Environmental Impacts On Seasonal Fish Diversity In Jamuna River, Bangladesh

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Abstract:
Jamuna River is one of the vital rivers in Bangladesh for its rich aquatic biodiversity. A total of 52 fish species were recorded during the study period, belonging to 9 orders, 20 families, from the three selected locations of the river. Fish populations are the highest during the dry winter season and the lowest during the monsoon season. The mean values of Shannon-Weaver diversity, Margalef's richness, and Pielou's evenness indices recorded as 3.29± 0.02, 0.58±0.01, and 7.00±0.10, respectively, varied from season to season. Nonmetric MDS and Canonical Correspondence analysis were used to evaluate the effect of environmental factors on the structure of the fish assemblage. The Nonmetric Multidimensional Scaling (nMDS) had attained in two groups in the cluster analysis, one of which showed the association of the fish samples between the summer and winter seasons, and the other included the species from the monsoon season among the sampling sites. The fish species responsible for the fluctuation in seasonal abundance up to a cumulative dissimilarity of 21.85%, and four species were responsible for this dissimilarity. Canonical correspondence analysis on the fish community was used to demonstrate the fascinating functions of alkalinity, total dissolved solids, electrical conductivity, and dissolved oxygen in Jamuna River.

Keywords: Jamuna river, Environmental variables, Fish assemblage, Seasonal variation, Diversity indices.

Introduction:
Bangladesh is surrounded by tremendous fisheries resources where fish are caught from different sources (Haque et al., 2021). It consists of around 800 rivers with a total length of 24,140 km (Banglapedia 2012; DoF 2013), indicating the country's impressive fishing capacity; Bangladesh is the third-largest producer of freshwater fish in the world (FAO, 2018), and 265 fish species are available in different types of freshwater bodies in Bangladesh (Rahman, 2005). In Asia, fish biodiversity ranks third (Hussain and Mazid 2001). Jamuna River is the second largest river in Bangladesh and one of the largest rivers in the world. It is the main distributary tributary of the Brahmaputra River as it flows from India to Bangladesh. Every year a large number of fish are caught in this river. During 2016-2017, 3793 metric tons of fish are obtained from Jamuna River (DoF, 2017). Mondol et al., (2015) reported that 49 species of fish from 8 orders and 8 families live in this river. Although, this river is a natural breeding ground for freshwater fish, but in recent years, the diversity of fish in the natural habitats of Bangladesh has gradually declined. The natural breeding ground is destroyed by environmental factors and the use of harmful fishing gear, overfishing, and illegal activities in the river. Throughout the last century, overexploitation and habitat degradation have reduced the fish population in riverine systems (Rahman et al., 2012). The demand for freshwater fish has been increasing day by day. However, the IUCN (2015) lists 64 species as threatened, accounting for 25.3% of the 253 fish species assessed. There are 9 species that are Critically Endangered (CR), 30 are Endangered (EN), and 25 are Vulnerable (VU). A total of 27 species were classified as Near Threatened (NT), 122 as Least Concern (LC), and 40 as data deficient (DD). The structure and function of organisms are destroyed by the destruction of the river ecosystem (Mohammed et al., 2013). The deterioration of water quality is one of the significant reasons for the decrease in the diversity and abundance of fish species in aquatic environments (Galib et al., 2018; Islam et al., 2017; Afrose and Ahmed et al., 2016; Rahman et al., 2015). The diversity of fish populations in a water body is determined by the ecological balance of water body. The quality of a water body depends upon its alkalinity, dissolved oxygen, temperature, pH, electrical conductivity, total dissolved solids (Shahnawaz et al., 2010; Brander., 2007; Allison et al., 2009). The temperature fluctuation in river water usually depends on the season, geographic location, sampling time, and temperature of effluents entering the stream (Ahipathy et al. 2006). Oxygen levels are essential for many aquatic organisms. Fish will suffocate if oxygen levels drop below 1 part per million (ppm) (Horne et al. 1994). Oxygen levels of 5 to 6 ppm are usually required for most aquatic organisms to live comfortably (APHA, 1995). The problem today is not only about water access but also ecological balance. Seasonal variation can have an impact on water quality parameters. Environmental variables like total dissolved solids, electrical conductivity (EC), dissolved oxygen (DO), and pH were affected by aquatic assemblage structure, which impacted overall fish production.
To conserve biodiversity in a specific area, we should first understand how different management practices affect diversity. The diversity index is a helpful measurement in the study of biodiversity and provides numerous clues regarding the abundance of species in a geographic area. The ability to quantify diversity in that way is an essential tool for biologists trying to understand community structure (Beals et al., 2000).
There is no study about environmental parameters' impacts on the Jamuna River's seasonal fish diversity. For this, the present work is aimed to assess the environmental effects on fish diversity along with the comprehensive biodiversity indices-based description of fish fauna in different seasons throughout the year in the Jamuna River.

Materials and methods:

Study area and duration:

The research lasted a year at three pre-selected stations (Station-1: Kalitola ghat, Station-2: Mothurapara ghat, and Station-3: Kutubpur Bazar) on the Jamuna River in Sariakandi, Bogura district, Bangladesh (Fig 1) . The environmental parameters and fish habitats are recorded during a year's three seasons (summer, monsoon and winter). Summer, monsoon, and winter seasons last from March to June, July to October, and November to February, respectively.

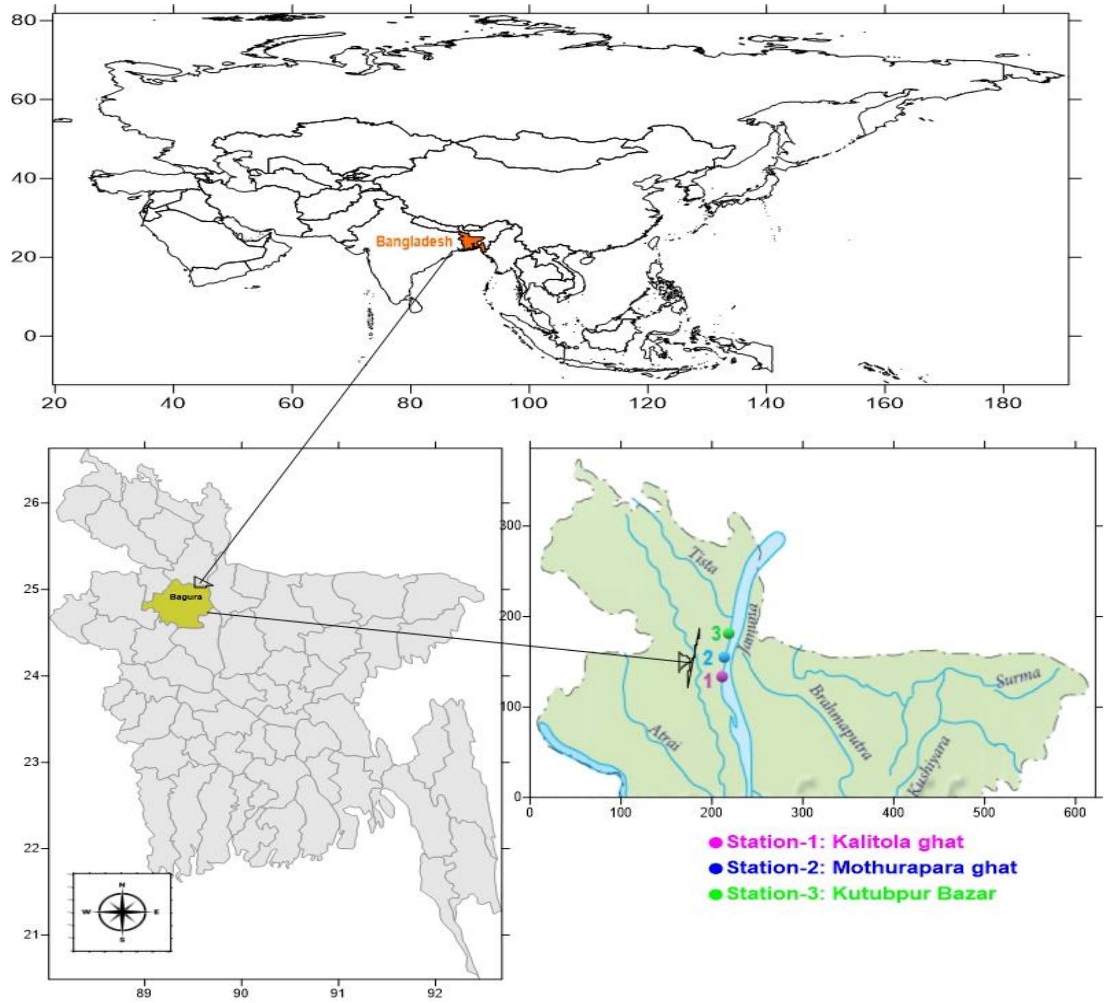

Fig.1. Locations of the sampling stations

Water Quality parameters measurement:

Samples were taken at each station for three seasons everyday. Surface water (500ml) was collected in a bottles for each site daily. Water quality parameters were measured on the river bank from 9:00 AM to 12:00 PM to assess the condition of aquatic environment. Water temperature was measured with a Celsius thermometer, and pH was measured with an electronic pH meter (Jenway 3020, UK). The HACH kit (model DR-2010, USA) was used to assess dissolved oxygen (DO), free carbon dioxide (CO2), and alkalinity of the samples. The Adwa AD31 Water EC/TDS tester measures electrical conductivity (EC) and total dissolved solids (TDS).

Fish sampling and identification:

Fish samples were collected at specific sampling points by skilled local fishermen everyday. Many types of gears, namely, gill net (current jal, sursuri jal, panti jal), seine net (ber jal/koiya Jal, moi jal, kochal jal, ghurni ber jal), lift net (dharma jal), cast net (jhaki jal), dragged gear (thela jal, moiya jal), fish traps (china jal, darki, kate, polo), hooks and line (borshi, hazari borshi or long line) were used for capturing fish species. Finally, the fish species collected were identified based on their morphometric and meristic characteristics according to Quddus and Shafi (1983), Quddus et al. (1988), Rahman (2005), Talwar and Jhingran (1991), and Roy et al. (2007).

Study of fish diversity indexes:

Shannon–wiener diversity index, Margalef's richness index, and Pielou's evenness index are suitable indicators to evaluate diversity, and we can analyze their response to environmental variables. The using formulas were:

Shannon-Weaver diversity index, $H = -Pi \times lnPi$ (Shannon-Weaver, 1949) [Where H stands for the Shannon-Weaver diversity index, ln is the natural logarithm, and Pi denotes relative abundance]

Margalef's richness index, $D = (S–1) / ln(N)$ (Margalef, 1968) [D denotes the richness index, N denotes the total number of species, S denotes the total number of species, ln is the natural logarithm]

Pielou's evenness index, $E = H / ln(S)$ (Pielou, 1966) [E denotes similarity or evenness, and ln is the natural logarithm, S is the total number of species]

Statistical analyses:
Environmental variables and fish abundance data were standardized by log10 (*x* + 1) transformation to minimize the possibility of distributional assumptions. Determination of F-value and P-value of environmental variables One-way ANOVA test was used. Principal component analysis was practiced to interrelate the environmental variables with the fish community. Nonmetric multidimensional scaling (nMDS) was used for assessing the similarity index of fish species assemblage. Analysis of similarity (ANOSIM) was taken to evaluate the variation in fish abundance. In the same way, Similarity percentage (SIMPER) analysis (Clarke and Warwick 1994) was practiced to assess the average contribution of each group among three seasons. The similarity matrices of the fish community are evaluated using the Bray-Curtis similarity index (Bray and Curtis 1957) method. Conical Correspondence analysis (CCA) revealed possible relationships between fish abundance and environmental variables. Finally, Statistical studies of the CCA relationships were conducted using a Monte Carlo permutation test. Paleontological Statistics software (Past) version 4.03 is used to analyze ANOVA, ANOSIM, SIMPER, and diversity indices of the fish population.

Result
Environmental parameters:
The environmental variables recorded throughout the study period are presented in Table 1. Seasonal variation severely changed the ecological status of Jamuna River. The highest average temperature was recorded during the summer season (31.23 ± 0.49 °C) due to the tropical nature of the study area. Due to water temperature, DO was notably lower during this season (5.32 ± 0.15 mg/L).

Table 1: The Mean and standard deviation values of environmental parameters of Jamuna River, Bangladesh.

Parameters	Summer	Monsoon	Winter	F Value	P Value
Water temperature (°C)	31.23±0.49	28.67±0.18	20.02±0.96	260.2	0.0010
Transparency	33.16±0.16	22.39±0.94	28.18±0.64	200.2	0.0006
pH	7.66±0.05	8.68±0.19	7.71±0.16	84.3	0.0004
Dissolved oxygen (mg/l)	5.32±0.15	6.75±0.12	7.35±0.21	93.73	0.0005
Total alkalinity (mg/l)	118.44±0.69	91.22±4.44	107.67±2.08	68.98	0.0030
Total dissolved solids (ppm)	133.44±1.64	116.56±2.14	124.44±1.26	72.36	0.0016
Electrical conductivity (µS/cm)	140.22±0.51	114.44±2.36	125.78±0.69	237.1	0.0023

More than that, fluctuations in DO are substantially affected by water temperature. The river's decreased water depth and flow gradually increased the number of pollutants in the water by raising alkalinity, TDS, and EC levels. However, the increased water flow during the monsoon season significantly improved the river's water quality. Seasonal differences in the environmental parameters were also narrated through PCA, and the first two axes were obtained to achieve the interpretation that jointly explained 99.60% of data variability. PCA 1 and 2 clearly distinguished the environmental parameters among the seasons (Fig.2). However, PCA 1 positively correlated with water temperature, transparency, total alkalinity, TDS, and EC. Inversely, PCA 2 became negatively prompted through water temperature and showed a negative relationship with DO and pH (Fig.2).

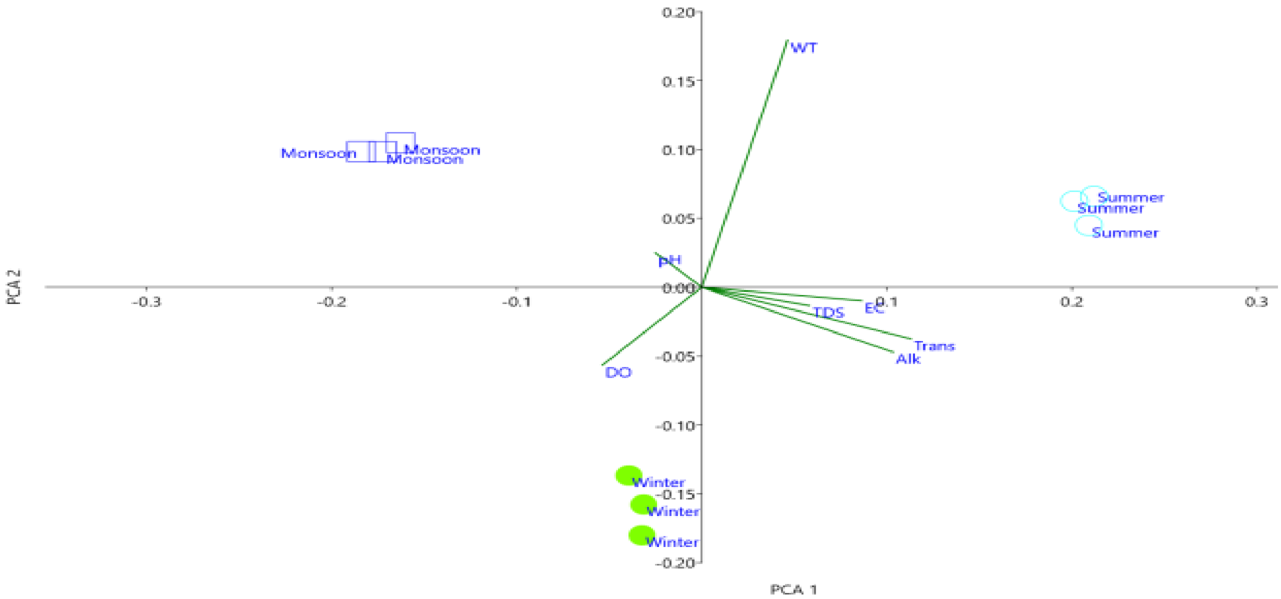

Fig.2. Principle component analysis of environmental parameters of Jamuna River, Bogura, Bangladesh during summer, monsoon, and winter seasons (Wt = Water temperature, DO = Dissolved oxygen, CO2 = Carbon dioxide, Alk = Total alkalinity, TDS = Total dissolved solids, EC = Electrical conductivity).

Fish Community Structure:
Fifty-two fish species belonging to nine orders and 20 families were identified from Jamuna River during the study period (Table 2). The total abundance of fish species with seasonal variation and species codes, percentage of total catch, IUCN Status for Bangladesh and global are also mentioned in the table 2. The most abundant species belonged to the family Cyprinidae (16 species).

Table 2: List of fish species collected during each season with their individual code in the Jamuna River, Bogura, Bangladesh**.**

Order	**Family**	**Scientific Name**	**English Name**	**Local Name**	**Code**	**% of Total Catch**	**Summer**	**Monsoon**	**Winter**	**IUCN Status (Bd)**	**IUCN Status (Global)**
Anguilliformes	Ophichthidae	*Ophisternon bengalense*	Bengal eel	Bamush	Ob	0.02	+	-	+	VU	NT
Cypriniformes	Cobitidae	*Johnius coitor*	Coitor Croakers	Bhola	Jc	0.07	-	+	-	NT	LC
		Botia Dario	Bengal loach	Bou/Rani	Bd	0.54	+	+	+	EN	LC
		Botia lohachata	Reticulate/ Y-loach	Kayakata	Bl	5.20	+	+	+	EN	NE
	Cyprinidae	*Barilius barila*	Barred baril	Baril/Borali	Bb	0.68	+	+	+	EN	LC
		Labeo bata	Bata	Bata	Lb	1.17	+	+	+	LC	LC
		Puntius chola	Swamp barb	Chola puti	Pc	7.83	+	+	+	LC	LC
		Salmostoma bacaila	Large razorbelly minnow	Chela	Sb	5.20	+	+	+	LC	LC
		Esomous danricus	Flying barb	Darkina, Darka	Ed	7.60	+	+	+	LC	LC
		Rohtee cotio	Cotio	Dhela	Rc	7.83	+	+	+	NT	LC
		Puntius sophore	Pool barb	Jatputi	Ps	5.41	+	+	+	LC	LC
		Labeo calbasu	Orange-fin labeo	Kalbaus	Lc	0.49	+	+	+	LC	LC
		Catla catla	Catla	Catal, Catla	Cc	0.64	+	+	+	LC	NE
		Amblypharyngodon mola	Mola carplet	Mola, Moa	Am	7.83	+	+	+	LC	LC
		Cirrhinus mrigala	Mrigal carp	Mrigel	Cm	0.45	+	+	+	NT	VU
		Labeo rohita	Roho labeo	Rui	Lr	0.46	+	+	+	LC	LC
		Puntius sarana	Olive barb	Sarputi	Psa	0.66	+	+	+	NT	LC
		Puntius ticto	Ticto barb	Titputi	Pt	5.41	+	+	+	VU	LC
		Aspidoparia jaya	Jaya	Sorili	Aj	2.28	+	+	+	LC	NE
		Barilius barila	Barred baril	Baril/Borali	Bb	0.68	+	+	+	EN	LC
Clupeiformes	Clupeidae	*Gudusia chapra*	Indian river shad	Chapila	Gc	0.68	+	+	+	VU	LC
		Tenualosa ilisha	Hilsa shad	Ilish	Ti	0.47	+	+	+	LC	LC
Osteoglossiformes	Notopteridae	*Notopterus chitala*	Clown knifefish	Chital	Nc	0.05	-	+	+	EN	NT
		Notopterus notopterus	Bronze featherback	Foli	Nn	0.06	+	-	+	EN	NT
Perciformes	Osphronemidae	*Colisa fasciata*	Banded gourami	Boro kholisha	Cf	5.61	+	+	+	NO	LC
		Colisa lalia	Dwarf gourami	Lal Khailsa	Cl	2.33	+	+	+	NO	LC
	Gobiidae	*Glossogobius giuris*	Tank goby	Bele/Baila	Gg	1.59	+	+	+	LC	LC
	Ambassidae	*Chanda nama*	Elongate glass-perchlet	Nama chanda	Cn	2.38	+	+	+	LC	LC

		Parambassis ranga	Indian glassy fish	Ranga chanda	Pr	5.38	+	+	+	LC	NE
	Nandidae	*Nandus nandus*	Mud perch	Bheda/Meni	Nna	0.30	+	-	+	NT	LC
	Channidae	*Channa striata*	Snakehead murrel	Shol	Cs	1.02	+	+	+	LC	LC
		Channa marulius	Giant snakehead	Gojar	Cm	0.54	+	+	+	EN	LC
		Channa punctata	Spotted snakehead	Taki	Cp	1.03	+	+	+	LC	LC
Perciformes	Belonidae	*Xenentodon cancila*	Freshwater garfish	Kaikka	Xc	1.17	+	+	+	LC	NE
Siluriformes	Sisoridae	*Gogangra viridescens*	Huddah nangra	Gang tengra	Gv	2.32	+	+	+	CR	LC
		Mystus vittatus	Stripped dwarf catfish	Tengra	Mv	2.33	+	+	+	LC	LC
		Bagarius bagarius	Gangetic goonch	Bagair	Bb	0.02	-	-	+	CR	NT
	Siluridae	*Wallago attu*	Freshwater shark	Boal	Wa	0.09	+	-	+	VU	NT
		Mystus tengara	Tengara mystus	Bujuri Tengra	Mt	2.32	+	+	+	NO	LC
		Ompok pabda	Pabdah catfish	Pabda	Op	0.64	+	+	+	CR	NT
	Bagridae	*Mystus aor*	Long whiskered catfish	Ayre/Aor	Ma	1.07	+	+	+	VU	LC
		Rita rita	Rita	Rita	Rr	0.58	+	+	+	EN	LC
		Sperata seenghala	Giant River Catfish	Veush	Ss	0.83	+	+	+	VU	LC
	Schilbeidae	*Eutropiichthys vacha*	Batchwa vacha	Bacha	Ev	1.91	+	+	+	LC	LC
		Ailia coila	Gangetic alia	Bashpata	Ac	1.58	+	+	+	LC	NT
		Clupisoma garua	Garua bacha	Ghaura	Cg	0.94	+	+	+	EN	NE
	Pangasidae	*Pangasius pangasius*	Pungas	Pangas	Pp	0.50	+	+	+	EN	LC
Synbranchiformes	Mastacembelidae	*Macrognathus pancalus*	Striped spiny eel	Guchi	Mp	0.68	+	+	+	LC	LC
		Macrognathus aculeatus	Lesser spiny eel	Tara baim	Mac	0.31	+	-	+	NT	NE
	Mastacembelidae	*Mastacembelus armatus*	Zig-zag eel	Sal baim	Mar	0.34	+	-	+	EN	NE
	Synbranchidae	*Monopterus cuchia*	Mud eel	Kuchia	Mc	1.05	+	+	+	VU	VU
Tetraodontiformes	Tetraodontidae	*Tetraodon cutcutia*	Ocellated pufferfish	Potka	Tc	0.09	-	+	+	LC	NO

In the Figure 3 shows that Cypriniformes was the most dominant order (60.18%), followed by Perciformes (21.32%) and Siluriformes (14.92%). Cobitidae, Channidae, Sisoridae, Siluridae, Schilbeidae, and Mastacembelidae constituted three species each, and Notopteridae, Osphronemidae, Ambassidae, Clupeidae, and Notopteridae constituted two species each. Seven other families included only one species each.

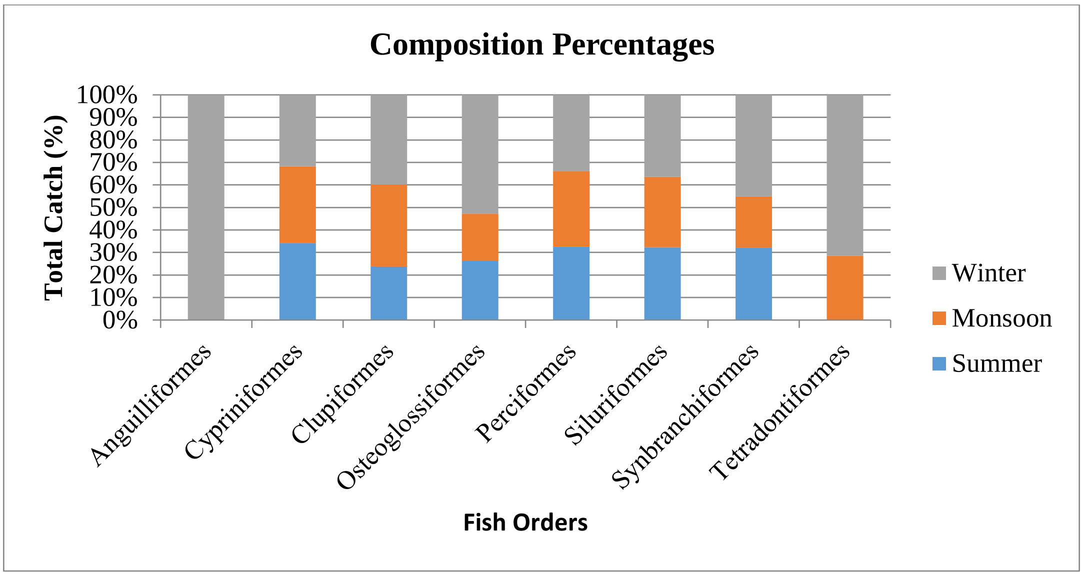

Fig.3. Order-wise percent composition of fishes collected from Jamuna River, Bangladesh.

Principle component analysis of fish species of Jamuna River during Summer, monsoon and winter seasons are presented in the Figure 4. PCA 1 and 2 showed a clear dissimilation in the species assemblage among the seasons (Fig. 4). PCA 1 showed a positive relationship with *Botia lohachata* (Bl), *Puntius chola* (Pc) , *Salmostoma bacaila* (Sb), *Esomous danricus (Ed)*, *Rohtee cotio* (Rc) , *Puntius sophore* (Ps), *Puntius ticto* (Pt), *Aspidoparia jaya* (Aj), *Colisa fasciata* (Cf), *Glossogobius giuris* (Gg) etc. and these fishes were more dominant in winter season. Inversely, PCA 2 showed a negative relationship among these species in monsoon because these species are less available during monsoon season. Swamp barb (*Puntius chola*, 7.83%), Flying barb (*Esomous danricus*, 7.60%), and Cotio (*Rohtee cotio*, 7.83%) were the commonly caught fish species followed by Pool barb (*Puntius sophore*, 5.41%), Banded gourami (*Colisa fasciata*, 5.61%), Indian glassy fish (*Parambassis ranga*, 5.38%), Large razor belly minnow (*Botia lohachata*, 5.20%) and others. However, the least proportion of the total catch was constituted equally by Freshwater shark (*Wallago attu*) and Oscillated puffer fish (*Tetraodon cutcutia*) at 0.09% was found in Jamuna River during the study period.

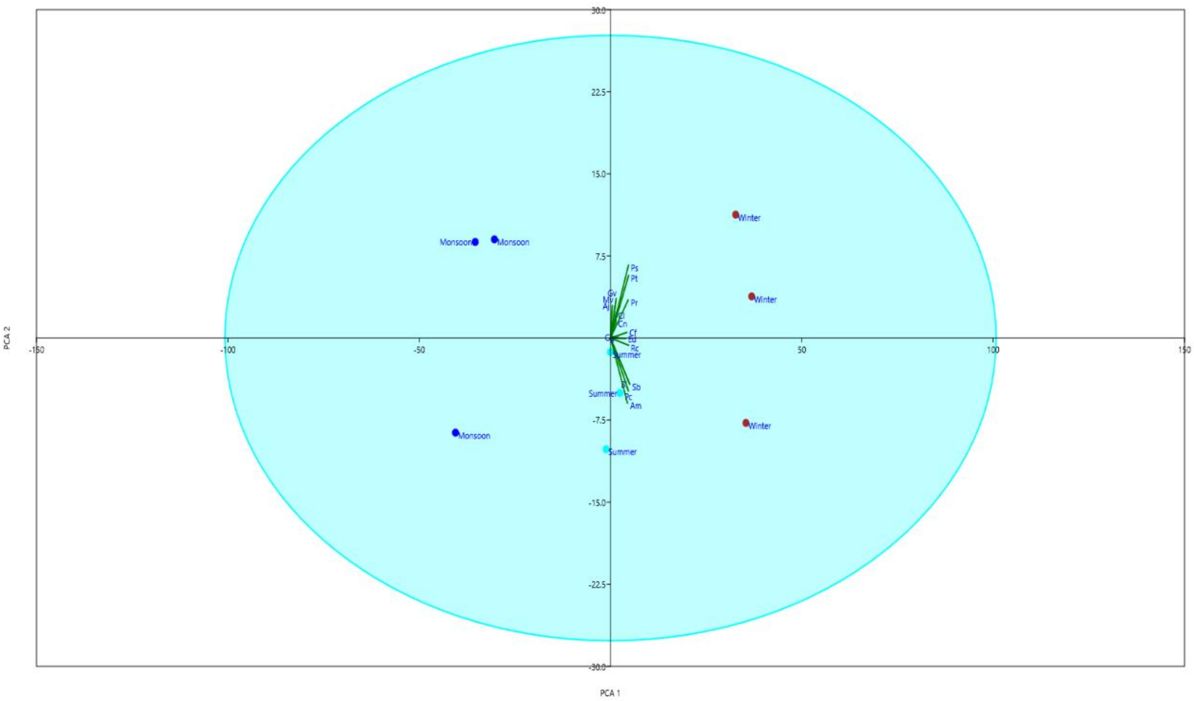

Fig. 4. Principle component analysis of fish species of Jamuna River, Bogura, Bangladesh during Summer, monsoon and Winter seasons. For species codes, refer to Table 2.

Nonmetric multidimensional scaling (NMDS) primarily based on Bray–Curtis's similarity index discovered that the monsoonal fish assemblage separated from the other two groups (Fig.5). The fish samples of all sampling seasons were divided into two groups. The first group indicated the association of the fish samples between the summer and winter seasons (right side of Fig. 5), and the second group consisted of the pieces from the monsoon season (left side of Fig. 5). However, the data were identical, so they did not differ among the stations. Meanwhile, a significant difference in species composition was also observed among the seasons according to ANOSIM ($P < 0.0037$, $R = 1$). SIMPER analysis stated an overall average dissimilarity of 9.816% among the seasons. SIMPER also revealed that the fish species responsible for the variation in seasonal abundance of up to the cumulative dissimilarity of 21.85% were as follows: *Mastacembelus armatus* (6.159%; *Macrognathus aculeatus (*6.017%); *Nandus nandus* (5.539%) and *Rita rita* (4.139%).

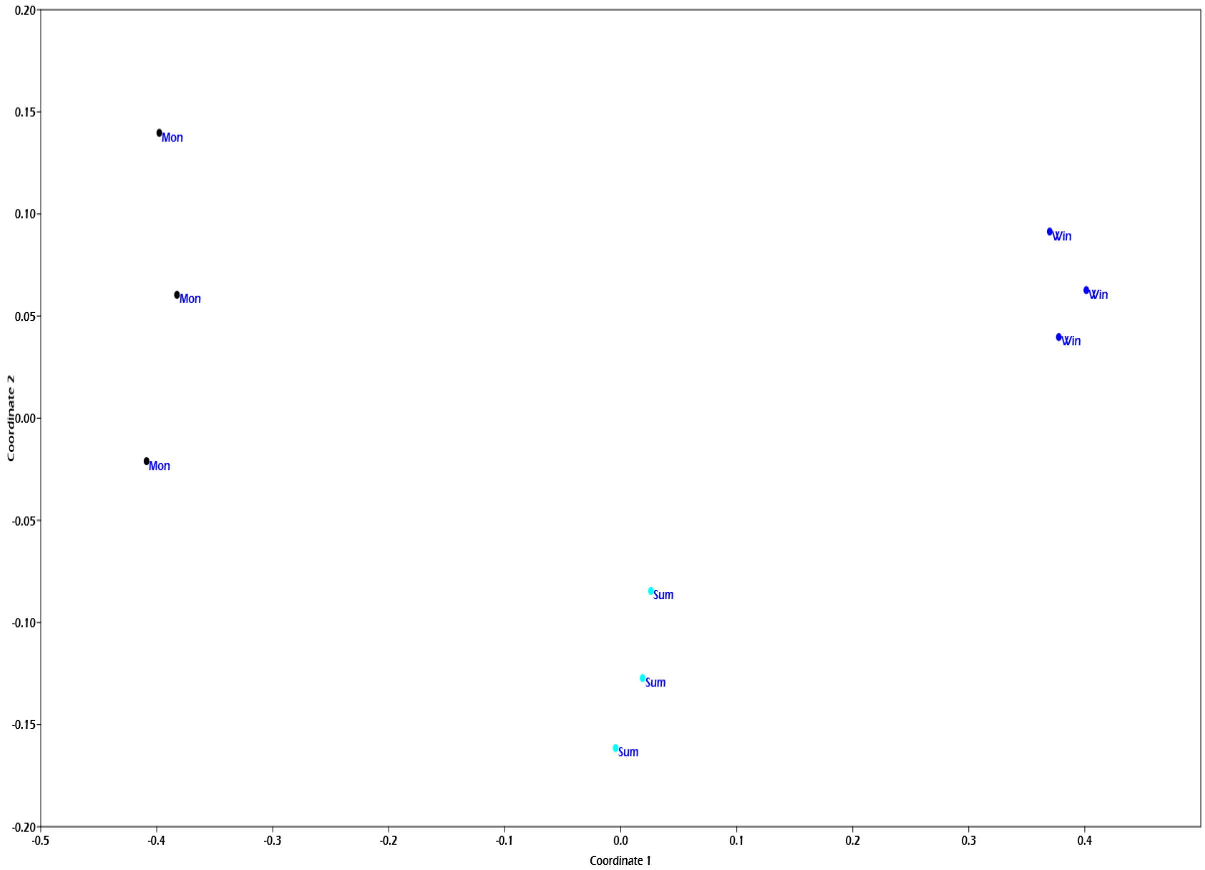

Fig. 5. Nonmetric multidimensional scaling (NMDS) plotting of log10 (1 + *X*) transformed fish species abundance data of Jamuna River, Bogura, Bangladesh based on Bray-Curtis Similarity resemblance matrix.

The season-wise values of Shannon–Wiener diversity, Pielou's evenness, and Margalef's richness indices are shown in the (Fig. 6). Outcomes of Shannon–Wiener diversity indexes are 3.25 ± 0.02 (summer), 3.20 ± 0.00 (monsoon) and 3.44 ± 0.0 (winter). Pielou's evenness explained diversity 0.56 ± 0.02 (summer), 0.57 ± 0.01 (monsoon) and 0.61±0.01 (winter). Margalef's richness revealed diversity 6.99 ± 0.09 in summer, 6.73 ± 0.13 in monsoon and 7.28±0.10 in winter.

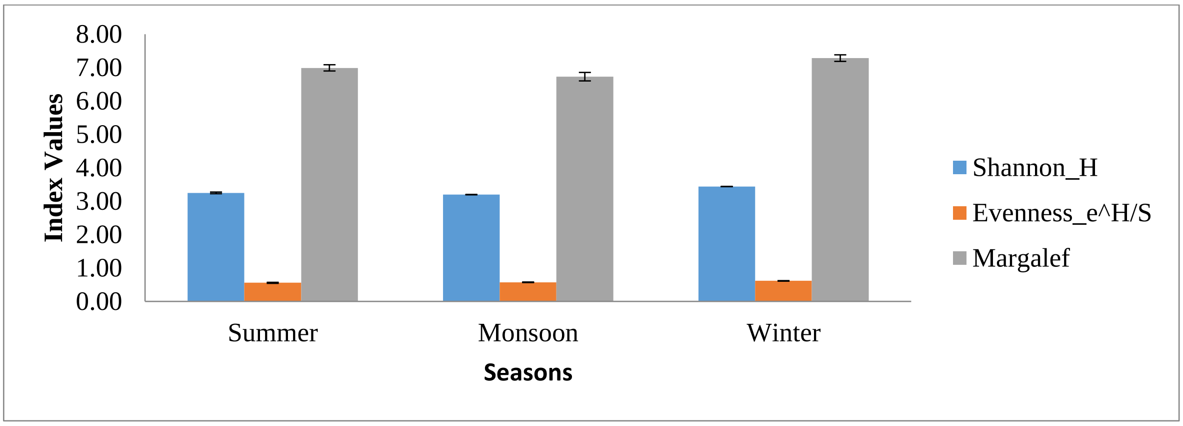

Fig. 6. Values of Shannon-Wiener diversity index, Pielou's evenness index and Margalef's richness index in the three different seasons in Jamuna River, Bogura, Bangladesh.

In a paired group algorithm, Bray–Curtis's similarity index revealed that the species were divided into two clusters at 85% of similarities (Fig. 7). The first cluster indicated the association of the fish samples between the summer and winter seasons, and the second cluster consisted of the samples from the monsoon season (Fig. 7).

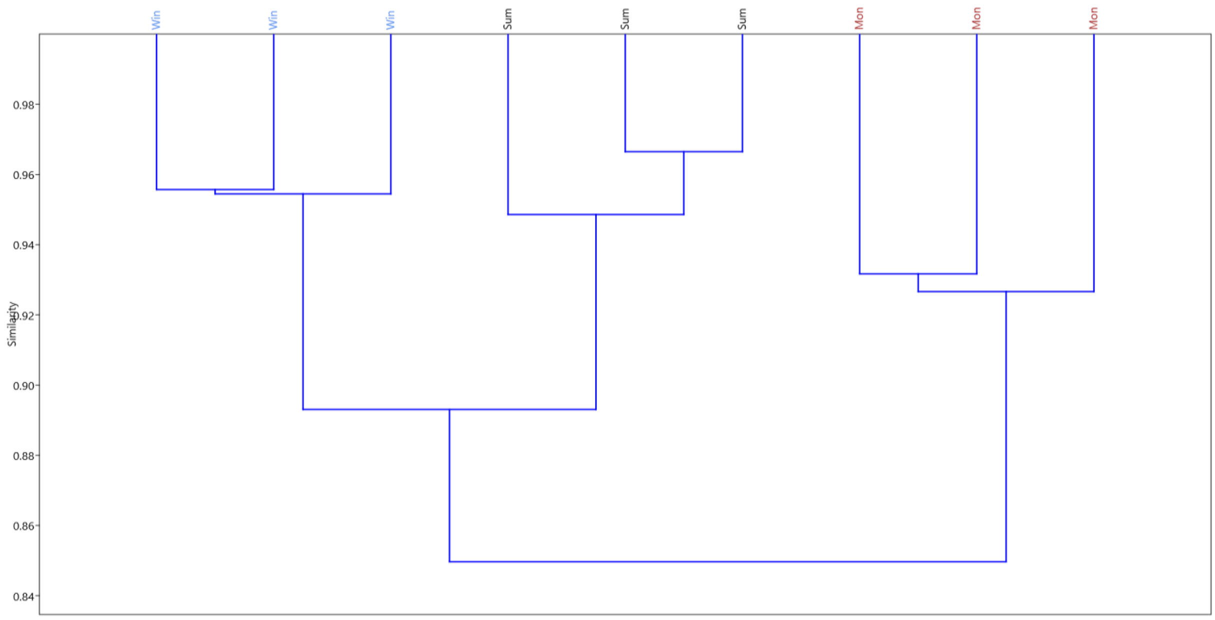

Fig. 7. Dendrogram of clusters based on Bray-Curtis similarity matrix of the different seasons showing structural variability of the fish communities.

Interaction between environmental parameters and fish species abundance:
The first two axes of the CCA (Fig. 8) cumulatively explained 60.56% of the variance in the species-environment biplot (axis 1, 68.33%, eigenvalue 0.009; axis 2, 17.09%, eigenvalue 0.002). The permutation test justified the significance of the CCA model at the 0.001 level. Moreover, only axis 1 showed a remarkable value in the permutation test. Axis 1 is positively correlated with pH and water temperature and negatively correlated with DO, alkalinity, transparency, and TDS contribute to the structure of fish species from summer to winter. Axis 2 influences the fish species that were common in all seasons.

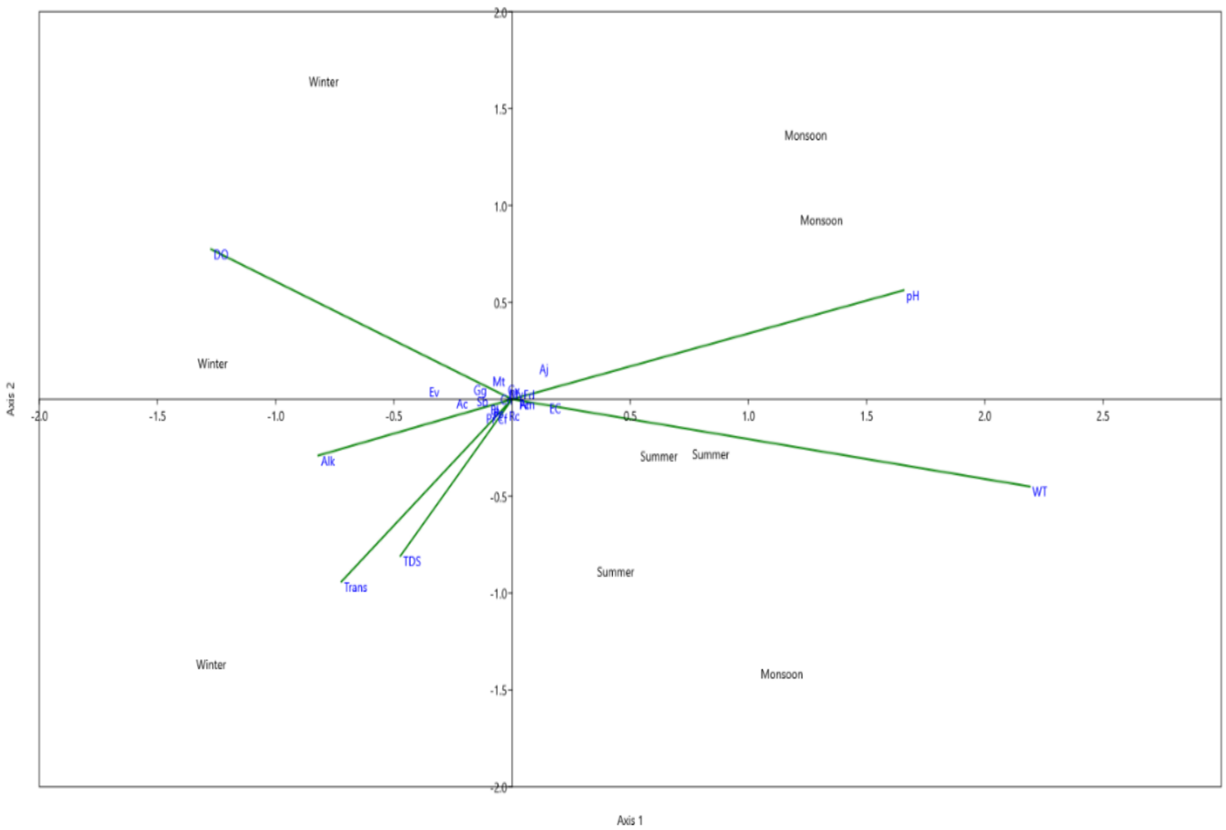

Fig. 8. Canonical correspondence analysis of fish species and environmental factors. The arrows represent the relative relevance and direction of change in the environmental factors. WT = water temperature, DO = dissolved oxygen, Alk = alkalinity, TDS = total dissolved solids, Trans =Transparency and EC= electric conductivity. For species codes, refer to Table 2.

Discussion:

Fish biodiversity is strongly influenced by habitat structure, composition and water quality (Shetty et al 2015). Therefore, changes in water quality parameters affect fish distribution, survival, and assemblage structure. In our present study the dominance of Cypriniformes (60.18%) was observed over other fish orders due to seasonal variations which is correlated with different environmental factors. Remarkable seasonal variations in the water quality parameters were observed during the study period and had several similarities with Islam et al. (2017) findings. The interpretation of species abundance may be due to the changes in hydrological parameters (Hossain et al., 2012). Hasan and Tripti (2021) showed that Cypriniformes (43%) are the most dominant group, followed by Siluriformes (33%) and Perciformes (19%) in the Old Brahmaputra River. Similar findings were also reported by Galib et al. (2009), Imteazzaman and Galib (2013), Sultana et al. (2018), Jewel et al. (2018), and Akhi et al. (2020). In the study area, due to the significance of the aquatic environment in their evolution and seed reproduction, the Cypriniformes order contained the highest number of fish species (Hanif et al. 2016). In our study, fish populations peaked in the winter and at their lowest during the monsoon due to the feed availability. The water levels of the river were scarce during the winter. Therefore, Fish abundance increased during this season, and fishes have become greater vulnerable to seize (fishery activities). Conversely, the increase in water level resulting from rainfall and flooding at some stage in the monsoon season reduces the efficiencies of fishing gears in catching the specified quantity of fish species (Galib et al. 2016, 2018). The conditions of the monsoon season also can affect the water body by lowering the available feed assets, affecting the fish assemblage shape.

Shannon-Weiner index accounts for both abundance and evenness of the species present in an area. In this study area, Shannon–Wiener diversity fluctuated from 3.20 to 3.44. While all species that make up a populace community are similarly plentiful, diversity is proven better. Akhi et al. (2020) conducted a study on the Karatoya River and showed the values of the Shannon-Weiner index fluctuated from 2.14 to 2.99, which was not more significant than the current findings. Margalef's richness is the most basic measure of biodiversity and is simply a count of the number of distinct species in a given area. This metric relies heavily on sample size and effort (Siddique et al., 2016). This study observed the lowest and highest Margalef's richness index value in summer and winter. We found Margalef's richness ranged from 6.73 to 7.28. Islam and Yasmin (2018) recorded a richness index of 4.793 to 7.438 on the Dhaleshwari River. Galib et al. (2018) assessed the fish species richness value in Bangladesh's Choto Jamuna River and found that values ranged from 6.973 in June to 8.932 in November, Jewel et al. (2018) recorded overall values of richness index in the Atrai River was 5.87, Rahman et al. (2015) was recorded the average values of richness (d) index 6.64 in the Talma River which was not higher than the present findings. Pielou's evenness index measures the evenness in which individuals are divided among the taxa present (Siddique et al., 2016). During the study period, we recorded the highest evenness value as 0.61 (winter) and the lowest value as 0.56 (summer), whereas the average value was recorded as 0.58 in the sampling area of the Jamuna river. We found a lower value of Pielou's evenness index than that Akhi et al. (2020) reported. However, Akhi et al. (2020) conducted a study on the Karatoya River and stated that the values of Pielou's evenness index fluctuated from 0.86 to 0.89, which was greater than the corresponding findings. On the other hand, Rahman et al. (2015) conducted a study on the Talma River, where the average value of the Evenness index was recorded as 0.86. These results differ from the present findings due to the study's different geographical locations. Therefore, the species equitability index for a few of the sampling areas and seasons suggests that the distribution of the Jamuna River's fish population is more or less diversified. The values are closely associated with Islam & Yasmin (2018); they recorded an evenness index 0.117 to 0.588 in the Dhaleshwari River, and Jewel et al. (2018) recorded overall values of the evenness index in the Atrai River was 0.66. The best values of Shannon–Wiener index and Margalef's richness index for the winter season have been additionally associated with the decreased water intensity for the time of this season, thereby leading to more fish species caught via fishery activities.

Conversely, the higher water depth at some stages in the monsoon season changed into liable for the lower values of Shannon–Wiener range and Margalef's richness. The reducing effect of monsoonal flood on the diversity and richness of fish species was reported by Rahman et al. (2015) in the Talma River in Northern Bangladesh. However, the variety of fish in the Karatoya River was satisfactory, according to Hussain et al. (2016), who reported that a Margalef's richness value of less than 3 indicates a poor diversity status. The diversity and richness index showed that the diversity of fish fauna becomes better inside the winter than in other seasons. The maximum number of fish species was also recorded during this time because water intensity was reduced to a minimum due to the lack of adequate rainfall, which permitted fishermen to hire their fishing gear more successfully. Nath and Deka (2012) also reported a similar result, who recorded the richest fish diversity in winter. The number of species was lowest during the Monsoon season because of heavy rain, which makes fishing very hard as the water stage reaches its maximum.

Seasonality can impact the environmental variables and fish assemblages of a water body (Kautza and Sullivan 2012). In the present study, TDS, EC, alkalinity, DO, and pH were the maximum crucial environmental variables that impact the shape of fish assemblages in Jamuna River. This finding is similar to Galib et al. (2018), who also reported that DO and pH could strongly influence fish assemblage patterns. The river water's chemical nature was more important than physical factors, as indicated by Tongnunui and Beamish (2009) and Suvarnaraksha et al. (2012). The above-mentioned phenomenon explains that the better recruitment of fish species all through the winter season was due to low temperature, and the decline in the fish abundance in the following season was possibly due to natural mortality, which took place with increasing temperature and lowering the water level. The decreased water level also increased the toxicity of pollutants. The increase in the river water's TDS, alkalinity, and EC might be responsible for the lower abundance of fish in the summer than in the winter. However, the effects of the climatic situation (rainfall) become primarily responsible for the decrease of fish abundance during the monsoon season.

The cluster analysis showed distinct separation. At the similarity of 85%, two significant groups were attained and indicated the association of the fish samples between the summer and winter seasons, and the second cluster consisted of the samples from the monsoon season. Hossain et al. (2012) found two different clusters of fish species at a similarity of 32% in the Meghna River of Bangladesh. Nasren et al. (2021) found two cluster groups with 72.9% similarity in the Ratargul swamp forest, with group A containing fish species from January, February, and March and group B containing fish species from April to December. On the other hand, Nonmetric scaling (nMDS) confirmed that the monsoonal fish assemblage became separated from the opposite two groups and that a significant difference in species composition was also observed among the seasons, according to ANOSIM. SIMPER evaluation revealed an overall 9.816% dissimilarity among the species in three seasons. Our findings appear to be supported by Akhi et al. (2020), who showed fish species responsible for variation in seasonal abundance of up to the cumulative dissimilarity of 21.41% in the Karatoya River.

In contrast to earlier findings, we found the cumulative dissimilarity of 21.85% was as follows: *Mastacembelus armatus* (6.159%; *Macrognathus aculeatus (*6.017%); *Nandus nandus* (5.539%) and *Rita rita* (4.139%). Barman et al. (2016) found 20% similarities in all seasons in the Karnafully River, and Rashed-Un-Nabi et al. (2011) found 65% similarities for finfish and shellfish in all seasons in the Bakkhali river estuary. Their findings are distinct from the overall results because of their different geographical locations, survey periods, and sampling error variation.

Conclusion:

Jamuna river is very important for its large number of natural fish production in Bangladesh. A large number of commercial and subsistence fisherman rely on this river for their livelihood. The seasonal variations in fish abundance indicates the influence of different types of environmental factors. This habitat are degrading day by day and fish diversity are reducing due to various factors. For habitat restoration immediate steps should be taken which would increase the fish diversity as well as the total production of Jamuna river. This present study will help to promote sustainable development of the Jamuna River.

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