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The Spatial and Temporal Disparity of Fish Assemblage and Its Association with Environmental Factors Through Multivariate Statistical Analysis in Jammu and Kashmir's Himalayan River System.

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Abstract

The goal of this study was to explore the dynamics of the environmental components with fish species assemblages in the Ravi and Chenab rivers of the Himalayan river system during the study period from July 2020 to June 2021. To examine the relationship between fish species and environmental parameters, multivariate statistical analyses including canonical correspondence analysis, principal component analysis and cluster analysis were applied to data from fish species. ANOSIM and SIMPER were used to determine whether fish assemblage varied with seasons or streams and to identify the fish species that contributed to this variation between the sampling sites. To study the effect of environmental factors on fish species richness, multiple regression analysis was used. Fish species belonging to 30 species and 12 different families (Cyprinidae, 66.6%) were recorded from three study sites (Bhini, Jhajjar and Chadwal streams) with Chadwal (34.3%) having the most ichthyofaunal population. Hillstream fish species dominated the Bhini stream, while catfish species dominated the Jhajjar stream. The Chadwal Stream was home to a diversity of fish species due to its vast fishing grounds. The values of free carbon dioxide (FCO2), bicarbonates (HCO3-), and habitat structure showed significant variations ($p<0.05$). The Shannon-Wiener (H'), Simpson dominance, and Margalef index values of fish communities were high. Differences in environmental parameters in each sampling site influenced the fish population in the present study. Our findings showed that environmental factors influenced species composition and provided evidence for the dynamic interaction between environmental variables and fish assemblage in the Ravi and Chenab rivers.

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Introduction

The fisheries sector has long been a vital part of the Indian economy, contributing to food and nutrition security, job creation, and foreign exchange earnings through fish export. So far 3,231 species of native finfish have been recorded from India, of which 2,443 species are from the marine environment, 113 from brackish waters and 877 are from freshwater habitats along with 291 exotic fish species.[1,2]

The rich biological legacy, biodiversity, and productivity potential of India's inland water resources are well known. Research is being conducted globally to establish systematic conservation planning to maintain freshwater biodiversity[3,4,5] since aquatic ecosystems face major risks to both biodiversity and ecosystem stability. As a result, different techniques, tactics, and priorities have been put forth.[6,7,8] Kottelat and Whitten[9] listed pollution, increased sedimentation, stream fluctuation, water diversion, and exotic species as the primary causes of decreased ichthyofaunal diversity in Asian countries. Also to feed the ever-growing population, significant development and improvement of aquaculture need to be given priority.

Jammu province's rivers originate in the middle and outer Himalayas and travel considerable distances before reaching the plains of this region. As a result, the riverine system in this area has a lot of longitudinal stratification, which means there are a lot of different habitats for the fish fauna that live there.[10,11,12,13,14,15]

The quantity and types of fish species in the river system vary with the diversity of environments. Food, spawning places, water quality, substrates, and flows within a river system all contribute to habitat variability and vary depending on where the river and its tributaries run. The inter relationship between fishes and their surrounding environment has a crucial part in the management and conservation of riverine fish species where any alteration in it causes a transformation in their population.[16] The distribution and composition of fishes in freshwater and marine ecosystems have been influenced by the concentration of environmental factors particularly water quality indices.[17,18,19] To determine the assortment status of aquatic residents, biodiversity measures such as dominance, evenness, Margalef, and H' diversity indices were utilised as pointers.[20,21] This study aims to 1) explain the spatial and temporal fluctuation of fish assemblage and 2) determine the relationship between environmental parameters and fish grouping in the Himalayan River System's Ravi and Chenab Rivers.

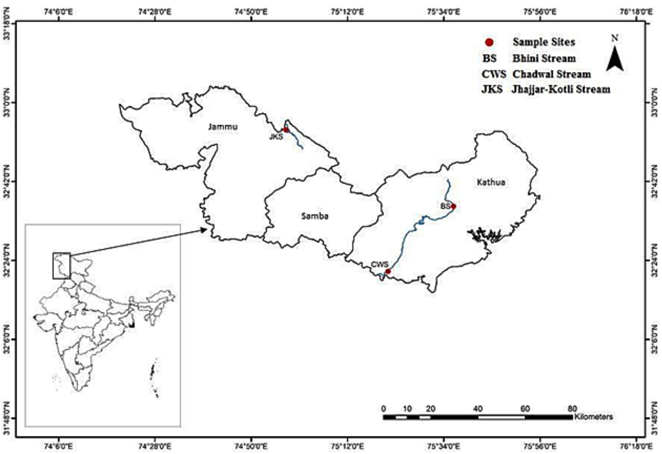

Fig. 1: Location of the three sampling stations on the map

Materials and Methods

Study Area

The present study was done on two of the rivers of the Himalayan River System- River Ravi and River Chenab from July 2020 to June 2021. The River Chenab originates from the Himalayas in the Lahaul and Spiti districts of Himachal Pradesh in India and courses through the Jammu region of J&K UT. River Ravi originates in the Himalayas in the Chamba district of Himachal Pradesh and flows North-westerly along the Indo-Pak border joining the Chenab River. The sampling stations for the present study were selected due to their spatial and temporal disparity. Two sampling stations (Bhini and Chadwal) were chosen from River Ravi and one from River Chenab (Jhajjar).

The Bhini stream (32.36°N, 75.36°E) is one of the tributaries of the River Ravi in the Kathua district in J&K. It is a perennial, rain and snow-fed stream that flows in the Shivalik Hills of the Outer Himalayas. The Chadwal stream (32.22°N, 75.20°E) is another tributary of River Ravi flowing in the middle Himalayan range with precipitation as the major source of water in the stream.

The Jhajjar stream (32.53°N,74.57°E) is a perennial, snow-fed tributary of River Chenab and is situated in the village Jhajjar-Kotli (Lesser Himalayas) in Jammu District in J&K.

Field Surveys and Laboratory Analyses

Fish, as well as water samples, were taken from all three streams for the analysis of physicochemical parameters, habitat structure and fish diversity during the study period from July 2020 to June 2021 (monsoon (June-September), post-monsoon (October-January) and pre-monsoon (February-May)). Gill and cast nets were used for the collection of fish specimens during the study months. The total number of species and specimens collected were counted and the specimens were preserved in 10% formalin. The samples brought back to the laboratory were identified using available literature.[22,23,24]

The water samples were collected in glass bottles and on-site analysis was done for pH, dissolved oxygen (DO), air and water temperature, depth, transparency and velocity of the stream. Temperatures were measured using a mercury bulb thermometer. pH was measured using a digital pH metre (Testo 206-pH1). For DO measurement, oxygen was first fixed by using the method recommended by APHA.[25] Further analysis was carried out in the laboratory. The depth of the streams was measured using metre rods and measuring tape while transparency was measured using a Secchi disc. The velocity of the water current was measured using a portable water flow metre. Substrate coverage was estimated using a quadrat of 50 squares of 4 X 4cm each and the elevation of sampling stations was measured using GPS. For other parameters (FCO_2, alkalinity, HCO_3^-, CO_3^{2-}, hardness, Ca^{2+}, Mg^{2+}, Cl^-), samples were brought to the laboratory and assessment was done using the Standard methods of APHA.[25]

The ichthyofaunal diversity was studied using the following indices:

1. Simpson's diversity index[26].
   $D = \sum (n/N)^2$

where N = total organisms of all species and
n = all the organisms of a particular species.

2. Shannon-Wiener diversity index[27].
   $H' = - \sum (P_i)(\log P_i)$

where $P_i = N_i/N$ is the percentage of individuals of species i.

3. Margalef richness index[28].
   $d = (S-1)/\ln N$

where N is the total individuals in the sample and S is the number of species.

4. Pielou's evenness index[29].
   $J = H'/\ln(S)$

where S is the total species in a sample and H' is the Shannon Weiner index.

Data Analysis

To determine any difference between sampling sites, ANOVA or one-way analysis of variance was employed for habitat (depth, transparency, air temperature, rocks, sand, silt, and plant cover) and hydrological variables (water temperature, DO, alkalinity, pH, hardness, and Cl^-). The means which differed substantially at a 0.05 level of probability were identified using a post hoc Tukey HSD test.[30]

The relationship between environmental variables and sampling stations was investigated using Principal Component Analysis (PCA). All physicochemical variables, habitat structure, and elevation were analysed using the PCA method.

Canonical Correspondence Analysis (CCA) was utilized for determining the association between environmental variables and the structure of fish communities. The PC1, PC2, and PC3 scores of environmental factors were utilised to describe the CCA axes. The variables with correlation coefficients less than 0.60 and statistical significance greater than 0.05 were used. The data of the most numerous species with presence in two or more sample points were used for the CCA, to show the contribution of abundant species in this study. Rare species were considered as those caught on a single occasion or in a single place for this investigation.[31]

To investigate if there are any significant differences between the fish assemblages detected by the CCA, a one-way analysis of similarity (ANOSIM) using fish abundances of the selected groups was used.[32] To determine the proportion of similarity among sampling stations, a similarity percentages analysis[32] (SIMPER) was used. This methodology also approximated the percentage of major contributing species for all of the sampling stations.

Cluster analysis using the Bray-Curtis metric and the unweighted pair-group technique with the arithmetic mean (UPGMA) was used to evaluate the similarity between the sampling stations using environmental parameters and fish species abundance. PAST (v 4.03) and SPSS (v 16) software were used for carrying out all these analyses.

The link between environmental variables and fish species richness was studied using multiple regression analysis (Minitab v.20.3.0). The environmental variable having a limited effect on richness was excluded in each step of regression analysis as shown by the greatest p-value. The analysis was done until environmental variables with $p \leq 0.05$ and related to the fish variables remained.

Results

Environmental Parameters

Data summarising the mean values of physicochemical parameters of water, habitat structure and elevation for all three sites are given in Table 1. Statistically significant differences for FCO_2 and HCO_3^- ($H = 7.2$, $p<0.05$) and habitat parameters (rocks, sand, silt and plants) ($H=10.47, p<0.05$) were revealed by the Kruskal-Wallis ANOVA test for the three sampling sites.

Table 1: Mean values of environmental variables of the sampling stations from June 2020 to May 2021 (Monsoon 2020-Pre-monsoon 2021).

Parameter	Bhini Stream	Jhajjar Stream	Chadwal Stream
Air temperature(°C)	32-27.7	29-25.8	37-28
Water temperature(°C)	25-20.6	15-13	25-14
Depth(feet)	8.2-4.7	18-11	7.4-4.2
Transparency(cm)	12-42	4-55	6-32
pH	8-8.1	8.3-8.2	7.6-7.4
DO(mg/L)	8.3-8.1	8.6-8.1	5.4-5
FCO_2(mg/L)	4.6-4.5	0	2.1-1.4
HCO_3^- (mg/L)	352-279	59.6-93.6	386.2-430
CO_3^{2-}(mg/L)	15-12.4	2.9-2.4	11-8.6
Ca^{2+}(mg/L)	21.3-18.7	20.9-19.4	12-16.1
Mg^{2+}(mg/L)	12.7-9.4	5.2-5.4	6-7.2
Cl-(mg/L)	4.8-7.2	8-9.8	10.8-15.2
Water velocity (ms^{-1})	1.9-1.7	1.3-1.1	0.8-0.6
Rocks (%)	35-75	25-65	5-20
Sand (%)	15-10	15-15	25-40
Silt (%)	45-10	50-15	55-35
Plants (%)	5-5	10-15	15-15

The ANOVA test revealed significant differences (H=3.85, $p<0.05$) in the mean values of FCO_2, alkalinity and Mg^{2+} between the Bhini and Jhajjar streams while pH, DO, FCO_2, alkalinity, Cl- showed significant differences (H=3.85, $p<0.05$) between Bhini and Chadwal streams. Between Jhajjar and Chadwal streams, significant differences (H=3.85, $p<0.05$) were revealed in the values of pH, DO, FCO_2, alkalinity and depth.

Table 2: Diversity and abundance of the fish species collected from the three study stations: Bhini stream (BS), Jhajjar stream (JS) and Chadwal stream (CS).

Order	Family	Species	Sampling stations	Abundance
		Barilius vagra	BS, JS and CS	43
		Puntius conchonius	BS	45
		Labeo dero	BS, JS and CS	15
		Tor tor	BS, JS and CS	12
		Crossocheilus latius	BS	9
		Osteobrama cotio	BS	13
		Rasbora rasbora	BS	16
		Chela bacaila	BS and CS	41
		Barilius bendelisis	JS and CS	48
Cypriniformes	Cyprinidae	*Garra gotyla*	JS and CS	28
		Tor putitora	JS and CS	31
		Crossocheilus diplochelius	JS	22
		Puntius sophore	JS and CS	34
		Puntius ticto	JS and CS	29
		Puntius sarana	CS	4
		Cirrhinus mrigala	CS	11
		Cirrhinus reba	CS	8
		Labeo rohita	CS	16
	Nemacheilidae	*Acanthocobitis botia*	BS, JS and CS	40
		Schistura denisonii	BS	2
	Danionidae	*Danio devario*	BS	20
	Cobitidae	*Lepidocephalichthys guntea*	BS	23
	Amblycipitidae	*Amblyceps mangois*	JS	7
Siluriformes	Sisoridae	*Glyptothorax pectinopterus*	JS	19
	Bagridae	*Mystus seenghala*	JS	4
	Siluridae	*Wallago attu*	JS	3
	Badidae	*Badis badis*	BS	5
Perciformes	Channidae	*Channa punctatus*	JS and CS	12
	Mastacembelidae	*Mastacembelus armatus*	CS	5
Beloniformes	Belonidae	*Xenentodon cancila*	JS and CS	18

Fish Species Distribution and Abundance

A total of 583 individuals were collected from the Bhini (29.5%), Jhajjar (36.1%), and Chadwal (34.3%) streams, representing 4 orders, 12 families, 22 genera, and 30 species (Table 2). The best-represented order was Cypriniformes with 4 families and 22 species. It was followed by the order Siluriformes with 4 families and 4 species and the order Perciformes with 3 families and 3 species. The order Beloniformes were represented by 1 species.

Diversity Indices For Fish

The values of diversity indices at all three sites were calculated for both stations and seasons (pre-monsoon, monsoon and post-monsoon). The H' index in biological communities ranges from 0 to 5 with values less than one indicating extremely contaminated conditions, values in the range of one to two indicating moderately polluted conditions, and values above three indicating stable environmental conditions.[31,32] The value of the H' index was found to be the highest at the Chadwal stream (2.749) during the post-monsoon season (Oct-Jan) and the lowest at the Bhini stream (2.38) during the monsoon season (June-Sept). The evenness index was highest at the Jhajjar stream (0.9377) and lowest at the Chadwal stream (0.8678). The values for the evenness index were higher during the pre-monsoon season (Feb-May) (0.936) while they were found to be lower during the monsoon season (June-Sept) (0.8457). The Margalef index has no limit value and it shows a variation depending upon the number of species. Margalef richness values were highest at the Chadwal stream (3.136) during the pre-monsoon season (Feb-May) and lowest at the Bhini stream (2.086) during the post-monsoon season (Oct-Jan). The Simpson index typically ranges from 0 to 1 where communities that are mature and stable have a high diversity value from 0.6 to 0.9, whereas communities that are under stress and have little diversity have a value that is close to zero.[33] The Simpson diversity index was highest for the Jhajjar stream (0.93) during the post-monsoon season (Oct-Jan) and lowest for the Bhini stream (0.8981) during the post-monsoon season (Oct-Jan).

Data Analysis

PCA identified three probable groups responsible for the data structure, with each group accounting for 86.3% of the total variance (Table 3; Fig 2). This enabled the grouping of the specified factors based on common characteristics, as well as accessing the incidence of each group on overall fish population variance. PC1 explained 39% of the total variation, with substantial positive correlation values for group 1 variables (air and water temperature, alkalinity, pH, DO, rocks, sand, and silt). PC2 accounted for 28.9% of the variation, and the second component (FCO2, hardness, Cl-, plant cover, and elevation) had a positive connection with the first. With 18.4% of the variance, PC3 containing group 3 components (depth and water velocity) demonstrated positive loading points.

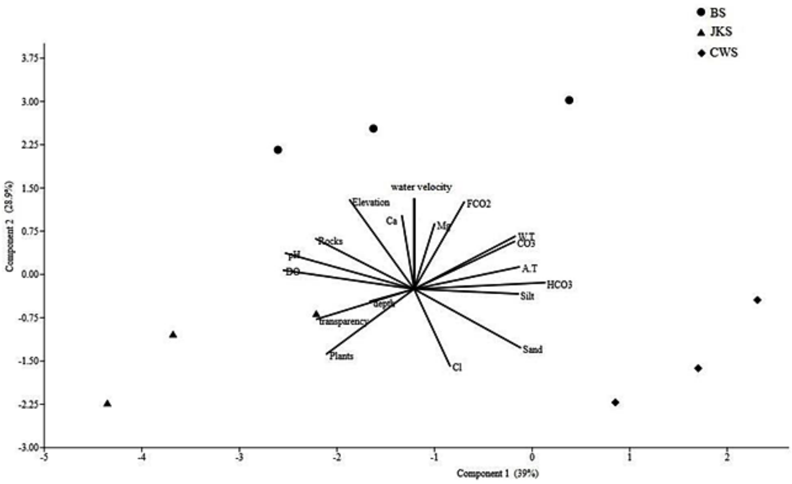

Fig. 2: Principal Component Analysis (PCA) of physicochemical variables of the water, variables of habitat structure and sampling sites.

Eleven species were identified as rare based on fish occurrence data, hence 19 species were utilised for CCA. Axes 1 and 2 explained 89.6% of the variability in the species-environment biplot, according to the CCA (Fig 3). The eigen values for axis 1 and 2 were 0.52 and 0.25, respectively, while the inertia (%) values were 60.3% and 29.6%.

Table 3: Principal Components Analysis (PCA) results displaying the environmental variable loadings on the first four principal components (Eigenvalue > 1 and correlation coefficient > 0.60) and the % of total variance explained by these components.

	PC1	PC2	PC3
A.T	0.721	-	-
W.T	0.6930	-	-
Depth	-	-	-0.9066
Transparency	-0.6690	-	-
pH	-0.8824	-	-
DO	-0.8965	-	-
FCO_2	-	0.8682	-
HCO_3^-	0.8975	-	-
$CO3_2^-$	0.6892	-	-
Ca_2^+	-	0.7305	-
Mg_2^+	-	0.6484	-
Cl^-	-	-0.7662	-
Water velocity	-	-	-0.7534
Rocks	-0.6740	-	-
Sand	0.7292	-	-
Silt	0.7145	-	-
Plants	-	-0.6477	-
Elevation	-	0.8892	-

FCO_2, CO_3^{2-}, Mg^{2+}, plants, and elevation all influenced Axis 1 in the species-environment relationship, accounting for 60.3% of the variance. The second axis accounted for 29.6% variance with pH, DO, HCO_3^- and Cl^-being the most significant contributors. The Bhini stream demonstrated a positive association with pH, DO, FCO_2, hardness, water velocity and elevation. *Barilius vagra*, *Tor tor*, *Acanthocobitis botia*, *Rasbora rasbora*, and *Schistura denisonii* were among the species linked to these factors. Depth, transparency, DO, water velocity and plants all had a positive association in the Jhajjar stream. *Tor putitora*, *Crossocheilus diplochelius*, *Amblyceps mangois*, *Glyptothorax pectinopterus*, *Channa punctatus*, and *Puntius sophore* were linked to these factors. Air temperature, HCO_3^-, Cl^-, sand, and silt were shown to have a positive correlation with the Chadwal stream and species such as *Danio devario*, *Xenentodon cancila, Labeo dero*, *Puntius ticto*, *Garra gotyla*, and *Barilius bendelisis* were associated with these factors.

ANOSIM revealed substantial variations in species composition among the three sampling locations (R=0.89, p=0.04); the R-value is quite high, indicating that a very small degree of overlap separated the sampling sites. ANOSIM also showed no significant changes in fish assemblage across seasons (R = -0.16, p= 0.74). So fish assemblage structure differed significantly at the spatial scale but not the temporal scale, according to an analysis of similarities (ANOSIM). According to the SIMPER study, there is an 85% difference between Bhini and Jhajjar stations, a 61% difference between Bhini and Chadwal and a 76% difference between Jhajjar and Chadwal. *Acanthocobitis botia*, *Lepidocephalichthys guntea*, *Puntius conchonius, P. ticto* and *P. sophore* are the main contributors to the dissimilarity between Bhini and Jhajjar stations. *P. conchonius, Danio devario*, *A. botia, Tor tor*, and *Rasbora rasbora* are the main contributors to the dissimilarity between Bhini and Chadwal stations. *D. devario, Crossocheilus diplochelius*, *Xenentodon cancila,* *P. conchonius,* and *Glyptothorax pectinopterus* are the main contributors to the dissimilarity between Jhajjar and Chadwal stations. As per SIMPER analysis, cold water fishes dominated the Bhini stream, catfish species along with a few hill stream fishes were found in the Jhajjar stream while the Chadwal stream contained an assortment of different fish species.

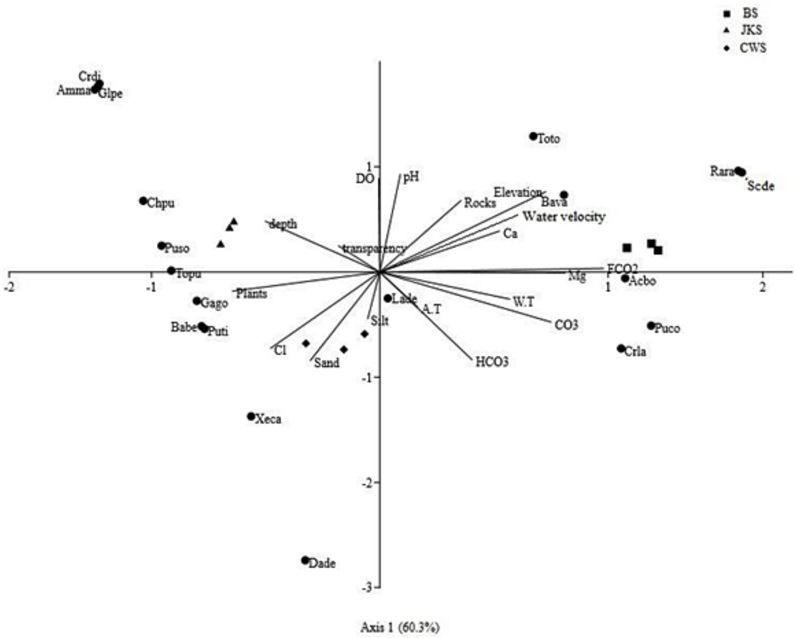

Fig. 3: CCA of 3 sites, 19 species (Crdi-*Crossocheilus diplocheilus*, Amma-*Amblyceps mangois*, Glpe-*Glyptothorax pectinopterus*, Chpu-*Channa punctatus*, Puso-*Puntius sophore*, Topu-*Tor putitora*, Gago-*Garra gotyla*, Babe-*Barilius bendelisis*, Puti-*Puntius ticto*, Xeca-*Xenetodon cancila*, Dade-*Danio devario*, Lade-*Labeo dero*, Crla-*Crossocheilus latius*, Puco-*Puntius conchonius*, Acbo-*Acanthocobitis botia*, Bava-*Barilius vagra*, Toto-*Tor tor*, Rara-*Rasbora rasbora* and Scde-*Schistura denisonii*) and environmental variables of PC1, PC2 and PC3.

Changes in species richness were found to be related to FCO_2, Ca^{2+}, C^{l-} and elevation. The effect of these four factors on species richness is depicted in the graphs (Fig 4). The results of the regression analysis showed that species richness was inversely related with FCO_2 (adj R^2 = 0.656, p=0.005), Ca^{2+}(adj R^2 = 0.464, p=0.026) and elevation (adj R^2 = 0.617, p= 0.007). As per regression analysis, a rise in FCO_2, Ca^{2+}, and elevation resulted in a decline in the species richness. The species richness showed a positive and direct correlation with Cl- (adj R2 = 0.488, p=0.022) as per regression analysis indicating species richness increases with an increase in the level of Cl^-.

Cluster analysis based on environmental and faunal similarities of sampling stations using Bray-Curtis distance and UPGMA algorithm yielded two groups at the similarity level of 70% separation, the first cluster consisting of Bhini and Chadwal stream and the second cluster having Jhajjar stream (Fig 5). In the 1st cluster at an 80% similarity level, the Bhini stream is pooled independently from the Chadwal stream. The Bhini stream has its pre and post-monsoon seasons clustered separately from the monsoon season while the Chadwal and Jhajjar streams have their pre-monsoon and monsoon season clubbed independently from their post-monsoon season.

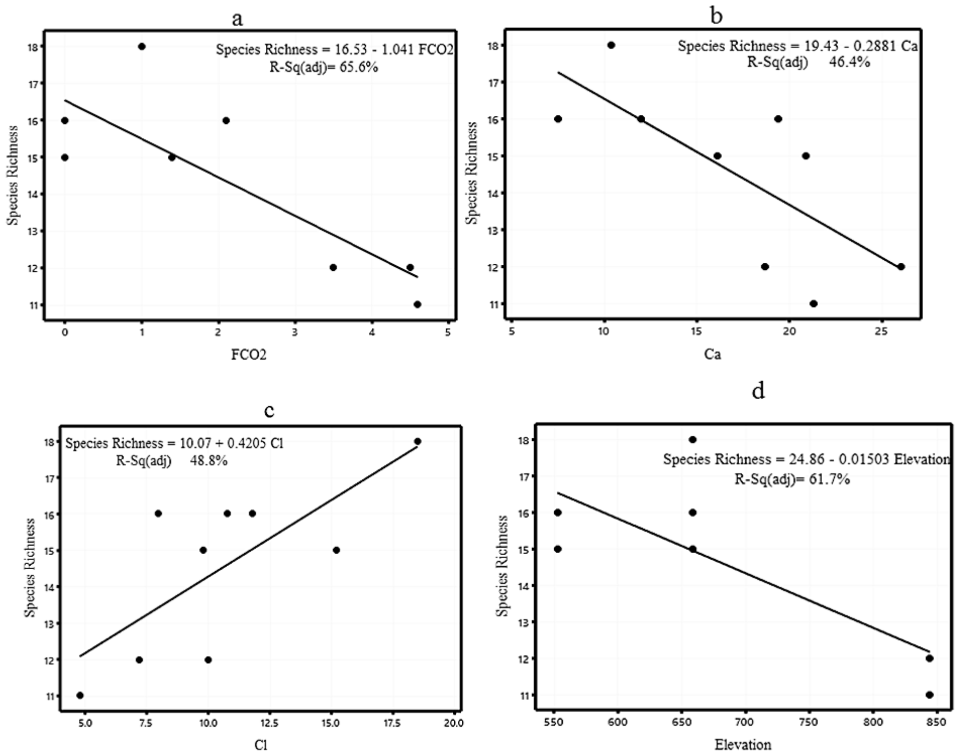

Fig. 4: Equations of linear regression for species richness (a), FCO_2 (b) Ca^{2+} (c) Cl^- (d) Elevation.

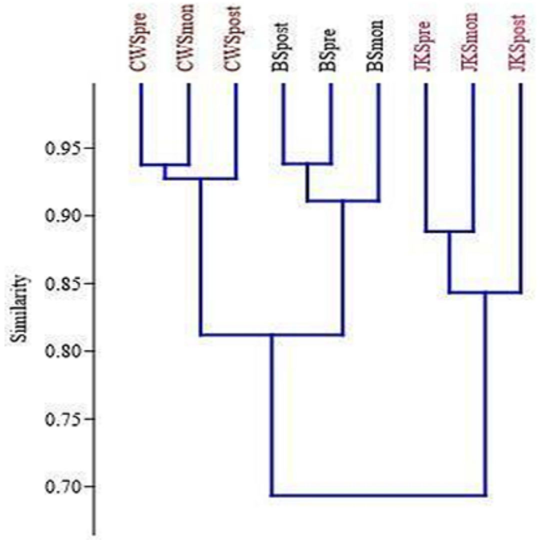

Fig. 5: Classical UPGMA clustering of faunal and environmental similarities in the studied stations using the Bray-Curtis similarity index.

Discussion

The biodiversity of an aquatic stream was influenced strongly by the water chemistry and habitat quality.[37] Variations in the FCO_2 and alkalinity level among the three sampling stations showed more impact on the spatial distribution of fish species at the Jhajjar stream as compared to the Bhini and Chadwal streams. The maximum level of fish abundance was detected from this stream as the low levels of FCO_2 and alkalinity encouraged the rapid photosynthetic activity of phytoplankton leading to enhanced primary productivity.[38] Changes in physicochemical parameters such as DO, pH, transparency, temperature, depth and alkalinity have an impact on the individuality of the aquatic environment and fish rearing,[39,40] abundance and allocation,[41] dispersal and relocation,[42] and fish viability[43] affecting fish assemblage and structure. The habitat and hydrological parameters of the three streams showed differences ($p<0.05$) which were significant and similar to the findings of Grimaldo.[44]

Biodiversity indices aim to describe the diversity of a population or sample by using a single number.[20] Two factors contribute to species diversity, the number or richness of species and the distribution of organisms within each species. However, the formal application of the concept and its evaluation were complicated.[45] The Evenness and Dominance indices considered the sample size and the percentage of common species while the Shannon-Wiener index explored the abundance and percentage of each species. Any differences in these diversity indices were found to be related to a number of factors, including a) seasonal fluctuations in nutrients in seagrass beds had an impact on the cohabitation of several fish species, as Huh and Kitting[46] predicted, b) environmental conditions and atmospheric air flow,[47] and c) seasonal fish migration.[48] The pre- and post-monsoon seasons which were considered dry months showed the highest diversity values as low water levels due to evaporation resulted in concentrated levels of nutrients. During this season, a diverse microalgae population resulted in great variability of food for fish species. Furthermore, during the monsoon season lower species diversity could be due to nutrient dilution by the large influx of water from catchment areas. The Shannon-Wiener index indicated that moderately polluted conditions dwelled in the three study stations, particularly the Chadwal stream where the high H' value could be attributed to large anthropogenic pressures. Presently, the H' index demonstrated a direct correlation with evenness ($r = 0.95$, $p< 0.05$) and supports the results shown by Nair.[49] Fish breeding during the monsoon season adds new individuals to the stock resulting in an increase in the evenness during the pre-monsoon season. The study stations used had stable communities with low-stress conditions as indicated by the Simpson index. The Simpson index was found to be highly correlative with the Shannon-Wiener index ($r = 0.98$, $p< 0.05$) in the present work.[50] Since fishing ground in the Chadwal stream was rather large and offered a diversity of microhabitats and resources to the fish species, a high Margalef richness index in this stream indicated the presence of a significant number of species. The Margalef index exhibited a positive and direct correlation with the H' index ($r =0.93$) emphasizing the relation between species diversity and the dominance diversity in a natural community.[49] Diversity indices thus exhibited a spatial variation with high diversity at Chadwal due to a stable and less contaminated stream ecosystem while pre and post-monsoon months showed high diversity leading to temporal variation in the fish assemblage.

The use of multivariate analysis was sufficient for analysing changes in fish communities and the environmental characteristics associated with them. In this work, PCA analysis of environmental parameters as statistical variables revealed the importance of these parameters in affecting the water quality of the three study sites. This could be owed to the importance of environmental variables in determining water quality and related parameters since PC1 accounted for 39% of the variance with substantial positive loadings on Group 1 variables. Zhou's[51] findings were comparable with these results and corroborated our findings. Air temperature, water temperature, alkalinity, pH, DO, rocks, sand, and silt made up 28.9% of PC2 variables, and these variations in the water were assumed to be related to anthropogenic interferences. Chemical factors and water velocity had a favourable link with *Barilius vagra*, *Tor tor*, *Acanthocobitis botia*, *Rasbora rasbora*, and Schistura denisoni in the Bhini stream. These hardy, hill stream species needed a higher pH and DO, as well as a shallow and fast-flowing water current, to survive. *Tor putitora*, *Crossocheilus diplochelius*, *Amblyceps mangois*, *Glyptothorax pectinopterus*, *Channa punctatus*, and *Puntius sophore* preferred a clear, deep water stream with higher DO and lower FCO_2

which was available to them at the Jhajjar stream. *Danio devario*, *Xenentodon cancila, Labeo dero*, *Puntius ticto*, *Garra gotyla*, and *Barilius bendelisis* were alkalinity tolerant but they needed more sand and silt in the substratum to grow which was available in the Chadwal stream. Because various species had distinct environmental requirements, they responded to changes in these variables in different ways leading to spatial and temporal disparity. Our findings were in line with those of Liu[52] and Agostinho,[53] who found that fish assemblage structure changed spatially and was influenced by fluctuations in environmental parameters.

Cluster analysis indicated two major groups in fish assemblage showing a 70% similarity with each other. In general, samples from Group 1 maintained a similarity with Group 2. The Bhini and Chadwal stations showed some similarity as they were situated close to each other and had roughly similar environmental parameters whereas the Jhajjar stream showed quite a dissimilarity with these streams as it was located farther with varied environmental conditions. Although their amount of contribution varied, the major contributing species in the three streams were more or less comparable. The main driver behind similarity and dissimilarity was seasonality, as it changed hydrological conditions and thus impacted the fish fauna in estuaries.[43,54,55]

Species richness showed a correlation with FCO_2, Ca^{2+} and Cl^- in all the sampling stations.[56,57,58,59] The sampling areas with lower elevation had a higher amount of species while the species number decreased as elevation increased supporting Rapoport's rule.[60,61] These results resembled other studies conducted in the Yangtze river basin,[62] in the Southern Appalachians,[63] in the Himalayas[64] and in the Central Andes.[65] These alterations in species diversity along the altitudinal gradient could be a result of altering climatic conditions or modifications to the dynamics of habitat structure and sampling stations. The station with the lowest elevation i.e. Chadwal stream had a slow running stream with a moderate water temperature throughout the year and more silt and sand in the substratum which was suitable for the fish species like *Puntius conchonius, P. ticto*, *Xenentodon cancila, Danio devario* and *Chela bacaila*.[23,66,67] The sampling station with the highest elevation i.e. the Bhini stream had a lower number of species in general. But the stream was less deep and fast flowing with higher oxygen concentration and had more rocks and plants in the substratum providing a suitable environment for hill stream fishes like *Barilius vagra*, *Lepidocephalichthys guntea*, *Tor tor*, *Crossocheilus latius* and *Labeo dero* as these species tend to prevail in shallow, swift-flowing streams with more plants and oxygen for food requirements and rocks for attachment and protection from predators.[68]

Conclusion

The present study was able to evaluate changes in fish assemblages spatially and temporally using environmental data. This study thus revealed that fish assemblages in River Ravi and Chenab varied significantly spatially but to a very small extent temporally. It was also deduced that different environmental variables had varying effects on fish populations in different sampling streams studied. The uncovered information in this study can be used to track the health of small rivers and streams in a regional ecosystem. Research on aquatic ecosystem diversity and ecological operations (such as preservation, restoration and acclimatization) could help in proper economic planning and execution by generating fact sheets on the distribution of rare and endangered fish species.

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Conflict of Interest

No potential conflict of interest was declared by the authors.

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