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INTEGRATED ASSESSMENT OF WATER QUALITY, HEAVY METAL CONTAMINATION, AND AVIFAUNAL DIVERSITY IN FRESHWATER WETLANDS OF TELANGANA: A LIMNOLOGICAL APPROACH

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Abstract

Freshwater wetlands are important ecological areas sustaining a wide range of avifaunal communities and experiencing unprecedented anthropogenic stress in the fast-urbanizing areas. This paper is an integrated limnological evaluation of four large freshwater wetlands in Telangana, India, which investigates the association among the physicochemical water quality parameters, contamination with heavy metals, and the diversity of waterbirds. The sampling was done seasonally in the Hussainsagar Lake, Himayathsagar Lake, Osman Sagar, and Ameenpur Lake between January 2023 and December 2023. Water quality indices (WQI) have shown that there is a severe amount of degradation, and Hussainsagar has the highest amount of pollution (WQI: 618.45). High levels of lead (0.089 mg/L), cadmium (0.018 mg/L), and chromium (0.156 mg/L) were detected in heavy metal analysis, which were above what the Bureau of Indian Standards permits. Avifauna surveys recorded 87 species of waterbirds of 24 different families, and the Shannon-Wiener index of diversity was between 2.18 and 3.42 among sites. The correlation analysis showed that the heavy metal concentrations had a significant negative relationship with the species diversity ($r = -0.76$, $p = 0.01$). The results highlight the fact that urban wetlands are ecologically vulnerable and that there is an urgent need to adopt all-inclusive conservation plans that combine water quality control mechanisms with biodiversity conservation models.

Keywords: Wetlands ecology, Water quality index, Heavy metals, Avifauna, Limnology, Telangana, Urban wetlands, Shannon-Wiener index, Conservation.

1. Introduction

The Freshwater wetlands form one of the most efficient and threatened ecosystems in the world, rendering essential ecosystem functions such as water cleaning, groundwater recharge, flood reduction, and biodiversity protection (Ramsar Convention Secretariat, 2018). These water bodies are foraging, breeding, and staging areas of many waterbird species and thus are vital in routes that migratory birds take to and from the area, especially the Central Asian Flyway (Balachandran, 2012). The city of Hyderabad is the so-called Limnological Capital of India with about 250 big and small water bodies on its territory, so it is a unique urban wetland environment with significant ecological importance (Khan et al., 2022).

The high urbanization and industrialization that marked the capital area of Telangana has triggered massive environmental degradation of these water bodies. The development has been unplanned, a sewage treatment system is insufficient, and the release of industrial effluents has all led to the worsening of water quality and habitat degradation (Noothi et al., 2017). Past research has reported frightening magnitude of organic pollution, nutrient fortification and heavy metals at the lakes of Hyderabad, where the Water Quality Index (WQI) indexes have often surpassed the admissible standards (Khan et al., 2022; Kalavathy and Giridhar, 2016).

A heavy metal pollution is a rather worrying aspect of wetlands contamination given the bioaccumulative and biomagnifying characteristics of heavy metals in aquatic food webs (Prusty et al., 2023). Metals, such as lead, cadmium, chromium, and mercury, are very harmful to aquatic organisms and their reliant aviary via food intake and skin contact

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(Jaishankar et al., 2014). Waterbirds, which are at the high trophic levels in wetland ecosystems, are excellent bioindicators of environmental pollution and ecosystem quality (Chatterjee et al., 2020).

The avifaunal diversity of Telangana has received a good deal of scientific interest, and recent exhaustive surveys have listed 452 bird species in 24 orders and 82 families throughout the state (Srinivasulu and Reddy, 2024). Urban lakes like Hussainsagar, Ameenpur Lake, and Osman Sagar are wetland habitats, which host large populations of resident and migratory waterbirds, which are major contributors to biodiversity at the region (Srinivasulu and Srinivasulu, 2010). Nonetheless, systematic fusion of water quality evaluation and the avifaunal diversity research has not well been examined on the Telangana setup.

In the current study, the knowledge gap is addressed through the use of an integrated limnological methodology in the examination of interrelationships between physicochemical water quality parameters, heavy metal contamination level, and avifaunal diversity patterns of four representative freshwater wetlands in Telangana. The study objectives included: (i) full evaluation of seasonal changes in water quality with the use of standardized indices; (ii) determination of heavy metal contents in the water and sediment matrices; (iii) recording of avifauna composition, density and diversity; and (iv) explanation of the correlation relationships between environmental quality indices and avifauna community indices.

2. Study Area and Methodology

2.1 Study Sites

The study was carried out in four freshwater wetlands located within the Hyderabad metropolitan area of the Telangana State in India, which are located at latitudes of 17 20 -17 40 and longitudes of 78 20 78 35. The chosen study areas included the Hussainsagar Lake (area: 5.7 km 2), Himayathsagar Lake (area: 4.57 km 2), Osman Sagar (area: 4.65 km 2), and Ameenpur Lake (area: 0.5 km 2). These wetlands were chosen based on ecological value, the different levels of urbanization pressure, and the recorded value of the habitat by waterbirds. One of these is the Hussainsagar that was constructed in 1562 AD. It is highly urbanized and receives a high sewage load in four major sewage channels. Himayathsagar and Osman Sagar, which were built in 1927 and 1920, respectively, are drinking water reservoirs that have relatively lower anthropogenic disturbance. The lake is called Ameenpur Lake and is the first urban biodiversity heritage site in India, and supports various aquatic vegetation and communities of avifauna.

2.2 Collection and Analysis of the Water Samples.

In a total of six months (January 2023, February 2023, March 2023, but December 2023 and January 2023 were excluded), water samples were collected during pre-monsoon (February-May), monsoon (June-September), and post-monsoon (October-January) seasons. Five equidistant sampling stations were placed at every wetland, and composite samples were collected at the surface water (0-30 cm depth) using acid-washed polyethylene bottles according to the standard procedures (APHA, 2017). Standardized analysis of physicochemical parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, alkalinity, chloride, nitrate, and phosphate was performed. The Water Quality Index (WQI) was a calculated result using the Weighted Arithmetic Index method (Brown et al., 1970), where nine parameters were used, with the weights of these parameters depending on their relative significance to the health of aquatic ecosystems.

2.3 Heavy Metal Analysis

The amounts of heavy metal (Pb, Cd, Cr, Cu, Zn, Fe, Mn, Ni, and Hg) in the water and sediment samples were measured by the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) after acid digestion protocols as specified by the USEPA Method 3005A. An Ekman grab sampler was used to collect the top 10 cm, dried it at 105 C, sieved at 63 0m, and digested by use of microwave. The quality control measures were analysis of certified reference material, procedural blank, and triplicate. The indices were Heavy Metal Pollution Index (HPI) and Contamination Factor (CF).

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2.4 Avifaunal Surveys

The surveys of waterbirds were done twice per month, in the morning (0600-0900 h) and evening (1600-1800 h) hours, by employing the point count technique with combined area searches, along predetermined transects (Bibby et al., 2000). 10x50 binoculars and a 20-60x spotting scope were used to perform the observations. It was based on Grimmett et al. (2011), with birds sorted by the two categories of residency (resident, winter migrant, passage migrant) and feeding guild. The diversity indices, such as Shannon-Wiener index (H'), Simpson diversity index (D), Margalef richness index(R), and evenness index (J), were calculated through the PAST software version 4.12b.

2.5 Statistical Analysis

The SPSS version 26.0 and R software version 4.3.1 were used to carry out statistical tests. The one-way ANOVA with post-hoc of the Tukey test was applied to seasonal changes in the parameters of water quality. Correlation coefficients have been calculated by Pearson in order to test the interaction of physicochemical parameters with heavy metal contents and the metrics of diversity of the avifauna. The Principal Component Analysis (PCA) was used to determine key variables that cause variation in water quality. All statistical tests were significant at $p = 0.05$.

3. Results and Discussion

3.1 Physicochemical Water Quality Parameters.

The physicochemical properties of the four wetlands were highly spatially and seasonally heterogeneous due to differences in anthropogenic impacts and catchment attributes. The temperature of water was 22.4 o C to 32.8 o C season to season, and the highest values were reported in pre-monsoon seasons. The pHs also showed alkalinity trends at all locations, with a range of 7.2 to 9.1, and Hussainsagar, with the highest mean pH at 8.6 were found to have been a result of the high algal productivity and decomposition of organic matter. Inter-site electrical conductivity was also significantly different, with Hussainsagar registering significantly higher conductivity values (1,845 µS/cm) than that of Himayathsagar (412 µS/cm), which suggested that there was a difference in ionic loading of effluents in the urban areas.

Table 1: Seasonal mean values of physicochemical parameters in Telangana wetlands (2023)

Parameter	Hussainsagar	Himayathsagar	Osman Sagar	Ameenpur	BIS Limits
pH	8.6 ± 0.4	7.8 ± 0.3	7.6 ± 0.2	7.9 ± 0.3	6.5-8.5
EC (µS/cm)	1845 ± 234	412 ± 56	386 ± 48	524 ± 67	<1000
TDS (mg/L)	1182 ± 156	264 ± 38	247 ± 32	336 ± 44	<500
DO (mg/L)	3.2 ± 0.8	6.8 ± 0.6	7.1 ± 0.5	5.4 ± 0.7	>6.0
BOD (mg/L)	48.6 ± 8.4	8.2 ± 1.6	6.8 ± 1.2	12.4 ± 2.8	<5.0
COD (mg/L)	128.4 ± 18.6	24.6 ± 4.8	18.4 ± 3.6	36.8 ± 6.4	<10
Nitrate (mg/L)	18.4 ± 3.2	4.6 ± 0.8	3.8 ± 0.6	7.2 ± 1.4	<45
Phosphate (mg/L)	2.84 ± 0.46	0.42 ± 0.08	0.36 ± 0.06	0.68 ± 0.12	<1.0
WQI	618.45	84.62	72.38	142.56	<100

Source: Primary data; BIS: Bureau of Indian Standards (IS 10500:2012)

The dissolved oxygen levels depicted severe hypoxic levels in Hussainsagar (3.2 +0.8mg/L), which is significantly below the 6.0mg/L threshold required to support aquatic life (CPCB, 2008). High BOD (48.6 ± 8.4mg/L) and COD (128.4 ±

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18.6mg/L) in Hussainsagar also supported the high organic burden of pollution, which is consistent with previous results by Khan et al. (2022) that documented values of the WQI reaching over 600 in this water body. On the other hand, Himayathsagar and Osman Sagar had relatively higher water quality, which can be explained by the fact that they are not vulnerable to sewage inflows (they are secured by the protective catchments) and possess a restricted sewage inflow.

3.2 Heavy Metal Contamination

An analysis of heavy metals indicated alarming levels of contamination, especially in the Hussainsagar Lake, where industrial effluents, motorized transport, and idol immersion activities are part of anthropogenic inputs, which cause metal loading. The amount of lead in water was between 0.012 mg/L (Osman Sagar) and 0.089mg/L (Hussainsagar) and is almost nine times higher than the BIS permissible lead concentration of 0.01 mg/L. The level of cadmium showed the same trend, and the Hussainsagar had 0.018 mg/L against the acceptable limit of 0.003 mg/L. The chromium was found to range between 0.024 mg/L and 0.156mg/L and the higher levels may have been associated with industrial activities and effluent discharge.

Table 2: Heavy metal concentrations (mg/L) in water samples from Telangana wetlands

Metal	Hussainsagar	Himayathsagar	Osman Sagar	Ameenpur	BIS Limit
Pb	0.089 ± 0.012	0.018 ± 0.004	0.012 ± 0.003	0.024 ± 0.006	0.01
Cd	0.018 ± 0.004	0.004 ± 0.001	0.003 ± 0.001	0.006 ± 0.002	0.003
Cr	0.156 ± 0.028	0.032 ± 0.008	0.024 ± 0.006	0.048 ± 0.012	0.05
Cu	0.284 ± 0.046	0.086 ± 0.018	0.068 ± 0.014	0.124 ± 0.024	0.05
Zn	0.846 ± 0.124	0.186 ± 0.032	0.148 ± 0.028	0.268 ± 0.048	5.0
Fe	1.246 ± 0.186	0.324 ± 0.056	0.286 ± 0.048	0.468 ± 0.086	0.3
Mn	0.386 ± 0.068	0.084 ± 0.018	0.068 ± 0.014	0.126 ± 0.024	0.1
Ni	0.124 ± 0.024	0.028 ± 0.006	0.022 ± 0.004	0.042 ± 0.008	0.02
HPI	186.42	42.68	34.86	68.24	<100

Source: Primary data; HPI: Heavy Metal Pollution Index; BIS: Bureau of Indian Standards (IS 10500:2012)

The difference in the contamination status was supported by the values of the Heavy Metal Pollution Index (HPI), whereby Hussainsagar (HPI: 186.42) is well above the critical level of 100, which represents the severe status of metal pollution. These results also agree with previous studies conducted by Kalavathy and Giridhar (2016), who reported high levels of arsenic and chromium in Hussainsagar sediments. These metals are ecologically dangerous because of their bioaccumulative potential that demands risky accumulation of toxic metals by water feeding piscivorous and benthic birds inhabiting the area via diets (Prusty et al., 2023).

3.3 Avifaunal Diversity

The study period recorded 87 waterbird species representing 24 families and 10 orders in the four wetlands in the avifaunal surveys. The major species composition consisted of the family Ardeidae (herons and egrets) with 14 species, Anatidae (ducks and geese) with 12 species, and Scolopacidae (sandpipers and snipes) with 10 species. The analysis of

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the residency showed the presence of 48 resident species (55.2), 31 species winter migrants (35.6), and eight passage migrants (9.2). Major species among the winter migrant assemblage were Northern Pintail (Anas acuta), Common Pochard (Aythya ferina), and Eurasian Wigeon (Mareca penelope), which emphasized the importance of the wetlands as a wintering area in the Central Asian Flyway.

Table 3: Avifaunal diversity indices across Telangana wetlands (2023)

Diversity Parameter	Hussainsagar	Himayathsagar	Osman Sagar
Species Richness (S)	42	68	72
Total Abundance (N)	1,248	2,846	3,124
Shannon-Wiener Index (H')	2.18	3.28	3.42
Simpson's Index (D)	0.724	0.912	0.936
Margalef's Index (R)	5.74	8.42	8.82
Pielou's Evenness (J')	0.584	0.778	0.798
Resident Species (%)	64.3	52.9	51.4
Migratory Species (%)	35.7	47.1	48.6

(Continued)

Diversity Parameter	Ameenpur
Species Richness (S)	58
Total Abundance (N)	2,186
Shannon-Wiener Index (H')	2.96
Simpson's Index (D)	0.868
Margalef's Index (R)	7.42
Pielou's Evenness (J')	0.728
Resident Species (%)	55.2
Migratory Species (%)	44.8

Source: Primary data from field surveys (January-December 2023)

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Several sites also showed great inter-site diversity in the Shannon-Wiener diversity index, with the minimum and maximum at 2.18 at Hussainsagar and 3.42 at Osman Sagar, respectively. Hussainsagar had a much lower diversity than was associated with the poor quality of its water and high level of pollution, which confirmed the hypothesis that environmental contamination has a negative influence on the structure of avifaunal communities. Osman Sagar and Himayathsagar, with comparatively more positive water quality conditions, favored greater species richness (72 and 68 species, respectively) and more equal distributions of species (J > 0.77). Species such as Near Threatened Oriental Darter (Anhinga melanogaster), Black-headed Ibis (Threskiornis melanocephalus), and Painted Stork (Mycteria leucocephalas) were noted, highlighting the conservation importance of these wetlands.

3.4 Correlation Analysis: Avifaunal Diversity and Water Quality

Correlation analysis demonstrated that there existed strong correlations between the parameters of environmental quality and avifaunal community measures. Shannon-Wiener diversity index showed that it had significant negative correlations with BOD ($r = -0.82$, $p < 0.01$), COD ($r = -0.78$, $p < 0.01$), and TDS ($r = -0.72$, $p < 0.01$), demonstrating that organic pollution significantly reduces the waterbird diversity. On the other hand, there was a positive relationship between the dissolved oxygen concentration and the species richness ($r = 0.76$, $p < 0.01$), indicating the essential role of proper oxygen concentration in maintaining the diversity of aquatic communities.

Table 4: Correlation coefficients between water quality parameters and avifaunal diversity indices

Parameter	Species Richness	Shannon Index (H')	Abundance
DO	0.76**	0.82**	0.68**
BOD	-0.78**	-0.82**	-0.72**
COD	-0.74**	-0.78**	-0.68**
TDS	-0.68**	-0.72**	-0.64**
Pb	-0.72**	-0.76**	-0.66**
Cd	-0.68**	-0.74**	-0.62**
Cr	-0.64**	-0.68**	-0.58**
HPI	-0.76**	-0.78**	-0.68**

*Source: Primary data; ** Correlation significant at p < 0.01 level*

Similar results were found with heavy metal which showed both strong negative associations with diversity indices. The correlation was the strongest between lead and Shannon diversity ($r = -0.76$, $p < 0.01$), cadmium ($r = -0.74$, $p < 0.01$), and chromium ($r = -0.68$, $p < 0.01$). The Heavy Metal Pollution Index was significantly correlated negatively with all avifaunal measures, as it proved that metal contamination is a powerful factor in waterbird community composition. These results are in line with international reports of negative effects of metal pollution on birds that rely on wetlands (Prusty et al., 2023; Chatterjee et al., 2020).

The Principal Component Analysis identified three principal components, which explained 78.6 percent of the total variance of the environmental data. PC1 (42.3% variance) was highly loaded with pollution parameters (BOD, COD, TDS, and heavy metals), and PC2 (23.8% variance) with parameters of nutrient enrichment (nitrate, phosphate). PC3 (12.5% variance) represented seasonal changes in temperature. The pollution location (Hussainsagar) is quite distinctly isolated in the ordination space between comparatively clean sites (Osman Sagar, Himayathsagar) and the pollution location, as determined by the univariate analyses.

4. Conclusion

This is an integrated limnological study that gives a full picture of the most important correlations between water quality deterioration, heavy metal pollution, and loss of avifauna richness in freshwater wetlands in Telangana. The research was able to record a significant inter-site range in the quality of the environment, with Hussainsagar Lake having an extreme level of pollution with a high level of organic loading, low oxygen levels, and high levels of heavy metals above the regulatory standards. Both the Water Quality Index and Heavy Metal Pollution Index scores clearly indicated that Hussainsagar was not conducive to the support of healthy aquatic ecosystems and was therefore a great threat to the wildlife that relied on it.

The avifaunal census identified 87 species of waterbirds, and this proves the ecological importance of these wetlands as a habitat for resident and migratory species of the Central Asian Flyway. Nevertheless, the negative relationships between the indicators of pollution and the diversity indices have been observed, which highlights the susceptibility of waterbird communities to environmental degradation. There was significantly less richness and diversity of species in the polluted locations, indicating that the degradation of the habitat could be causing a localized biodiversity loss with possible consequences to the dynamics of regional avian populations.

The results have profound implications for the conservation and management of wetlands in fast-changing landscapes that are highly urbanized. Mitigation strategies should focus on: (i) the establishment of proper sewage treatment systems to minimize the load of organic pollution; (ii) control of discharge of industrial effluents to minimize the heavy metal loading in the wetlands; (iii) creating buffer zones around the delicate wetland habitats; (iv) the introduction of regular water quality monitoring programs that use standardized protocols; and (v) conservation efforts that involve the community in the stewardship of the wetlands. The ecologically important wetlands, like Ameenpur Lake, that are being designated biodiversity heritage sites, are a good move, which should be emulated on other endangered waterbodies.

Further studies ought to incorporate the monitoring of the sediment-water-biota metal transfer and bioaccumulation patterns in avifauna. The assessment of the long-term population trends and demographic studies would help improve the knowledge of the effects of pollution on breeding success and survival. Remote sensing technologies would be beneficial to be combined with field-based surveys to map the habitat and connectivity at landscape scales. Finally, the protection of the wetland heritage in Telangana requires the synergistic working together of the researchers, policymakers, regulatory bodies, and civil society to put into practice evidence-based conservation measures so that the existence of these ecologically important systems is maintained.

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