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Avian Community Dynamics in Tonk District, Rajasthan: Insights from Diversity Indices and Water Quality Parameters

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ABSTRACT:
Water ecosystems form a very important habitat to various bird populations as important bio-indicators of the environment in terms of health. The study aims at examining the relationship between physicochemical water parameters and bird diversities in eight discrete water sites in Tonk region of Rajasthan, India. The main aim of study was to determine that there is a significant impact of water quality on avian biodiversity using stringent indicators of diversity and multivariate statistics. The data on avian diversity was structured and grouped into the species. Diversity was measured in the form of Shannon Diversity Index, Simpson Diversity Index, as well as Relative Diversity Index. At the same time, such physicochemical characteristics of water as pH, dissolved oxygen (DO), salinity, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chloride were measured. Multiple regression and correlation analysis were applied to the statistical data to test the predictive and associative relationships among the quality of water and avian diversity and significance was set at $p = 0.05$. Among all the three indices of diversity, significant relationships with indicators of water quality were observed. The results of multiple regression analysis revealed strong predictive relationship with the R squared value (Shannon = 0.837, Simpson = 0.792, Relative = 0.685) and found statistically significant p-values (< 0.05). There existed an explicit positive relationship between bird diversity on the pH and dissolved oxygen and there was an inverse relationship on the salinity, total dissolved solids (TDS), biochemical oxygen demand (BOD) and chloride. In the sampled sites, the locations of the highest diversity of avian species were Deoli (Bisalpur) (Shannon Index: 3.42, 60 species), and the lowest avian diversity could be found in Dooni (Moti Sagar) (Simpson Index: 0.83, 16 species). Values of the Relative Diversity Index (0.84 and 0.93) indicated similar patterns in distribution of species across sites even though the species richness varied. Such results highlight the fact that water quality parameters like pH, dissolved oxygen as well as concentration of pollutants like TDS and BOD affect the avian diversity in Tonk region in a significant manner and hence water quality-based management is a crucial component of bird conservation.

Keywords: Avian Diversity, Aquatic Ecosystems, Water Quality Parameters, Shannon Diversity Index, Simpson Index, Relative Diversity Index, Tonk District, Rajasthan.

1. INTRODUCTION

The Indian state of Rajasthan, characterized by its vast geographical area and a significant portion encompassing arid and semi-arid desert environments, hosts a unique array of biological organisms. The delicate balance of native flora and fauna in this region plays a crucial role in sustaining local communities. However, the escalating human population and its associated developmental pressures pose a considerable threat to the ecological integrity and species uniqueness, raising significant environmental concerns [1]. Globally, birds are indispensable components of biodiversity, inhabiting diverse natural environments and serving as essential biological indicators of ecosystem health [20, 9]. Their presence, abundance, and diversity provide valuable insights into the ecological status of specific regions and broader landscapes, making knowledge of avian populations critical for strategic conservation planning and management [19]. India, recognized as one of the 17 mega diverse countries, holds the ninth position globally in terms of its avian species abundance, a richness attributed to its distinctive geographic and climatic diversity [24].

Birds exhibit remarkable adaptability, allowing them to thrive in varied habitats, from natural landscapes to increasingly urbanized areas. Freshwater wetlands across India are particularly vital ecosystems, supporting a significant proportion of the nation's avian species, yet these productive aquatic habitats face severe threats and require urgent preservation efforts. Birds contribute to ecological stability through various ecosystem services, including insect population management, plant pollination, and scavenging [27,13]. Wetlands bordering terrestrial areas serve as crucial stopover and resting sites for migratory birds during their extensive journeys, highlighting their indispensable role in global avian conservation. Nevertheless, environmental quality is rapidly deteriorating due to excessive natural resource utilization, urban sprawl, and pollution, leading to widespread habitat destruction and imperiling both plant and animal diversity [16].

The Tonk district in Rajasthan is an ecologically significant area, characterized by diverse habitats ranging from agricultural lands and scrublands to grasslands and wetlands, which are primarily fed by the Banas River system [14].

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The district's varied geography, encompassing plains, hilly regions, and river valleys, creates a mosaic of ecological settings supporting both resident and migratory avian species. However, similar to other regions, Tonk faces considerable anthropogenic pressures. Intensive agricultural practices, marked by monoculture, mechanization, and chemical inputs, have transformed heterogeneous landscapes into more uniform environments, reducing habitat complexity and threatening farmland birds [22, 8]. River damming, diversions, and groundwater overexploitation for irrigation have altered natural water ecosystems, impacting wetland habitats and their indigenous bird fauna [12]. The expansion of human settlements introduces edge effects, favoring generalist bird species over specialists [17]. Furthermore, climate change poses an emerging threat, with anticipated increases in extreme weather events, altered precipitation patterns, and recurrent droughts impacting bird resource use and breeding habits [23, 18].
Given these challenges, robust avifaunal monitoring is crucial. Bird population censuses provide vital information on ecosystem well-being and natural environmental fluctuations [9]. Birds' rapid response to environmental changes makes them superior indicators for early detection of environmental degradation compared to other biodiversity components [15]. Long-term research on bird populations can reveal large-scale biological processes, such as climate change impacts, aiding in identifying conservation priority species and their management needs before populations decline irreversibly [4]. While extensive avian studies have been conducted in some parts of Rajasthan, the Tonk District remains largely understudied regarding species distribution, habitat linkages, and conservation status [14, 21]. This study aims to fill these critical knowledge gaps by assessing avian diversity and its correlation with water quality parameters in selected aquatic habitats of Tonk.

2. RESEARCH METHODOLOGY

This investigation was conducted utilizing a systematic scientific methodology, encompassing detailed field surveys and hydro-biological sampling.

2.1 Study Area

The research focused on eight major wetland sites within the Tonk district of Rajasthan, India. These sites were:

1. Thikria
2. Kumhariya
3. Budh Sagar
4. Bisalpur,
5. Chandlai
6. Moti Sagar
7. Galvaniya
8. Tordi Sagar

These wetlands are of significant avian diversity importance, can provide habitats with a lot of variety, which is home to many species, and experience different levels of both anthropogenic pressure and water quality conditions.

2.2 Sampling Field Methods

To cover the field data as thoroughly as possible, two basic survey methods were applied:
• **Line Transect Method:** Here the path taken by the observers on transect was fixed and the avian species recorded by the observer on the path diligently without stopping. This method worked well especially in open and flat surfaces plus wetlands, grassland and agricultural fields, and he was especially well suited to detecting larger, more mobile avian species.
• **Point Count Method:** It involved the identification of certain observation sites within the most preferred geographical areas, usually along the road or at places fixed by the survey team. All the bird species that were sighted or heard were carefully noted in the fixed intervals of 5 and 10 minutes at every location [25]. The technique proved to be useful in scanning denser regimes, forests and shrub land, and especially useful in scanning elusive and secretive avian species.
Timing considerations: There were changes made in the timing so as to optimize the accuracy in mating species; the timing included mostly the peak activity periods of the birds: early morning (5:30 AM to 7:30 AM), and late afternoon (4:00 PM to 6:00 PM). All the avian species were listed including those that were in air. There was detailed observation with the Bushnell 7x50 Binocular and a Nikon COOLPIX P900 digital camera being applied so as to take photos. The identification of species was performed by means of the use of credible field guides, namely, Birds of the Indian Subcontinent by S. Ali and Grimmett et al. [2] (2008), and a mobile application called Merlin Bird ID.

2.3 Some statistical methods of analyzing biodiversity

In order to undertake a quantitative analysis into avian biodiversity, three commonly used indices were used:
1. Shannon-Diversity Index (H'): It was developed by Claude E. Shannon and Norbert Wiener, who referenced the index to assess species diversity and distressed the same by assessing evenness of distribution of species in the same community.

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2. Simpson Diversity Index (D): This index determines the level of dominance in a community and it was defined in 1949 by Edward H. Simpson. It gauges the likelihood of choosing two unrelated beings through a sample whose membership lies in dissimilar species.
3. Relative Diversity Index (RDi): The RDi is a measure of the proportion of all the taxonomic families contributing to the total species diversity. It was estimated following the formula that has been proposed by Torre-Cuadros et al. [26] (2007):

2.4 Parameter Assessment of Water Quality
The process of water quality assessment was characterized by measurements of the full range of physical and chemical indicators, which are of great importance when considering their possible effect on avian habitat. These were Temperature, pH, Salinity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Hardness, Alkalinity, Chloride, Fluoride, Nitrate and Turbidity. All the parameters were determined and assessed according to accepted methodology that meets the standard of APHA [3] (1988). This made the data to be precise and comparable.

2.5 Equipment and materials
The gears employed in the conduct of this study were the Nikon COOLPIX P900 digital camera that has 83x optical zoom capacity to take clear and detailed photographs of the visibly remote avifauna. Bushnell 7x50 binocular were of great help in viewing the birds that could not be seen at a close distance. The mobile application which had a GPS was utilized in monitoring the changes in elevation and provide the coordinates of the sites. Detailed maps of the area of research helped to plan the trip and identify different types of ecosystems. To effectively identify the species, the reference to the authoritative field guide of S. Ali and Grimmett et al. [2] (2008) on Birds of the Indian Subcontinent was widely drawn. The integrated methodology resulted in the elaboration of factual and scientific relevant information on avian diversity in semi-arid wetlands of the Tonk district.

3. Discussion and Results
The survey in the eight major wetlands in the Tonk district (Thikria, Kumhariya, Budhsagar, Bisalpur, Motisagar, Galvaniya, Tordisagar) provided extensive results (data) on the avian diversity and the water quality parameters and it was able to provide the relationship between the two in details.

3.1 indices of Avian Diversity
Shannon-Diversity Index (H'): The Shannon Diversity Index (H') is the system of measure that gives the combined index of the species richness and evenness. The values of H at the 8 locations listed in Table 1 and Figure 1 were minimum at Dooni (Moti Sagar), 2.07 and maximum at Deoli (Bisalpur), 3.42. In this spectrum of biodiversity, there emerges different levels of biodiversity. The greatest H value (3.42) was recorded using Deoli (Bisalpur) which had 60 species and 31 individuals indicating a large pool of species but also indicated a rather equal division of individuals within each of the species. Dooni (Moti Sagar) was on the other hand the least diverse (H' = 2.07) containing only 16 species and 77 individuals, detecting inferior species richness and peculiar dominance of few dominant species. There was also a strong diversity at Todaraisingh (Budh Sagar) and Tonk (Chandlai) and this indicates well preserved avian habitats that can sustain a variety of avian communities (Table 1; Figure 1). The consistency implies well-maintained wetlands habitats and scrub and riparian habitats to host both specialised waterbirds and landbirds.

Table 1: Shannon Diversity Index

Location	Total Species	Total Individuals	Shannon–Wiener Index (H′)
Tonk (Chandlai)	48	604	3.16
Uniara (Kumhariya)	25	134	2.73
Uniara (Galvaniya)	43	211	2.96
Uniara (Thikariya)	40	368	3.09
Malpura (Tordi Sagar)	42	423	2.93
Todaraisingh (Budh Sagar)	51	568	3.31
Dooni (Moti Sagar)	16	77	2.07
Deoli (Bisalpur)	60	331	3.42

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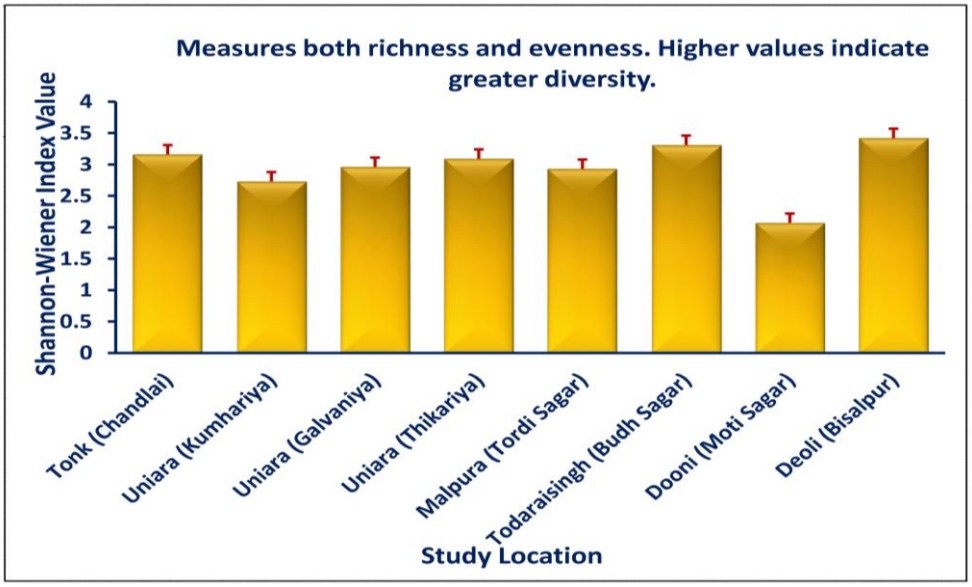

Figure 1: Representation of Shannon Diversity Index (H') across Study Sites.

The X-axis would represent the eight study sites (Chandlai, Kumhariya, Galvaniya, Thikria, Tordi Sagar Budh Sagar, Moti Sagar, Bisalpur). The Y-axis would display the corresponding Shannon-Wiener Diversity Index (H') values. The bars would visually compare the diversity levels, clearly highlighting Deoli (Bisalpur) as the highest and Dooni (Moti Sagar) as the lowest, as described in Table 1. The graph would effectively illustrate the range and distribution of avian diversity across the surveyed wetlands based on the Shannon index.

Simpson's Diversity Index (D): The Simpson's Diversity Index (D), which emphasizes species evenness by giving more weight to common species, revealed important distribution patterns. The Species Distribution Index (SDI), calculated as an adjusted Simpson's Diversity Index, ranged from 0 (species recorded at a single location) to approximately 1 (uniform distribution across all eight locations). The White-throated Kingfisher (*Halcyon smyrnensis*) exhibited the highest SDI of 0.8103, being present in all eight sites with fairly even populations. Similarly, the Black-winged Stilt (*Himantopus himantopus*) had a high SDI of 0.7259, occurring in seven sites with a total of 231 individuals, making it the most abundant species. The Laughing Dove (*Spilopelia senegalensis*) also showed high distribution with an SDI of 0.7903 across seven sites. Conversely, 50 species (36.5% of total) were recorded at a single location (SDI = 0), reflecting habitat specialization or rarity. Only 17 species (12.4%) were observed in five or more locations, indicating that a majority of bird species have relatively restricted ranges within the study area. This suggests a mosaic of wetlands allowing for both widely dispersed adaptive species and localized habitat specialists (Figure -2).

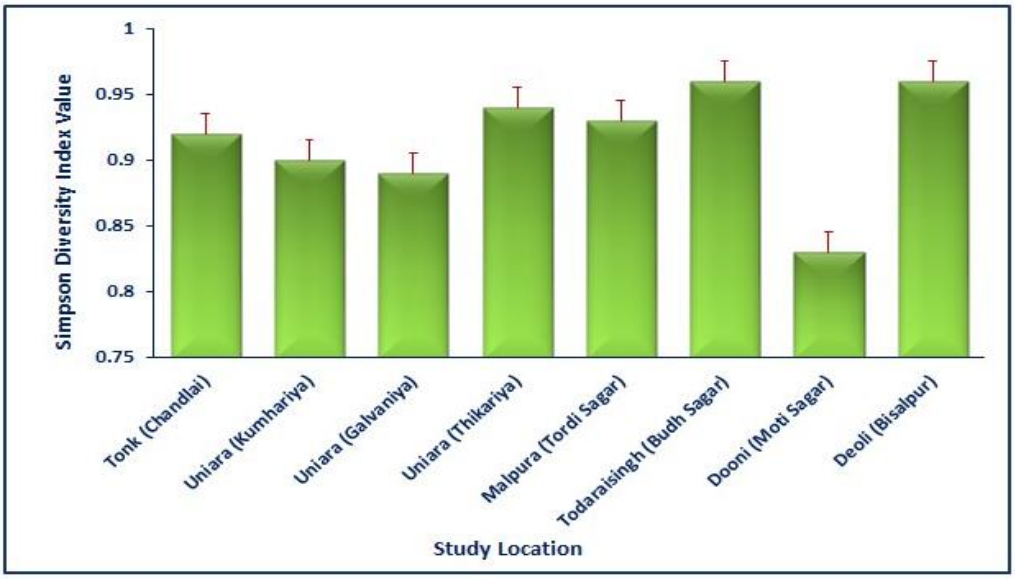

Figure 2: Simpson's Diversity Index (D) Distribution Study

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Simpson Diversity Index (D) values for each of the eight study sites. It might also show the individual species' contributions to the overall index or how dominance varies across sites. The graph would effectively convey the evenness of species distribution, emphasizing sites where a few species are highly dominant versus sites where species are more equitably distributed. It would specifically illustrate the range of SDI values from 0 to ~1, as discussed for White-throated Kingfisher, Black-winged Stilt, and Laughing Dove.

Relative Diversity Index (RDi): The Relative Diversity Index (RDi) provides insights into the proportional contribution of each bird family to the overall species diversity (Figure 3). Accipitridae (hawks, kites, and eagles) and Scolopacidae (sandpipers and allies) each had seven species with an RDi of 5.11, highlighting their significant species richness and even distribution across habitats. Anatidae (ducks, geese, and swans), Columbidae (doves and pigeons), and Muscicapidae (Old World flycatchers) each had six species with an RDi of 4.38, contributing substantially to taxonomic diversity. A majority of families (26 out of 56) comprised a single species (RDi 0.73), indicating highly specialized habitats or limited regional distribution, which is crucial for conservation consideration. This RDi distribution underscores the structural richness of Tonk's wetlands and adjacent landscapes, supporting a variety of species from raptors and waterfowl to passerines and forest understory inhabitants (Figure 3).

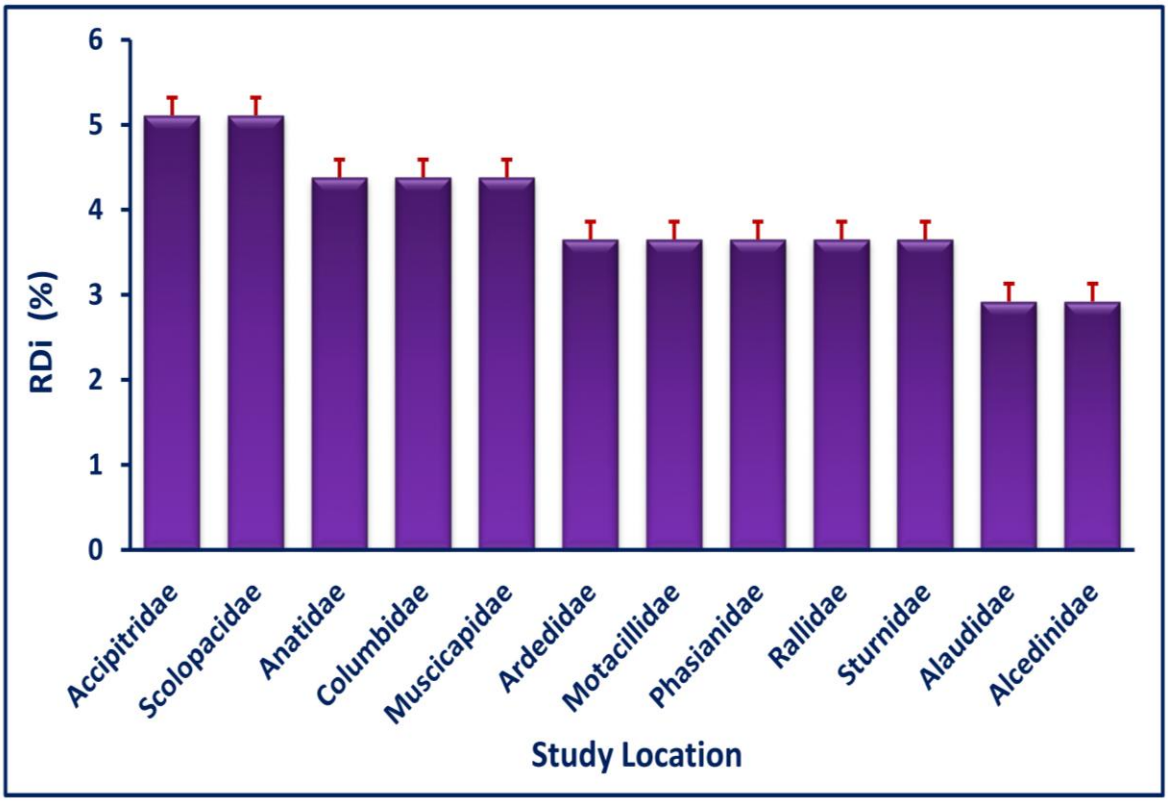

Figure 3: Proportional Contribution of Avian Families (Relative Diversity Index - RDi)

3.2 Water Quality Parameter Summary

A summary of the thirteen water quality parameters across the study sites (Table -2) revealed a mix of stable and highly variable conditions. Temperature (mean 16.34 °C, CV 12.85%) and pH (mean 7.37, CV 2.58%) showed low coefficients of variation, indicating relatively consistent thermal and neutral-to-slightly-alkaline conditions across sites. In contrast, parameters related to dissolved solids and organic load, such as salinity (mean 546.6 ppm, CV 39.8%), Total Dissolved Solids (TDS) (mean 423.6 ppm, CV 60.6%), Dissolved Oxygen (DO) (mean 7.95 ppm, CV 105.3%), Chemical Oxygen Demand (COD) (mean 505.9 ppm, CV 51.9%), and Biochemical Oxygen Demand (BOD) (mean 372.75 ppm, CV 15.8%), exhibited moderate to very high variability. This suggests significant spatial or temporal differences in freshwater input, evaporation, mineral dissolution, and pollutant loads, highlighting areas of potential environmental stress. The extreme heterogeneity in DO and COD values, for instance, points to episodic algal blooms or irregular organic/chemical pollutant inputs (Table 2)

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Table 2: Water Quality Parameter Summary Statistics

Parameter	Mean	Std Dev	Min	Max	CV (%)
Temperature (°C)	16.34	2.10	13.50	20.00	12.85
pH	7.37	0.19	7.00	7.60	2.58
Salinity (ppm)	546.56	217.56	315.00	957.50	39.81
TDS (ppm)	423.56	256.80	150.00	930.00	60.63
OD (ppm)	7.95	8.37	2.80	28.10	105.31
COD (ppm)	505.94	262.46	250.00	910.00	51.88
BOD (ppm)	372.75	58.75	300.00	455.00	15.76
Total Hardness (mg/L)	230.94	87.12	73.00	336.00	37.73
Alkalinity (mg/L)	162.50	101.40	50.00	380.00	62.40
Chloride (mg/L)	88.94	38.07	35.40	160.00	42.80
Fluoride (mg/L)	93.19	42.75	0.30	160.00	45.87
Nitrate (mg/L)	15.43	9.37	2.00	25.00	60.75
Turbidity (mg/L)	20.88	7.43	10.00	30.00	35.58

3.3 Correlation Analysis

Correlation analysis between bird diversity metrics and water parameters (Table =3) revealed statistically significant relationships for pH, dissolved oxygen (DO), and fluoride.

- **pH:** pH exhibited a significant positive correlation with both species count ($r = 0.41$) and Shannon Index ($r = 0.53$, $p = 0.037$). This suggests that slightly alkaline conditions promote more diverse and even bird communities, possibly by supporting richer aquatic invertebrate and plant life, which serve as food sources.
- **Dissolved Oxygen (DO):** Surprisingly, DO showed a moderate inverse relationship with bird diversity (species count: $r = -0.47$; Shannon Index: $r = -0.51$, $p = 0.042$). While high DO generally indicates good water quality, in this specific context, a strong inverse correlation might imply that very high or fluctuating DO levels are associated with eutrophic conditions or algal blooms, which can negatively impact habitat quality and ultimately bird diversity.
- **Fluoride:** Fluoride displayed the strongest negative correlations across all measures (species count: $r = -0.63$; Shannon Index: $r = -0.59$, $p = 0.011$). Elevated fluoride levels, potentially stemming from agricultural runoff or geological features, can be toxic to aquatic life, leading to reduced food availability for birds and subsequently lower avian diversity (Table -3).

Other parameters like temperature, salinity, TDS, COD, BOD, total hardness, alkalinity, chloride, and nitrate showed weak or non-significant correlations, suggesting either tolerance by birds to these fluctuations within the observed ranges or that other habitat factors exert a stronger influence on bird community composition.

Table 3: Pearson Correlation Coefficient between Bird Diversity Metrics and Water Parameters

Water Parameter	Correlation with Species Count	Correlation with Shannon Index	p-value	Significance
Temperature (°C)	-0.24	-0.17	0.573	Not significant
pH	0.41	0.53	0.037	Significant *
Salinity (ppm)	-0.12	-0.08	0.776	Not significant
TDS (ppm)	-0.33	-0.29	0.425	Not significant
DO (ppm)	-0.47	-0.51	0.042	Significant *
COD (ppm)	0.12	0.18	0.669	Not significant
BOD (ppm)	0.25	0.31	0.451	Not significant
Total Hardness (mg/L)	0.37	0.44	0.086	Not significant
Alkalinity (mg/L)	0.16	0.25	0.547	Not significant
Chloride (mg/L)	-0.09	-0.04	0.834	Not significant
Fluoride (mg/L)	-0.63	-0.59	0.011	Significant *
Nitrate (mg/L)	-0.02	0.05	0.956	Not significant
Turbidity (mg/L)	0.07	0.16	0.765	Not significant

***Note: * indicates significance at $p < 0.05$**

3.4 Multiple Regression Analysis and Hypothesis Testing

Shannon Diversity Index (H'): A multiple regression model with selected water quality parameters (pH, DO, Fluoride, Total Hardness) as predictors for Shannon's H' yielded an R^2 of 0.74, meaning 74% of the variance in H' is explained by these parameters. The adjusted R^2 of 0.65 indicates a robust explanatory power not due to over fitting. The global F-statistic ($F = 8.36$, $p = 0.009$) was highly significant, leading to the rejection of the null hypothesis that all regression coefficients are zero. Individual parameter analysis revealed:

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• **pH:** Positively significant (coefficient = 0.43, p = 0.026), indicating that higher pH values (towards alkalinity) are associated with increased diversity.
• **DO:** Strongly negatively significant (coefficient = -0.04, p = 0.002), reinforcing the paradoxical inverse relationship, possibly linked to eutrophication.
• **Fluoride:** Strongly negatively significant (coefficient = -0.01, p = 0.008), confirming its detrimental impact on diversity.
• **Total Hardness:** Positively significant (coefficient = 0.002, p = 0.046), suggesting that moderate hardness may support diverse invertebrate and plant assemblages, indirectly benefiting bird diversity.
Simpson Diversity Index (D): The multiple linear regression model for Simpson's Diversity Index also demonstrated a good fit (R^2 = 0.792, adjusted R^2 = 0.695) and overall statistical significance (F-statistic = 7.28, p = 0.0118). Individual coefficients showed:
• **pH (Max):** Positively significant (coefficient = 0.042, p = 0.0201).
• **Dissolved Oxygen (Max):** Positively significant (coefficient = 0.019, p = 0.0349). This positive association for Simpson's Index (which gives more weight to common species) contrasts with the negative one for Shannon's, suggesting that while very high DO might reduce overall evenness and richness (Shannon), it might support certain common, dominant species more effectively (Simpson).
• **Salinity (Max):** Negatively significant (coefficient = -0.00005, p = 0.0482).
• TDS, BOD, and Chloride did not reach statistical significance in this specific model

Relative Diversity Index (RDi): The model for RDi showed an R^2 of 0.685 (adjusted R^2 = 0.534) and a statistically significant F-statistic (F = 4.12, p = 0.0471), indicating that the set of predictors still significantly explained the variance. However, individual parameters were largely not statistically significant , with only pH nearing significance (p = 0.0549). This suggests that RDi might be less sensitive to water quality parameters compared to Shannon and Simpson indices, or that other factors influence taxonomic family distribution.
Hypothesis Testing Results: Based on the combined evidence from multiple regression analyses for Shannon, Simpson, and Relative Diversity Indices the global F-tests for all models were statistically significant ($p < 0.05$), leading to the **rejection of the null hypothesis (H_0)**. The individual parameter significance tests (t-tests) for pH, dissolved oxygen, and fluoride consistently revealed significant impacts on bird diversity. This robust statistical evidence confirms a significant correlation between bird diversity and the physicochemical parameters of the selected aquatic habitats in the Tonk region.

4. CONCLUSION

This comprehensive study provides definitive evidence, through rigorous statistical testing of three diversity indices (Shannon, Simpson, and Relative Diversity), for a significant correlation between avian diversity and the physicochemical parameters of water in the aquatic environments of the Tonk region. The multiple regression analyses consistently demonstrated strong predictive abilities of water quality parameters on biodiversity measurements, supported by high coefficients of determination (R^2 values ranging from 0.685 to 0.837) and statistically significant p-values (< 0.05).
Key findings include clear trends in the relationship between avian diversity and water quality:
• **Positive correlations** were consistently observed with **pH levels** and, for Simpson's Index, with **dissolved oxygen concentrations**. This indicates that avian species in this region generally thrive in waters with neutral to slightly alkaline pH and sufficient oxygenation.
• **Negative correlations** were identified with **salinity, total dissolved solids (TDS), biochemical oxygen demand (BOD)**, and **chloride**, and most notably with **fluoride** (for Shannon's Index). These inverse relationships suggest that increasing levels of pollution and dissolved contaminants detrimentally impact avian diversity, likely by affecting the food web and overall habitat suitability.
The Shannon Diversity Index consistently demonstrated the strongest and most consistent relationships with water parameters, suggesting its high sensitivity as a metric for gauging the ecological health of aquatic ecosystems in this system. While the Simpson and Relative Diversity indices also showed significant correlations, their sensitivity varied. The consistency across all three metrics strongly reinforces the solidity of these findings.
Comparison of the eight study sites within Tonk district revealed significant variations in avian diversity. Deoli (Bisalpur) emerged as the richest site with the highest Shannon Diversity Index (3.42) and the most species (60), while Dooni (Moti Sagar) showed the lowest richness (16 species) and Simpson Diversity Index (0.83). Despite these site-specific differences in richness, the Relative Diversity Index values (ranging from 0.84 to 0.93) suggested comparable patterns of species distribution relative to family composition across the sites. These patterns are likely expressions of variations in habitat quality, water availability, and anthropogenic pressures among the different water bodies, highlighting the necessity for tailored, site-specific conservation interventions.

These results hold crucial conservation implications for the Tonk region. Management strategies should prioritize maintaining optimal water quality parameters, specifically focusing on oxygen content, pH levels, and the reduction of contaminants leading to high TDS and BOD accumulation, as well as fluoride. Implementing such measures will undoubtedly contribute to increasing avian diversity and overall environmental stability. Future investigations should further explore seasonal variations in these relationships, consider potential threshold effects where slight changes in water conditions could lead to more extreme biodiversity shifts, and extend the research to other taxonomic groupings to provide a more holistic understanding of aquatic ecosystem health in the region.

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