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WATERBIRD HABITAT MANAGEMENT: IDENTIFICATION OF INFLUENCING FACTORS THROUGH A PILOT STUDY OF TWO RIVER CATCHMENT AREAS IN INDIA

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ABSTRACT

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This pilot study compared the richness and abundance of wintering waterbird species between two deep-water habitats, Kadamdeuli Dam and Gangdua Dam, in Bankura district, West Bengal, over three mid-wintering seasons (2021-2024). 59 waterbird species from 17 families were observed using the total count method. Kadamdeuli Dam had better water quality (73.8% water quality index) and higher dissolved oxygen, while Gangdua Dam (43.5% water quality index) faced agricultural runoff and sewage deposition. Despite poorer water quality, Gangdua's larger area and depth supported more waterbirds, especially divers, while Kadamdeuli's shallower waters attracted more dabblers. Gangdua's longer shoreline supported more waders, though some waders preferred Kadamdeuli due to lower human activity. However, periodic water level fluctuations at Kadamdeuli influenced bird diversity. Canonical correspondence analysis confirmed these patterns. The study emphasises the importance of managing resource availability, habitat heterogeneity, and reducing anthropogenic interference for effective waterbird habitat conservation.

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INTRODUCTION

In the last century, nearly 50% of wetlands have degraded globally, and according to Coleman *et al.* (2008), the average loss rate was 95 km^2/year. The degradation of most of the enduring wetlands was mainly due to anthropogenic activities like urbanisation and changes in land use patterns (Fraser and Keddy 2005). Wetlands are important roosting, foraging, and waterbird breeding grounds (Rajpar and Zakaria 2013). So, due to the degradation of the habitat quality of wetlands, the richness and diversity of waterbirds have been reduced over time (Ma *et al.* 2010, Rush *et al.* 2010), and that's why sustainable conservation of waterbirds is the need for this hour (Erwin 2002, Taft *et al.* 2002).

Mainly owing to the loss and habitat degradation of natural wetlands, waterbirds are dependent on using the artificial wetlands as their roosting and resting grounds (Robertson and Hutto 2006, Pärt *et al.* 2007). However, non-natural water bodies cannot entirely substitute for the purposes and ecosystem services of natural habitats as waterbird roosting and foraging grounds (Ma *et al.* 2004, Desrochers *et al.* 2008). Vymazal (2010) identified artificial wetlands as man-made wetlands largely designed to retain water for drinking and irrigation purposes. These areas are frequently swamped with water from adjacent catchment areas throughout the year and thus can serve as apt breeding and roosting grounds for many waterbird species (Locky *et al.* 2005). According to Rajpar *et al.* (2010), these wetlands are usually rich in various food resources that waterbirds can consume. However, the regulation of the natural course of rivers through dam construction has intensely altered wetland ecology and abolished many natural wetland habitats. Abundant negative effects of individual dams on individual river ecosystems were well documented (Graf 2006), and for dam construction, wetland-dependent species, particularly waterbirds, are more or less negatively affected (Kingsford and Thomas 2004, Brandis *et al.* 2011). On the contrary, a meticulous study by Hamilton *et al.* (2017) showed that river dams could also harbour high bird diversity.

Besides that, habitat heterogeneity has a significant influence on disparity in species richness (Bonilla *et al.* 2012). Physical attributes of habitat, like area, depth, shore length, water level fluctuation, etc, contribute to the habitat heterogeneity within a wetland and are the most critical variables that influence the species richness of waterbirds (González-Gajardo *et al.* 2009, Almeida *et al.* 2018). Present conservation strategies of migratory waterbirds mainly consider the migration pattern, species abundance and richness of migratory waterbirds, and sustainable management of wetland networks (Bassi *et al.* 2014). Thus, understanding the significance of different physical habitat characteristics in shaping the community structure of both resident and migratory birds is essential.

This pilot study estimated the diversity and richness of wintering waterbird species in two river dams, namely Kadamdeuli Dam and Gangdua Dam, in Bankura district, West Bengal. These two wetlands' topographic conditions and environmental parameters were more or less comparable. However, these river dams had diverse physical habitat qualities such as area, depth, shore length, and water level fluctuation. These wetlands were also exposed to dissimilar anthropogenic pressure. Another major objective of the present investigation was to evaluate the variance of waterbird species composition and abundance and to depict the possible effects of physical habitat attributes of both waterbodies on the community structure of waterbirds. Another aim of this study was to quantify the pollution level in the study sites by indicators like oxygen saturation (*OS*%) and water quality index (*WQI*) that the information from this research article would aid in the future conservation of wintering waterbirds in these important wintering grounds worldwide.

MATERIAL AND METHODS

Study areas

West Bengal has nine prominent physiographic regions (Alam *et al.* 2003). Bankura, a western district of West Bengal, connects the Chhotanagpur plateau to the plains of Bengal. A brief description of the two study sites is given below, and the locations of the sites are represented in Figure 1. The total area and length of the shoreline were calculated

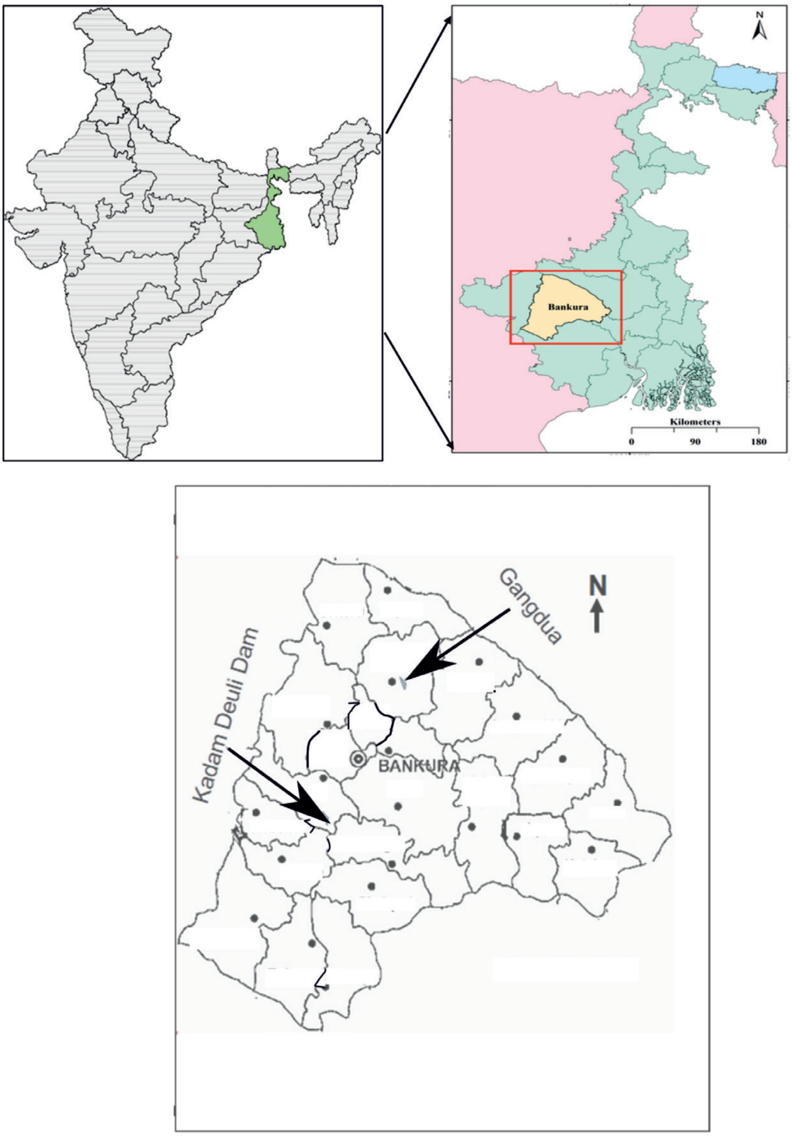


Fig. 1. Location of the study sites: in India, West Bengal and Bankura district (maps not in scale)

with the help of *GPS* (eTrex 10, Garmin) and *Google Earth Pro* software. The depth of the study sites was measured by dropping measurement riggings from various points of the wetlands, and then these data were averaged to get the mean depth. Water level fluctuations were measured from the water level markers of the dams.

Kadamdeuli Dam [Site 1] (23°06'N, 86°51'E): Shore length: 5.26 km, Area: 38 ha, Altitude: 116 msl, Mean Depth: 4.5 m. It is situated in the Bankura District, a dam area of the Shilabati or Silai River, where a canal from the Mukutmanipur-Kangsabati dam meets. Scrubs and patchy jungles primarily bound this artificial wetland; however, infertile lateritic areas are also present. The far-flung location from human settlements makes this habitat somewhat safe from enormous anthropogenic pressure. However, local people use this wetland for daily needs like bathing, washing, cattle washing, etc. *Ipomea aquatica* and *Nymphoides hydrophylla* are the most dominant vegetation of this wetland.

Gangdua Dam [Site 2] (23°24'N, 87°04' E): Shore length: 9.24 km, Area: 92.7 ha, Altitude: 108 msl, Mean Depth: 7.5 m. It is a 4900 ft. long dam on the Shali River, a tributary of the Damodar River, located in the Bankura district. This dam saves nearby villages from flooding, and the stored water is used for irrigation. The vicinity of this wetland is mainly dotted with agricultural fields, and runoff from agricultural fields could cause the dilapidation of the water quality of this wetland. Moreover, due to its human habitation adjacent location, fishing, picnics, tourism, and illegal hunting of waterbirds create a burden on this wetland. *Nymphoides indica* and *Typha sp*. are the most dominant vegetation.

Bird counting

The study sites were surveyed three times each during the mid-wintering period in eastern India (December 15th to January 31st) over three consecutive years: 2021/2022, 2022/2023, and 2023/2024. This period coincides with the coldest temperatures in Gangetic West Bengal, as reported by the National Climate Centre Office (NCCO 2008). Waterbird abundance and species richness were recorded using the total direct count method from pre-selected vantage points around the wetlands, following Mukherjee *et al.* (2022). The counts were made along an imaginary line surrounding the wetlands. All sides of Site 1 with a smaller width (ca 100 m), where approachable, were surveyed during each sampling session, by walking along with five such lines of the length of 1 km each. Observations were made from 6 points on each line, each point was 200 m apart from the previous/next point on the line, independently by three trained observers at three specific time intervals (06:00– 07:00, 12:00–13:00, and 17:00–18:00 h) during each of the survey days. For Site 2 (width >100 m), a manual country boat was used to sail along the length of the wetland following imaginary grid lines, 100 m apart from each other. On each line, birds on either side of the line within 50 m were counted from the points 200 m apart from each other. This method, which falls under the total count category rather than sampling estimates, is particularly suited for accurately enumerating wetland bird populations (Urfi *et al.* 2005). The sequence of sampling was randomised to minimise bias, and aerial species were counted separately; their abundance was excluded from the overall population assessment. Character traits and feeding behaviours of the waterbirds were observed using a Nikon Fieldscope (25–75 × 82 ED) and Zeiss binoculars (8x40). Identification and nomenclature followed Grimmett *et al.* (2011).

Water Quality Assessment

The *pH*, water temperature, and electrical conductivity (*EC*) were measured on the spot using the Eutech Multi-parameter PCSTester 35. Merck portable *DO* Kit measured dissolved oxygen (*DO*) according to standard methods (APHA 1999).

Oxygen saturation (*OS*) was calculated from the following formula:

$$OS\ \% = \frac{C}{C_S} \times 100(1)$$

Where *C* = dissolved oxygen concentration obtained from the analysis. *Cs* = saturation concentration of pure water at a similar temperature and pressure. Data on *Cs* were collected from standard methods for the examination of waste and wastewater (APHA 1999). For the determination of the water quality index (*WQI*) of two study sites, the following empirical equation was used (Pesce and Wunderlin 2000):

$$WQI = k\ \frac{\sum_i C_i P_i}{\sum_i P_i}$$

Where *k* was a subjective constant (value of *k* between zero and one), *Ci* was the normalized value of the parameter, and *Pi* was the relative weight assigned to each parameter based on European Union Standards (EU 1975). In this study, the constant *k* was not considered. Hernandez-Romero *et al.* (2004) and Sanchez *et al.* (2007), in their respective studies, also did not consider the subjective constant (*k*).

Statistical Analyses

Sorensen index, or Sorensen's similarity coefficient (*SSD)*, was also calculated using this formula:

$$SSD = \frac{2a}{2a+b+c}$$

Where ***a*** is the number of species in both sites, ***b*** is the number of species in the second site only, and ***c*** is the number of species in the first site only (Magurran 2004).

One-way analysis of variance (ANOVA) was done (significance level $p < 0.05$) to comment on the significant differences in waterbird abundances and physicochemical parameters. ω^2 is the effect size estimator.

For ease in canonical correspondence analyses (*CCA*), the waterbird species were sectioned into four categories, viz., dabblers, divers, waders, and wetland-associated birds (*WAB*), according to Sibley *et al.* (2001). Waterbirds were classified primarily based on their foraging techniques. Divers are predominantly fed by diving underwater. Dabblers showed various feeding techniques like head-dip, neck-dip, beak-dip, filtering, and upending. Waders used picking and striking as foraging techniques. Wetland-associated birds directly or indirectly depend on the wetlands for foraging or resting.

CCA is a multivariate technique to order species along canonical axes, permitting a reasonably easy ecological understanding of species assemblages (Borcard *et al.* 2011). *CCA* was applied to understand the effect of different physical habitat features (area, depth, length of the shoreline, and water level fluctuation) on the abundance of different categories (divers, dabblers, waders, and *WAB*). Eigenvalues, the total percentage of inertia of the primary axis of each *CCA* plot, are mentioned in Table 1. The absolute value of correlation (p) for each CCA plot was also mentioned in Table 1. PAST 4.12 software was used to draw *CCA* plots.

Table 1
Eigenvalue, total percent of inertia of the primary axis of each *CCA* plot, and the absolute valueof the correlation (*p*) of *CCA* plots.

CCA Plot	Eigenvalue	% of total inertia	*p*
Divers	0.041	97.28	0.52
Dabblers	0.293	98.5	0.51
Waders	0.232	99.93	0.54
WAB	0.036	99.44	0.51

RESULTS

Abundance of waterbirds

A total of 59 species of waterbirds of 17 families were recorded during the present study. Both sites were represented by 51 species of waterbirds each (Table 2). The total abundance of waterbirds was higher in Site 2. 14 species belonged to the *Anatidae* family, followed by the *Ardeidae* family with 9 species. 4 families of waterbirds, viz. *Anhingidae*, *Accipitridae*, *Rostratulidae*, and *Laridae* were exemplified by a single species. Out of 59 species, 30 species were winter migratory species to this part of the Indian continent, and the rest were resident or local migratory. One species, namely, Common Pochard *Aythya ferina*, belonged to the IUCN red list Vulnerable (*VU*) category, and four species, viz. Black-headed Ibis *Threskiornis melanocepalus*, Lesser Adjutant *Leptoptilos javanicus*, Asian Woolly-necked Stork *Ciconia episcopus,* and Oriental Darter *Anhinga melanogaster* belonged to the Near Threatened (*NT*) category. The rest of the 54 species were in the Least Concern (*LC*) category (*www.iucn.org*). Divers, dabblers, waders, and wetland-associated birds were represented by 11, 10, 30, and 8 species of waterbirds.

Table 2
Total species and average abundance of waterbirds in mid-wintering season in two study sites.
Site 1: Kadamdeuli Dam, Site 2: Gangdua Dam.
Migratory status: Winter migrant (WM) - Resident (R).
IUCN status: Least Concerned (LC), Near Threatened (NT), Vulnerable (VU).
Source: www.iucnredlist.org

FAMILY/Common Name	Migratory status	IUCN status	Site 1	Site 2
ANATIDAE				
Lesser Whistling-duck	R	LC	14.2±5.3	235.6±47.2
Fulvous Whistling-duck	WM	LC	1.0±0.5	Not recorded
Cotton Pygmy-goose	R	LC	112.2±33.7	87.4±11.2
Gadwall	WM	LC	94.5±27.1	78.0±43

Indian Spot-billed Duck	R	LC	2.0±0.1	Not recorded
Northern Shoveler	WM	LC	12.2±3.4	8.8±3.2
Northern Pintail	WM	LC	17.2±7.9	1.0±0.5
Garganey	WM	LC	3.7±0.4	Not recorded
Common Teal	WM	LC	2.8±1.0	8.2±3.3
Red-crested Pochard	WM	LC	52.8±13.4	143.4±51.5
Common Pochard	WM	VU	13.0±1.1	22.4±7.9
Ferruginous Duck	WM	LC	4.0±3.2	14.5±3.3
Tufted Duck	WM	LC	9.2±4.5	4.5±1.2
Bar-headed Goose	WM	LC	Not recorded	4.3±3.2
PODICIPEDIDAE				
Little Grebe	R	LC	24.7±13.0	43.2±11.7
Great-crested Grebe	WM	LC	3.4±0.5	12.8±2.2
CICONIIDAE				
Asian Openbill	R	LC	12.2±8.9	7.4±2.7
Asian Woolly-necked Stork	R	NT	Not recorded	2.5±0.5
Lesser Adjutant	WM	NT	2.5±2.3	3.0±1.0
THRESKIORNITHIDAE				
Black-headed Ibis	WM	NT	2.2±3.4	2.8±2.0
Red-naped Ibis	WM	LC	2.2±1.9	5.8±3.1
Glossy Ibis	WM	LC	Not recorded	1.2±0.5
ARDEIDAE				
Cinnamon Bittern	R	LC	Not recorded	2.2±0.5
Black Bittern	WM	LC	2.8±1.1	4.2±1.0
Indian Pond Heron	R	LC	22.7±5.3	19.4±2.3
Grey Heron	R	LC	2.5±1.6	3.2±1.1
Purple Heron	R	LC	1.0±0.5	6.5±4.2
Cattle Egret	R	LC	5.2±1.3	10.8±4.5
Little Egret	R	LC	12.5±10.3	23.4±9.1
Intermediate Egret	R	LC	NR	1.0±0.1
Great Egret	R	LC	NR	2.4±1.2
ANHINGIDAE				
Oriental Darter	WM	NT	3.2±0.4	6.8±2.0
PHALACROCORACIDAE				
Little Cormorant	R	LC	23.5±17.2	44.8±7.9
Indian Cormorant	WM	LC	7.2±3.0	15.5±1.2
Great Cormorant	WM	LC	4.4±0.5	13.0±2.0
ACCIPITRIDAE				
Eurasian Marsh Harrier	WM	LC	1.2±0.1	Not recorded
RALLIDAE				
White-breasted Waterhen	R	LC	5.5±1.7	6.5±4.0

Purple Swamphen	R	LC	11.7±2.1	23.4±12.3
Common Moorhen	R	LC	11.8±3.4	6.4±1.0
Eurasian Coot	R	LC	45.5±6.5	42.8±6.9
JACANIDAE				
Bronze-winged Jacana	R	LC	32.2±5.1	67.4±12.3
Pheasant-tailed Jacana	R	LC	155.7±45.0	45.4±2.5
CHARADRIIDAE				
Grey-headed Lapwing	WM	LC	14.2±4.1	Not recorded
Yellow-wattled Lapwing	R	LC	3.2±2.1	Not recorded
Little Ringed Plover	R	LC	3.8±1.2	8.5±1.3
ROSTRATULIDAE				
Greater Painted-snipe	R	LC	0.8±0.5	1.8±1.1
SCOLOPACIDAE				
Common Redshank	WM	LC	Not recorded	4.0±1.0
Wood Sandpiper	WM	LC	2.8±0.5	Not recorded
Common Sandpiper	WM	LC	2.5±0.3	3.0±0.9
LARIDAE				
Brown-headed Gull	WM	LC	Not recorded	1.0±0.2
ALCEDINIDAE				
Stork-billed Kingfisher	R	LC	0.8±0.5	1.7±0.1
White-breasted Kingfisher	R	LC	2.5±0.5	5.7±1.0
Common Kingfisher	R	LC	3.0±1.2	2.2±0.3
Pied Kingfisher	R	LC	2.0±0.9	Not recorded
HIRUNDINIDAE				
Barn Swallow	WM	LC	123.2±45.2	156.4±56.3
Wire-tailed Swallow	WM	LC	7.0±3.2	23.8±7.2
MOTACILLIDAE				
White Wagtail	WM	LC	5.2±1.0	14.2±3.3
Grey Wagtail	WM	LC	Not recorded	6.8±1.1
White-browed Wagtail	R	LC	1.0±0.1	3.2±2.0

Pheasant-tailed Jacana *Hydrophasianus chirurgus* and Cotton Pygmy-goose *Nettapus coromandelianus* were the two dominant species in Site 1, whereas Lesser Whistling-duck *Dendrocygna javanica* and Red-crested Pochard *Netta rufina* showed maximum abundance in Site 2. A high abundance of Barn Swallow *Hirundo rustica* was recorded from both study sites. *SSD* was calculated to show the similarity in species composition, and it was 85%.

Year-wise variation in abundance

In Site 1, the waterbird abundance was highest in 2023-2024, followed by 2021/2022, and 2022/2023 (Fig. 2). However, in Site 2, the waterbird abundance was highest in

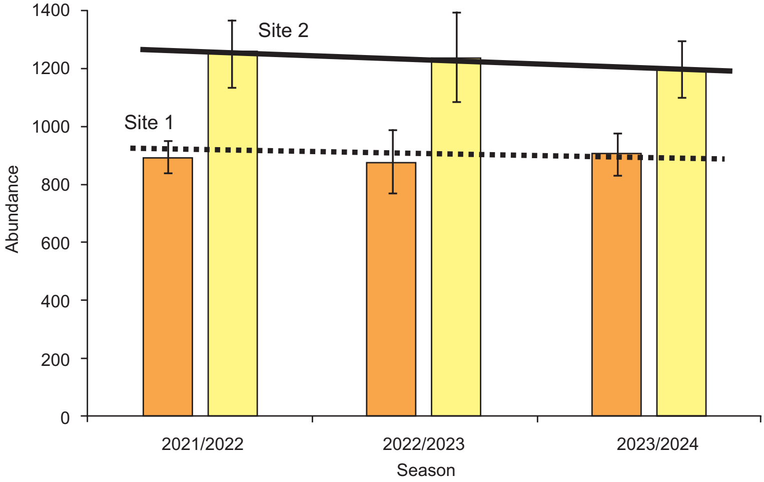


Fig. 2. Changes in waterbird abundance in study sites

2021/2022, followed by 2022/2023, and 2023/2024 (Fig. 2). Furthermore, a significant difference in yearly abundances was also noted in Site 1 (2021/2022 and 2022/2023: $F = 240.0$, $p < 0.05$, $\omega^2 = 0.975$, 2022/2023 and 2023/2024: $F = 38.2$, $p < 0.05$, $\omega^2 = 0.861$, 2021/2022 and 2023/2024: $F = 255.5.0$, $p < 0.05$, $\omega^2 = 0.977$) and Site 2 (2021/2022 and 2022/2023: $F = 45.5$, $p < 0.05$, $\omega^2 = 0.881$, 2022/2023 and 2023/2024: $F = 407.1$, $p < 0.05$, $\omega^2 = 0.985$, 2021/2022 and 2023-2024: $F = 442.5$, $p < 0.05$, $\omega^2 = 0.986$).

Physicochemical factors and water quality

pH was in the weakly alkaline range (7.78-8.12) in both study sites (Table 3). Subsurface water temperature ranged between 20.9°*C* and 21.3°*C* in the study sites. It was interesting to note that *EC* was significantly higher ($F = 2940.0$, $p < 0.05$, $\omega^2 = 0.998$) in Site 2 (280.0 ± 23.0 *μS.cm-1*) than in Site 1 (209.0 ± 45.0 *μS.cm-1*). However, *DO* was significantly higher in Site 1 ($F = 63.8$, $p < 0.05$, $\omega^2 = 0.912$) (Table 3).

Table 3
Physicochemical characteristics of water in Kadamdeuli Dam (Site 1) and Gangdua Dam (Site 2), data represented as mean ± *SE*, during the study period.

Variables	Site 1	Site 2
Water Temperature (˚*C*)	20.9±2.2	21.3±1.8
pH	7.78±0.14	8.12±0.25
Electrical Conductivity (μS.cm^{-1})	209.0±45.0	280.0±23.0
DO (mg.L^{-1})	5.3±1.6	1.9±0.9

To evaluate the water pollution level in both wetlands, *WQI* and *OS*% were calculated, as both these parameters were excellent indicators of water quality. *OS*% value in Site 1 and Site 2 was consecutively 64.5 and 20.5. *WQI* values for Site 1 and Site 2 were 73.8% and 47.5%, respectively.

Physical habitat attributes and waterbird community composition

Both Site 1 and Site 2 showed different physical habitat attributes like wetland size or area, depth, length of the shoreline, and water level fluctuation. The average abundance of all four groups of waterbirds, divers ($F = 2292.0$, $p < 0.05$, $\omega^2 = 0.997$), dabblers ($F = 515.4$, $p < 0.05$, $\omega^2 = 0.988$), waders ($F = 96.0$, $p < 0.05$, $\omega^2 = 0.940$), and wetland-associated birds ($F = 67.9$, $p < 0.05$, $\omega^2 = 0.917$) differed significantly between Site 1 and Site 2. Site 2, with a larger area and greater depth, harboured a significantly higher number of birds than Site 1. The abundance of divers was also higher in Site 2. However, the abundance of dabblers was higher in Site 1. Site 2, with a larger shore length, provided refuges to a higher number of waders. Water level fluctuation was more prominent in Site 1, affecting the abundance of many waterbird species. However, the abundance of some wader species was increased during low water conditions. *CCA* plots also depicted the effects of area, depth, length of shoreline, and water level fluctuations on the four different categories of birds. It was evident from Figure 3 that the depth of the water bodies mostly influenced the abundance of divers. More than 60% of diver species preferred the deeper Site 2. Similarly, Site 2, with a larger shoreline, harboured a higher abundance of waders. On the contrary, nearly 70% of dabbler species preferred Site 1. *WAB* was not affected by these four attributes. All four *CCA* plots showed a modest level of correlation (the absolute value of correlation (p) as $[0.36 \leq 0.67]$).

DISCUSSION

Both wetlands were in the Rarh region of the Bankura district of West Bengal, i.e., the connecting zone between the Chottanagpur plateau fringe and the lower Gangetic plain. Both study sites provided refuges to abundant migratory and resident waterbirds and were located on overlapping two important bird migration flyways, namely the Central Asian Flyway and the East Asian-Australasian Flyway (Mukherjee *et al.* 2021). Nandi *et al.* (2004) also recorded a high diversity of wintering waterbirds from this physiographic region. Sørensen index (*SSD*), which depended on the present-absent data, was calculated to assess the resemblance of species composition of the two study sites. *SSD* was 85%, which showed that the species composition of the two study sites was quite similar. Ma *et al.* (2010) reported that waterbodies harbour similar waterbirds in the same geographic area.

According to previous findings by Nandi *et al.* (2004) and Mukherjee *et al.* (2022), many wetlands in these parts of western West Bengal showed overwhelming abundance (> 50% of the total number of waterbirds) of Lesser Whistling-duck. However, the Lesser Whistling-duck was the most dominant species in Site 2, but its abundance was nearly 19% of all the waterbirds recorded. On the contrary, in Site 1, its abundance was much less (nearly 0.2%).

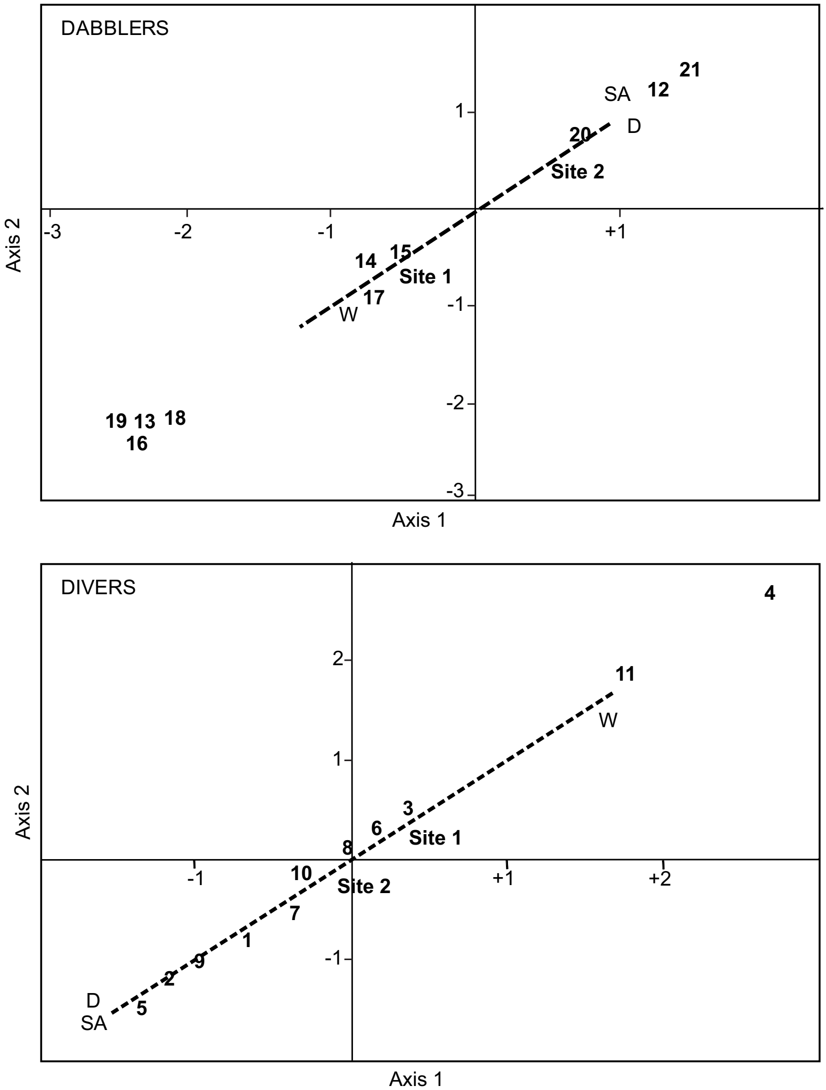
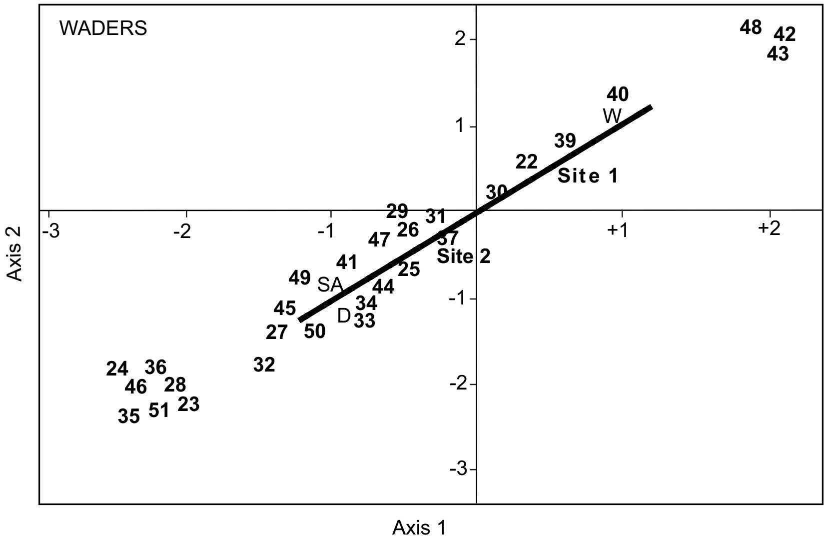


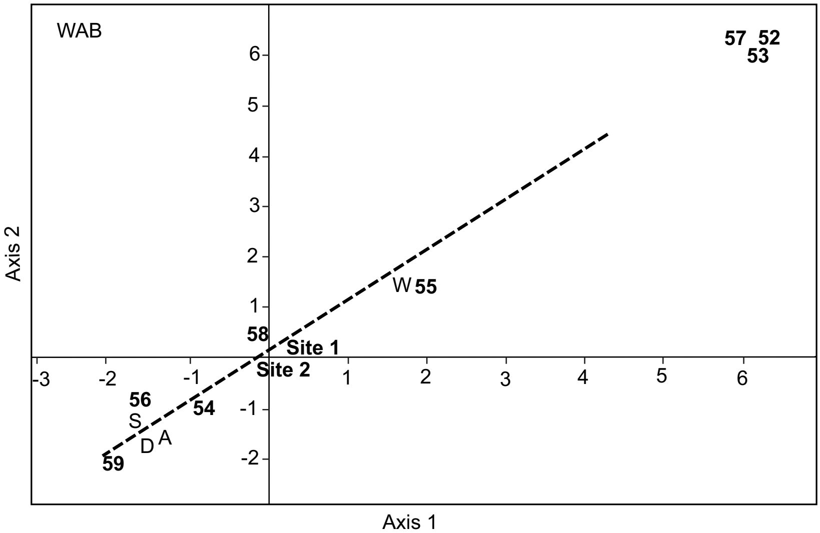
Fig. 3. CCA plots indicating the effect of physical habitat attributes on the community structure of waterbirds. Physical habitat attributes: **A** – Area of the wetland, **D** – Depth, **S** – Shore length, **W** – Water level fluctuation.

DIVERS: 1. Red-crested Pochard, 2. Ferruginous Duck, 3. Common Pochard, 4. Tufted Duck, 5. Great-crested Grebe, 6. Little Grebe, 7. Oriental Darter, 8. Little Cormorant, 9. Great Cormorant, 10. Indian Cormorant, 11. Eurasian Coot;

DABBLERS: 12. Lesser Whistling-duck, 13. Fulvous Whistling-duck, 14. Cotton Pygmy-goose, 15. Gadwall, 16. Indian Spot-billed Duck, 17. Northern Shoveller, 18. Northern Pintail, 19. Garganey, 20. Common Teal; 21. Bar-headed Goose;

WADERS: 22. Asian Openbill, 23. Asian Woolly-necked Stork, 24. Glossy Ibis, 25. Lesser Adjutant, 26. Black-headed Ibis, 27. Red-naped Ibis, 28. Cinnamon Bittern, 29. Black Bittern, 30. Indian Pond Heron, 31. Grey Heron, 32. Purple Heron, 33. Little Egret, 34. Cattle Egret, 35. Great Egret,





36. Intermediate Egret, 37. White-breasted Waterhen, 38. Grey-headed Swamphen, 39. Common Moorhen, 40. Pheasant-tailed Jacana, 41. Bronze-winged Jacana, 42. Grey-headed Lapwing, 43. Yellow-wattled Lapwing, 44. Little-ringed Plover, 45. Greater Painted Snipe, 46. Common Redshank, 47. Common Sandpiper, 48. Wood Sandpiper, 49. White Wagtail, 50. White-browed Wagtail, 51. Grey Wagtail;

WETLAND-ASSOCIATED BIRDS (WAB): 52. Eurasian Marsh Harrier, 53. Brown-headed Gull, 54. Stork-billed Kingfisher, 55. Little Kingfisher, 56. White-breasted Kingfisher, 57. Pied Kingfisher, 58. Barn Swallow, 59. Wire-tailed Swallow.

Both the study sites harboured one vulnerable waterbird species, Common Pochard. Site 1 harboured three Near Threatened species, and Site 2 harboured four Near Threatened species. BirdLife International (2024) projected that the global abundance of Common Pochard *Aythya ferina* will decrease by 31% in the coming 17 years. However, both study sites harboured a steady wintering population of this species throughout the study period, indicating the study sites' importance.

Chapman (1996) reported that latitude, elevation of the area, time of the day, cloud cover, and wetland depth have profound effects on the regulation of surface water temperature. Both the study sites were located in the same physiographic region; thus, the subsurface water temperatures were comparable. During the entire study tenure, *pH* values were weakly alkaline. Water *pH* in the weakly alkaline range abetted the flourishing of aquatic macrophytes and higher nekton and benthos communities, thereby increasing the waterbirds' foraging resources (Longcore *et al.* 2006). This might have helped both these age-old wintering grounds to harbour abundant waterbirds. A study by Mukherjee *et al.* (2021) also recorded a high number of waterbirds from these sites. *EC* was significantly higher in Site 2, and Pal *et al.* (2015) recommended that this parameter could effectively monitor water quality. Site 2 was located near the wide-spreading agricultural fields and received regular runoff from these fields (Mukherjee *et al.* 2021). Agricultural runoff might have increased the chloride, phosphate, and nitrate ions, which were crucial in increasing the *EC* level at this site. However, the *DO* level was higher in Site 1. Lower level *DO* specified the higher levels of organic pollution in a water body and runoff from agricultural fields, and the deposition of domestic sewage might be the causing agents behind the low *DO* levels in Site 2. Kumar and Reddy (2008) similarly stated that the release of public wastes deteriorated the *DO* level in a municipal waterway.

To evaluate the water pollution level in wetlands, *WQI* and *OS%* were calculated, as both these parameters were excellent indicators of water quality. *OS%* in Site 1 and Site 2 were consecutively 64.5 and 20.5. Primarily, a direct proportional relationship existed between the organic matter load of water and OS% (Shekha and Al-Abaychi 2010). Moreover, the variation of *OS %* appeared to be directly proportional to the *WQI*. *WQI* values for Site 1 and Site 2 were 73.8% and 47.5%, respectively. According to CCME (2001), the water quality of Site 1 was fair (Grade C), and the water quality of Site 2 was moderately poor (Grade D). Anthropogenic pressure was more pronounced in Site 2, primarily due to its location adjacent to human settlements. This contributes to the degraded habitat quality in Site 2. However, it was interesting to note that despite moderately poor water quality, Site 2 provided shelters to various waterbirds. However, the number of birds decreased throughout the investigation tenure, and the lowest abundance was recorded in 2023-2024.

The wetlands showed contrasting features like area, shore length, depth, and water level fluctuation. According to Almeida *et al.* (2018), these physical habitat factors played a deterministic role in shaping the species composition in a wetland. Studies by Froneman *et al.* (2001) and Sanchez-Zapata *et al.* (2005) showed higher waterbird species richness and abundance in wetlands with large areas. Figure 3 represents the association of four categories of waterbirds with the physical habitat attributes of the study sites. And the present study corroborated this result. According to Borcard *et al.* (2011), the absolute value of correlation (*p*) could lie in the modest range from 0.36 to 0.67 in *CCA* analysis. Modest correlations are an expected and acceptable outcome in *CCA* because they align with the complexities and multifactorial influences typical in ecological data. These modest associations still provide valuable insights into species-environment relationships (Borcard *et al.* 2011). Site 2, with a larger area (nearly 2.4 times) than Site 1, harboured a significantly higher abundance of waterbirds. Moreover, habitat heterogeneity is related to the size of a wetland (Paracuellos 2006, Dauda *et al.* 2017). Site 2, being more habitat-heterogeneous, could support more waterbirds.

Previous studies by Elphick and Oring (1998), Colwell and Taft (2000), and Isola *et al.* (2002) have shown that depth is an important variable that determines the species composition of a specific wetland. Water depth directly regulates the effective foraging microhabitats of waterbird species. According to Stapanian (2003), wetlands with greater depths can support a comparatively higher number of divers. In this study, the water depth of Site 2 was higher than that of Site 1. For this reason, a higher abundance of divers like Red-crested Pochard *Netta rufina*, Common Pochard, Ferruginous Duck *Aythya ferina*, Little Grebe *Tachybaptus ruficollis*, Great-crested Grebe *Podiceps cristatus*, Little Cormorant *Phalacrocorax niger*, Indian Cormorant *Phalacrocorax fuscicollis,* and Great Cormorant *Phalacrocorax carbo* were recorded from Site 2 (Table 2). However, the abundance of Tufted Duck *Aythya fuligula*, another diver, was marginally higher in Site 1.

The abundance of dabbling waterbirds, like Cotton Pygmy-goose, Northern Pintail *Anas acuta*, Northern Shoveler *Anas clypeata*, and Gadwall *Mareca strepera*, was higher in shallow Site 1. Two other dabblers, Garganey *Anas querquedula* and Indian Spot-billed Duck *Anas poecilorhyncha*, were only recorded from Site 1. Dabblers mostly used beak-dip, head-dip, neck-dip, filtering, and upending techniques for foraging.A less deep Site 1 might have given them a more significant opportunity to forage using these techniques. These findings corroborated the findings of Taft *et al.* (2002) and Elphick and Oring (2003). However, another dabbler, the Bar-headed Goose *Anser indicus,* was exclusively recorded from Site 2, which is more of an exception.

A more extensive habitable shoreline could also augment the habitat heterogeneity within a wetland (Gawlik 2002), and a wetland with a longer shoreline could harbour more diversity and density of waders. A higher abundance of waders was also recorded from Site 2. However, waders of the *Charadriidae* family (Grey-headed Lapwing *Vanellus cinereus* and Yellow-wattled Lapwing *Vanellus malabaricus*) were only recorded from Site 1. In the case of Site 1, water level fluctuation was prominent, which could be mainly caused by the disbursement of water for irrigation. After mid-January water level significantly decreased in Site 1. Mukherjee *et al.* (2020) recorded a significant decrease in the abundance of Red-crested Pochard *Netta rufina* in low-water conditions from this wetland.

That study also recorded a change in foraging techniques employed by this species in altered habitat conditions. However, a higher number of waders like Asian Openbill *Anastomus oscitans*, Lesser Adjutant, Red-naped Ibis *Pseudibis papillosa*, and Black-headed Ibis *Threskiornis melanocephalus* were recorded during low water-level situations. Ntiamoa-Baidu *et al.* (1998) and Gordon *et al.* (1998) also reported more waders in wetlands with water-level fluctuations, especially in low water-level conditions. Furthermore, wetland-associated birds were not significantly related to the physical habitat attributes. Thus, wetland-associated birds showed comparable abundance in both wetlands. The *CCA* plot constructed on the species-wise abundance of four different categories of waterbirds about the area, depth, shore length, and water-level fluctuation in both the study sites also highlighted the quality of the physical habitat in structuring the waterbird communities.

CONCLUSIONS

Waterbird species exhibit diverse and often contrasting habitat requirements to thrive, making habitat heterogeneity essential for survival. Variations in physical habitat conditions across wetlands within a specific geographical region significantly influence waterbird community structures. Additionally, water quality is a critical factor in maintaining healthy waterbird populations. For instance, in Site 2, low *DO* levels and poor *WQI* have led to a gradual decline in waterbird abundance over the study period. Effective waterbird management necessitates a comprehensive knowledge of wetland physical habitat characteristics, physicochemical properties, and region-specific patterns of waterbird community assemblages. However, current wetland management practices often focus on limited physical habitat features, potentially overlooking key ecological drivers. Future research exploring the implications of habitat heterogeneity and water quality on regional waterbird communities is crucial for sustainable management. It is important to note that different waterbird species may respond differently to specific management interventions. Optimal wetland management for multi-species conservation should involve thorough assessments of foraging resource availability and a balanced approach to addressing the needs of diverse waterbird groups, including divers, dabblers, waders, and wetland-associated birds. Such integrative management strategies will ensure the conservation of waterbird biodiversity while maintaining the ecological integrity of wetlands.

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