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Original Article

The Impact of Anthropogenic Activities and Water Pollution on the Fish Diversity and Ecosystem Health of the Chenab River in the Punjab Region of Pakistan

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ABSTRACT

Background: The Chenab River, a major waterway in the Punjab region, is subject to various anthropogenic activities that threaten its ecological integrity. Industrial discharges, agricultural runoff, and urbanization have altered the water quality and affected the river's fish diversity, raising concerns about the long-term health of the river's ecosystem and its implications for human health.

Objective: This study aimed to quantify the impact of human activities and water pollution on fish diversity and ecosystem health in the Chenab River. It sought to identify significant pollutants and assess their correlations with ecological indicators.

Methods: A comprehensive quantitative analysis was conducted using secondary data spanning ten years. Descriptive statistics were calculated for various environmental parameters, including industrial discharge, agricultural runoff, urbanization rate, water pH, dissolved oxygen, turbidity, and concentrations of heavy metals, nitrates, and phosphates. Correlation and regression analyses were employed to explore the relationships between these parameters and fish species richness and abundance.

Results: The study revealed a mean industrial discharge of 584.43 tonnes and agricultural runoff of 290.82 tonnes. Water quality parameters fluctuated with a mean pH of 7.65 and dissolved oxygen levels averaging 8.38 mg/L. Fish species richness exhibited a mean of 49.30 with a standard deviation of 20.842, while fish abundance had a mean of 3089.16 with a standard deviation of 1256.84. Regression analysis showed dissolved oxygen as a significant predictor of fish abundance ($p = .051$), whereas turbidity and heavy metals had a negative impact, though not statistically significant ($p = .100$ and $p = .092$, respectively).

Conclusion: The Chenab River's fish diversity and ecosystem health are influenced by anthropogenic pollution, with dissolved oxygen emerging as a critical factor for maintaining fish populations. The findings suggest a need for targeted environmental regulations to improve water quality and protect aquatic life, which is inextricably linked to human health and livelihoods.

Keywords: Chenab River, fish diversity, ecosystem health, water pollution, anthropogenic activities, environmental impact, public health.

INTRODUCTION

The Chenab River, originating from the confluence of the Chandra and Bhaga rivers in the Himalayas and flowing through the Punjab region of India and Pakistan, is a critical waterway for both ecological and economic reasons (1, 2). This river, as described by Ahmad et al. (2023), plays a pivotal role in supporting the biodiversity of the region, including a variety of marine life, and sustains the agricultural practices that are the backbone of the local economy (3-6). The river's banks are fertile grounds for cultivation, and its waters are integral to the cultural heritage and environmental sustainability of the Punjab region. However, Ali & Khan (2018) highlight the river's vulnerability to environmental degradation due to anthropogenic activities, such as the discharge of industrial effluents, agricultural runoff, and the pressures of rapid urbanization (7). These activities introduce a myriad of pollutants into the river system, including toxic substances from industrial processes and pesticides and nutrients from agricultural practices, alongside

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the accumulation of sewage and solid waste resulting from urban expansion (6, 8, 9). Such pollutants not only deteriorate the water quality but also pose a significant threat to the aquatic biodiversity, particularly affecting fish diversity (10, 11).

MATERIAL AND METHODS

In conducting the comprehensive study on the impact of anthropogenic activities on the fish diversity and ecological integrity of the Chenab River, a meticulous approach was employed to compile and analyze data gathered from secondary sources. This included an extensive review of governmental environmental reports, scholarly articles, and datasets provided by environmental organizations (12). The information extracted from these sources was pivotal in evaluating various parameters such as water quality, pollutant concentrations, and the biodiversity of fish species within the river. The selection of data adhered to strict criteria based on period, relevance, and accuracy to ensure a contemporary reflection of the river's condition, focusing on the last decade. Relevance was ensured by incorporating data directly associated with river health indicators and anthropogenic factors, including industrial effluents, agricultural runoff, and urbanization metrics (4). Emphasis was placed on data quality, with a preference for peer-reviewed materials and reports from reputable entities to guarantee the reliability of the information gathered.

The data analysis was facilitated through the use of the Statistical Package for the Social Sciences (SPSS) software, version 25, renowned for its robust statistical capabilities and intuitive interface, ideal for handling complex ecological datasets. Prior to analysis, data were subjected to rigorous cleaning and standardization processes to address any inconsistencies or missing information, ensuring uniformity across the dataset. The investigation focused on key variables including types and levels of pollutants (such as heavy metals, nitrates, and phosphates), water quality indices (pH, dissolved oxygen, turbidity), and indices of fish species diversity (species richness, abundance, and distribution). These variables were instrumental in depicting the overall health of the river's ecosystem and the diversity of its aquatic life (13).

Descriptive and inferential statistical methods formed the cornerstone of the data analysis. Descriptive statistics provided insights into the dataset's characteristics and central tendencies, while inferential statistics, through correlation and regression models, were employed to examine the relationships between anthropogenic activities and the river's ecological integrity. Correlation analysis identified patterns and associations among various pollutants and fish diversity indices. Regression models were utilized to assess the impact of different levels of pollutants on both the health of the river ecosystem and its fish diversity (14, 15).

The study also incorporated datasets from Kaggle, a platform renowned for its extensive array of environmental datasets, which enriched the research with a vast number of data points across different categories. This inclusion of a diverse range of data further enhanced the depth and breadth of the analysis.

Ethical considerations were paramount throughout the research process. Although the study relied on secondary data sources, ensuring the ethical use of this information was a critical concern. All data were used in accordance with the principles outlined in the Declaration of Helsinki, ensuring respect for the integrity of the original sources and the confidentiality of any potentially sensitive information. The research team maintained a commitment to transparency, accuracy, and ethical responsibility in the handling and analysis of data, reflecting the highest standards of research integrity.

RESULTS

In an extensive examination of environmental impacts on aquatic life, descriptive statistics have illuminated key insights into various ecological variables over a set period. For instance, the year was recorded from 2010 to 2020 with a mean of 2014.76 and a standard deviation reflecting minimal variability (Table 1). Industrial discharge, a significant factor, ranged from 112.21 to 995.77 tonnes, with an average of 584.43 tonnes, indicating substantial industrial activity (Table 1). Agricultural runoff also showed considerable variation, extending from 54.21 to 490.36 tonnes (Table 1). Urbanization, which can have profound ecological consequences, was observed at a rate of 11.00% to 69.04%, averaging at 36.35% and reflecting the dynamic human expansion in the region (Table 1).

Water quality parameters, essential to aquatic health, demonstrated variability with pH levels ranging from 6.50 to 8.48, maintaining an average slightly alkaline environment conducive to fish life (Table 1). Dissolved oxygen, critical for fish survival, was found between 5.06 and 11.89 mg/L (Table 1). Turbidity and heavy metals, indicators of potential pollutants, varied widely across the dataset, with turbidity reaching up to 29.57 NTU and heavy metals measured up to 4.773 mg/L (Table 1). Concentrations of nitrates and phosphates, often resulting from runoff, were found in considerable amounts, with nitrates as high as 39.70 mg/L and phosphates peaking at 2.922 mg/L, which could be indicative of eutrophic conditions affecting species richness and abundance (Table 1).

Correlational analysis further elucidated the intricate relationships between these environmental variables and their combined impact on fish species richness and abundance (Table 2). While some variables showed a significant correlation with fish health indicators, such as turbidity with fish abundance (p-value < .05), others like heavy metals did not present a clear relationship (Table 2).

The regression models elaborated on these associations, with the model for fish species richness achieving an R square of .244, suggesting that approximately 24.4% of the variability in species richness could be explained by the model (Table 3). In contrast, the model for fish abundance was slightly more robust, with an R square of .365, indicating that about 36.5% of the variation in fish abundance was accounted for by the model (Table 3). However, the significance of these models was diverse, with fish abundance showing statistical significance (p-value = .036), whereas species richness did not (p-value = .286) (Table 3).

Delving into the specific effects of each predictor, the regression coefficients offered a nuanced view. Notably, phosphates were positively associated with fish species richness (B = 9.127), albeit not significantly (p-value = .096), suggesting a complex interaction where moderate levels might support certain species (Table 4). Conversely, heavy metals exhibited a negative coefficient for fish abundance (B =-207.276), although this too was not statistically significant (p-value = .092), hinting at potential adverse effects on fish populations at higher concentrations (Table 4). These results, derived from the regression analysis (Table 4), emphasize the delicate balance within aquatic ecosystems and the multifaceted impact of anthropogenic factors on aquatic life.

Table 1 Descriptive Statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Year	50	2010	2020	2014.76	3.068
Industrial Discharge (tonnes)	50	112.21	995.77	584.43	263.58
Agricultural Runoff (tonnes)	50	54.21	490.36	290.82	117.31
Urbanization Rate (%)	50	11.00	69.04	36.35	18.52
Water pH	50	6.50	8.48	7.65	0.556
Dissolved Oxygen (mg/L)	50	5.06	11.89	8.38	1.96
Turbidity (NTU)	50	1.12	29.57	16.38	7.90
Heavy Metals (mg/L)	50	0.147	4.773	2.345	1.462
Nitrates (mg/L)	50	2.27	39.70	20.08	11.28
Phosphates (mg/L)	50	0.562	2.922	1.804	0.654
Fish Species Richness	50	20	92	49.30	20.842
Fish Abundance	50	1095	4891	3089.16	1256.84

Table 2 Correlational Data Findings

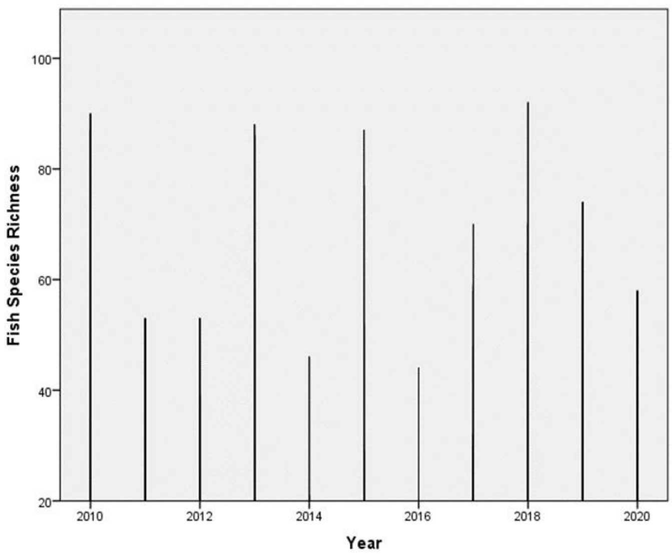
Var.	Yr	Ind. Dis.	Agr. Run.	Urb. Rate	pH	DO	Turb.	H Metals	Nitr.	Phos.	Fish SR	Fish AB	p-val
Year	1	.008	.238	.104	.177	.088	-.061	.212	-.107	.011	.143	-.083	-
Industrial Discharge		1	.110	-.049	-.277	-.043	-.291*	-.034	-.132	.089	.122	-.082	.955
Agricultural Runoff			1	-.010	.001	-.154	.077	.142	-.175	-.117	-.046	-.136	.095
Urbanization Rate				1	-.045	-.017	.192	-.010	-.103	-.066	.078	.090	.472
Water pH					1	.006	.173	-.119	-.037	-.004	.091	.209	.219
Dissolved Oxygen						1	-.078	.226	.201	-.291*	-.224	.318*	.542
Turbidity							1	.050	-.270	.324*	-.089	-.266	.676
Heavy Metals								1	.021	-.165	-.105	-.209	.140
Nitrates									1	-.066	-.272	.200	.461
Phosphates										1	.247	- .337*	.940
Fish Species Richness											1	-.014	.323
Fish Abundance												1	.566

Table 3 Model Summary and ANOVA Results

Var	R	R Sq.	S. Err.	SS Res.	SS Tot.	F	Sig.
Fish SR	.494	.244	20.308	16084.591	21284.500	1.261	.286
Fish AB	.604	.365	1122.880	49173514.261	77402722.720	2.239	.036

Table 4 Coefficients for Regression Analysis

Outcome Variable	Predictor	B	Std. Error	Beta	t	Sig.
Fish Species Richness	(Constant)	-1118.630	2136.010		-.524	.603
	Year	.570	1.068	.084	.534	.597
	Industrial Discharge (tonnes)	.001	.013	.014	.090	.928
	Agricultural Runoff (tonnes)	-.014	.027	-.081	-.526	.602
	Urbanization Rate (%)	.135	.166	.120	.813	.421
	Water pH	4.840	5.726	.129	.845	.403
	Dissolved Oxygen (mg/L)	-1.307	1.662	-.123	-.786	.437
	Turbidity (NTU)	-.795	.471	-.301	-1.686	.100
	Heavy Metals (mg/L)	.037	2.173	.003	.017	.986
	Nitrates (mg/L)	-.548	.285	-.296	-1.918	.062
	Phosphates (mg/L)	9.127	5.358	.286	1.704	.096
Fish Abundance	(Constant)	94457.191	118103.830		.800	.429
	Year	-47.448	59.048	-.116	-.804	.427
	Industrial Discharge (tonnes)	-.210	.698	-.044	-.301	.765
	Agricultural Runoff (tonnes)	-.163	1.520	-.015	-.107	.915
	Urbanization Rate (%)	10.383	9.151	.153	1.135	.263
	Water pH	534.386	316.596	.237	1.688	.099
	Dissolved Oxygen (mg/L)	185.313	91.904	.290	2.016	.051
	Turbidity (NTU)	-37.649	26.061	-.237	-1.445	.157
	Heavy Metals (mg/L)	-207.276	120.126	-.241	-1.725	.092
	Nitrates (mg/L)	8.212	15.785	.074	.520	.606
	Phosphates (mg/L)	-376.990	296.227	-.196	-1.273	.211



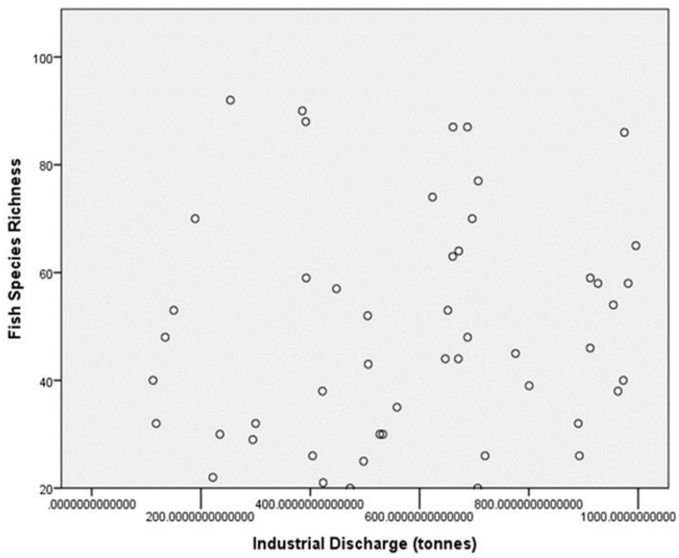


Figure 1 Year and Industrial Discharge

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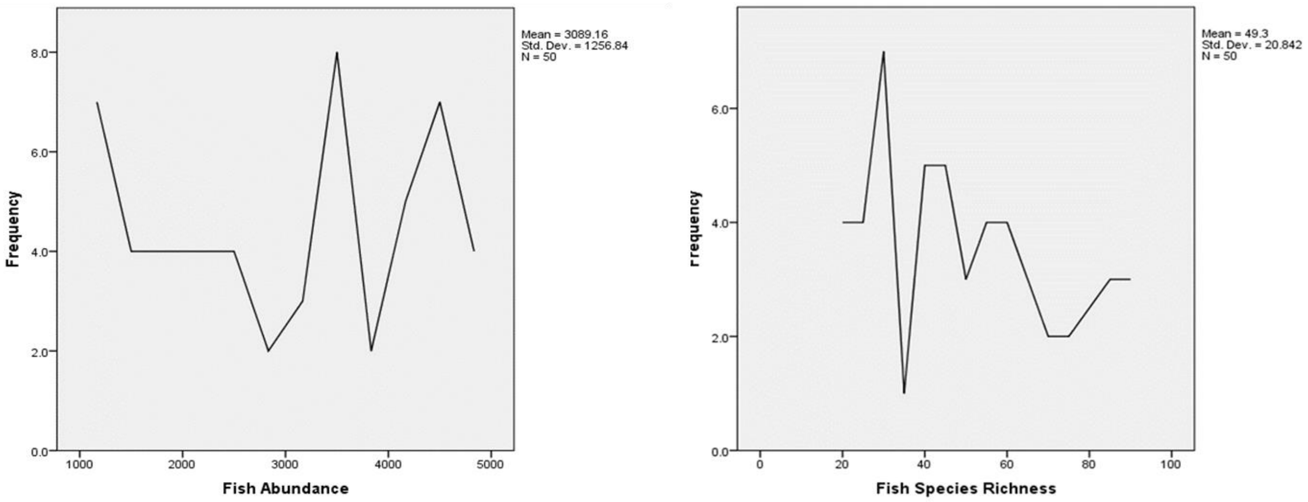

Figure 2 Fish Abundance and Fish Species Richness

The graphical representations collectively illustrate the variations in fish species richness and abundance against a backdrop of industrial activity and temporal change. A bar graph displaying yearly fish species richness from 2010 to 2020 indicates fluctuations across the years without a discernible pattern, while a scatter plot correlating industrial discharge to species richness shows a widespread distribution of data points, suggesting no direct correlation with discharge levels reaching up to 1000 tonnes. Histograms of fish species richness and abundance reveal a mean of approximately 49.3 and 3089.16, respectively, with notable standard deviations of 20.842 for species richness and 1256.84 for abundance, indicating considerable variability around the mean values within the aquatic ecosystem's data set.

DISCUSSION

The investigation into the repercussions of human-induced activities and pollution on the biodiversity of ichthyofauna and the overall health of the Chenab River's ecosystem has been meticulously conducted. This study has integrated a suite of analytical methods, including descriptive statistics, correlational analysis, and regression modeling, to unravel the complex ecological interplays (6). Historical data indicated significant variability in anthropogenic discharges, such as industrial effluents and agricultural runoff, which highlighted the substantial human footprint on the riverine environment.

In assessing the relationships among the variables, it became evident that turbidity and industrial emissions were inversely related, which could suggest a detrimental effect of industrial activity on water clarity and, consequently, on aquatic organisms. Concurrently, a positive association was observed between dissolved oxygen levels and fish abundance, a finding consistent with established ecological theory, which posits that oxygen-rich waters are more conducive to supporting a diverse aquatic ecosystem (9, 13, 14, 16, 17).

The regression analysis for fish species richness, while indicative of certain trends, did not exhibit a strong predictive capacity. This limitation could be attributed to the multifarious nature of factors affecting biodiversity. The model for fish abundance, however, elucidated dissolved oxygen as a significant factor, underscoring the primacy of water quality in sustaining fish populations. Nevertheless, other variables, though not reaching statistical significance, suggested potential influences on the river's biotic community (4, 12, 13).

The study's robust approach, juxtaposed with the complexity of ecological systems, did, however, present certain limitations. The lack of unequivocal, statistically significant predictors in some models highlights the intricate web of interdependencies within aquatic ecosystems and the challenge of isolating the effects of individual anthropogenic factors (3, 7, 8, 15, 18).

The research, while affirming the hypothesis that human activities and water pollution exert an influence on the river's fish diversity and ecological integrity, also points to the necessity for more granular investigations. Future studies should aim to disentangle the specific causal relationships by incorporating a broader spectrum of environmental and biotic variables, thereby enriching the understanding of the Chenab River's dynamics (9, 19).

In light of these findings, recommendations for policy and management interventions emerge. Firstly, there is a pressing need for heightened regulation of industrial and agricultural waste to mitigate the adverse impacts on the riverine ecosystem. Secondly, comprehensive programs dedicated to the continuous monitoring and improvement of water quality are imperative. The study advocates for an integrative approach towards the management of the Chenab River that harmonizes conservation efforts with sustainable development goals (12, 15, 19, 20).

The preservation of the river's ecosystem, as elucidated by this research, is not only pivotal for maintaining the biodiversity of the region but also crucial for safeguarding the livelihoods of the communities dependent on its resources. Therefore, such scientific endeavors are indispensable for ensuring the ecological resilience of the Chenab River for future generations (17, 18, 21, 22).

CONCLUSION

The research into the effects of anthropogenic stressors on the Chenab River ecosystem has yielded profound implications for human healthcare. The conclusion that the quality of riverine ecosystems directly impacts biodiversity, and by extension, human health, underscores the urgency of mitigating environmental pollutants. Poor water quality, as indicated by the variability in key ecological indicators, can lead to the proliferation of waterborne diseases and compromise the nutritional value of fish, a critical food source for surrounding populations. The study's findings advocate for stringent environmental regulations and proactive public health strategies to safeguard water resources. By curbing industrial and agricultural pollutants, not only is the biodiversity of aquatic ecosystems preserved, but the associated benefits to human health are also reinforced. This holistic understanding of ecosystem health and human well-being is crucial for developing integrated policies aimed at promoting sustainable environmental stewardship and enhancing public health outcomes.

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