This statistically insignificant result may be due to the occurrence of a variety of shrubs, flowering trees and diverse array of diets such as fishes, amphibians, reptiles, mammals, and aquatic invertebrates resulting from a large fertility of sewerage treatment plant (Rajpar & Zakaria 2013; Mukhopadhyay & Mazumdar 2019) culminating in the attraction of different guilds. The diversity of feeding guild observed among birds in the vicinity of the study site certainly suggests that it may be an important avian habitat to support various foraging behaviors.

## CONCLUSION

Overall, the present study provides a comprehensive assessment of the avian biodiversity present at the Babesa STP. The results reveal that the site harbors a great variety of bird species, including vagrant, resident and migrant birds as well as birds of various feeding guilds. These findings are particularly remarkable given the relatively small size of the study site. Additionally, the findings also underscore the ecological significance of man-made habitats in reinforcing biodiversity, since such ancillary habitats can afford crucial resources and support for a diverse array of species, and act as winter sojourn for migratory birds.

In light of the findings of this study, it is recommended that concerned authorities and policymakers take further action to safeguard the site as it is important for bird conservation. For instance, a valuable intervention measure for the area may be fencing to keep away potential predators such as stray dogs, which are quite common in the area. Additionally, certain points may be identified as photography spots to minimize human-induced disturbance to the birds. Otherwise, apart from serving as a suitable area for recreation, bird watching and scientific study, the site can also be a great source of educational opportunities for students, teachers, and the general public interested in learning about the features and importance of constructed wetlands in sustaining wildlife habitats and biodiversity (Semeraro et al. 2015). Further research is warranted, especially concerning the underlying factors that trigger large assemblages of birds at the site.

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The Managing Editor, JoTT,  
c/o Wildlife Information Liaison Development Society,  
43/2 Varadarajulu Nagar, 5<sup>th</sup> Street West, Ganapathy, Coimbatore,  
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ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

July 2023 | Vol. 15 | No. 7 | Pages: 23463–23630

Date of Publication: 26 July 2023 (Online & Print)

DOI: 10.11609/jott.2023.15.7.23463-23630

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