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Habitat Characterization and Fish Community Structure in the River Ghaghara, India

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ABSTRACT

Habitat characterization, water quality assessment and freshwater fish diversity investigation of Ghaghara River flowing in Uttar Pradesh, India was carried out. River water was clear except at site S5 with pebbly and sandy substrate. The mean water quality of study sites was found to have pH 7.8, water temperature 25.8°C, dissolved oxygen 5.4 mg/l, total hardness 212 mg/l, alkalinity 179 mg/l (as $CaCO_3$), Turbidity 16.9 NTU, NO_3 1.7 mg/l, NO_2 0.04 mg/l, ammonia 0.3 mg/l and conductivity 390.2µS/cm. Altogether 62 fish species were recorded during the study. We used principal component analyses (PCA) to determine the influence of environmental conditions on species occurrences and assemblage characteristics. The MANOVA on habitat parameters showed a difference in habitat structure among the sampling sites. Our results suggest the significance of local environment influences on the fishes of conservation importance and their assemblage distinctiveness in an unimpacted river and provide a framework and reference conditions to maintain restoration efforts of relatively altered fish habitats in tropical rivers of India.

1) INTRODUCTION

Habitat characterization provides a foundation for understanding the relationships between biotic and abiotic components of a geographic region. Such assessments are essential to the management of natural resources within specified regions, including aquatic systems, such as oceans, lakes, rivers, and streams. Water is most important chemical compound for the perpetuation of life on this planet. In India, ponds, rivers and ground water are used for domestic and agricultural purposes. The quality of water may be described according to their physic-chemical and micro-biological characteristics. During recent years an alternative approach based on statistical correlation, has been used to develop mathematical relationship for comparison of physic-chemical parameters [1].

Approximately 75% of the earth is water, which constitutes aquatic ecosystem. The degradation of aquatic ecosystems and linked aquatic biodiversity is the worldwide concern, particularly for riverine landscapes [2] which are most affected due to ever increasing human intervention with increasing global population. Freshwater fishes may be the most susceptible group of vertebrates on earth after amphibians and the global extinction rate of fishes due to this degradation is believed to be in excess than higher vertebrates [3], as a result many of the aquatic species are declining rapidly. The study of the species distribution, which has long been a central focus of ecology and biogeography, is taking on new urgency as evidence of the global biodiversity crisis mounts [4]. Estimates of diversity are considered as indicators of the comfort of ecological systems. The well-documented patterns of spatial and temporal variation in diversity by early investigators of the natural world continue to stimulate the minds of ecologists today. Functional species diversity is an asset at the population level that is more strongly related to ecosystem stability and stresses, physical and chemical factors for determining population dynamics in the ecosystem. Hence, it is very important to study the factors adversely affecting the species diversity which depends not only the single ecosystem but on the interaction between ecosystems existing in a particular region for example aquatic fauna in aquatic ecosystem is remarkably affected by the terrestrial ecosystem of that region. It is necessary and need of the day to protect ichthyofaunal diversity in their natural habitat [5, 6]. Biodiversity and its conservation are regarded as one of the major issues of enabling sustainable use of natural resources. The principal reason behind the loss of biodiversity in freshwater are the impacts of habitat degradation and fragmentation, exotic species introduction, water diversions, pollution, and global climate change [7]. Among Indian rivers, the tributaries of river Ganges basin inhabit rich biodiversity that provides livelihood and nutritional safety to the country. Sufficient study however, of these tributaries has not been done in the past. In view of these facts, habitat characterization and spatial variation in fish species composition in river Ghaghara, India was done in the present

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study to know the present status of different sites of the river flowing in eastern region of Uttar Pradesh, India. The main objective of this study was to establish a correlation between the habitat conditions and the fish community structure.

2) MATERIAL AND METHODS

The present study comprises an extensive sampling in different sites of Ghaghara River, a major tributary of the Ganga river system in northern India. The river Ghaghara is one of the major tributaries of the Ganges, which rises, in the southern slopes of the Himalayas in Tibet at an altitude of about 13,000 feet (3962 meters) above sea level. In the state of Uttar Pradesh Ghaghara flows in a southeast direction to the town of Chhapra where after a course of 570 miles (917 Km) it meets the Ganges. The Ghaghara River is an important source of revenue in state of Uttar Pradesh by virtue of fisheries production and waterways. Agricultural production in its huge exceptionally fertile adjoining plains further augments its significance in the state. The major sub tributaries of Ghaghara i.e. Rapti, Sharda, Chhoti Gandak and Sarju bless the whole coverage with dynamism. The sampling points have been shown in the river map **(Fig 1)**.

2.1. Habitat Characterization: On the basis of many pre-field studies and also the literature records sample stations were selected in upstream, midstream and downstream areas based on the physical habitat structure and depth, water velocity, size and structure of the substratum and distance coverage [8]. A site might consist of several sub sites but most frequently only a single sub site. In the present study nearly 600 km stretch of the Ghaghara River in Uttar Pradesh was covered. The study was carried out at five sampling sites during May 2009 to September 2010; the sites were selected along the entire stretch of river Ghaghara **(Table 1)** and marked on the stretch **(Fig 1).** The four aspects in our study were followed as (1) habitat survey (2) habitat inventory (3) fish diversity (4) collection of water samples in different study sites.

Habitat measurements were made on 18 physical and chemical habitat parameters in view to monitor seasonal changes in the water quality parameters and their relation to fish species abundance and distribution. These include physical coordinates (latitude, longitude, and altitude (GPS). Water depth (m), water velocity (ms^{-1}) were determined by Water flow meter (JDC electronics SA; Switzerland) and depth meter (Speedtech Instruments make) respectively. Water temperature (^{o}C), pH, dissolved oxygen (mgL^{-1}), electrical conductivity (μScm^{-1}), total dissolved solids (TDS) were taken at the time of the survey using sensor based multi parameter

Fig.1: Location map of the study area

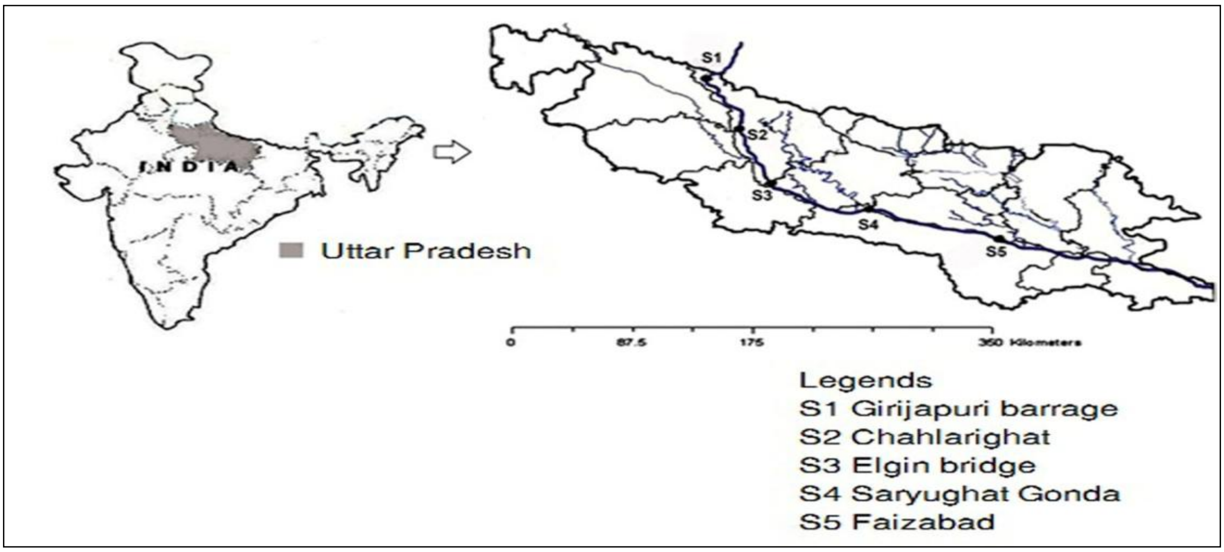


Table: 1 Sampling sites and their physical attributes

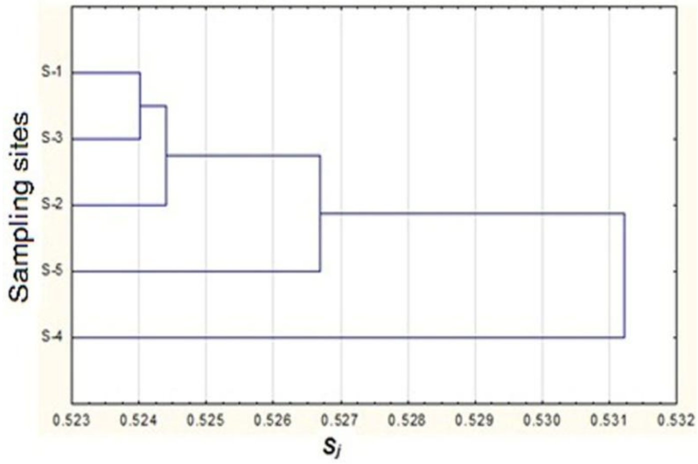
Name of site	Altitude (ft)	Stream type	Position	Land use pattern	Habitat type(s)
Girijapuri barrage	385	Upstream	28°16.321' N – 081 °05.467' E	Protected forest area, Barrage Agriculture, Rural Hamlets	CC, FW, DP, ShW, SW
Chahlarighat	350	Upstream	27°78.525' N – 81°16.621' E	Agriculture, Rural hamlets	FW, ShW, SW, FP
Elgin bridge	284	Midstream	27°05.680' N – 081°29.160' E	Agriculture, Semi urban, barrage, Domestic sewage	FW, FP, DP, OR, SW
Saryughat, Gonda	258	Downstream	27°25.416' N – 081°48.193' E	Agriculture, Rural hamlets, Sewage discharge	DP, ShW, SW
Faizabad	234	Downstream	26°48.040' N – 082°06.941' E	Agriculture, Urban , Temples, Domestic and industrial sewage, Cremation	FW, ShW, SW, DP

FW=fast flowing water, CC=channel confluence, ShW=shallow water, DP=deep pools, OR=open river, FP=flood plain, SW=slow water.

equipment (WTW make) and turbidity (NTU, nephelometric turbidity unit) was measured using turbidity meter. Overhanging vegetation (%), number of pools, and substrate type were coded. For analysis of selected chemical parameters (total alkalinity, total hardness, nitrate, nitrite, orthophosphate, ammonia) water samples from each sampling site in each month were collected and transported to analytical laboratory for further processing. The chemical analysis in laboratory was performed using Spectroquant NOVA-60 Spectrophotometer with the help of standard quality test kits (Merck make). Sampling, preservation and transportation of the water samples to the laboratory were as per standard methods [9]. The dominant substrate material for each sampling site was determined by inspection and striking the river bottom with a bamboo pole. The total percentage of each substrate class was calculated using transects within each sampling site.

Canonical correspondence analysis (CCA) [10] was used to identify the relationships of environmental variables with fish assemblage. Results of CCA were tested with a Monte Carlo randomization method, which randomly reassigns the values for the species data to the values for the environmental variables. Partial CCAs were used to determine the variance explained by individual variables after the removal of variables with inflation factors >10 [11]. All statistical analyses were conducted using the Multivariate Statistical Package (MVSP) trial version 3.1 [12], SPSS version 16.0 and CALIBRATE 1.0. A dendrogram showing the relationship among various sampling sites and their similarity in possessing fish species was drawn as per standard methods [13] **(Fig 2)**.

Fig.2: Dendrogram of the relationship among various sampling sites drawn from similarity of fish species



2.2. Sampling methodology

About 600 km of the Ghaghara River covering entire stretch from upstream to downstream in Uttar Pradesh state was studied. The study sites were chosen on the basis of their accessibility and similarity in physical habitat and were identified as Girijapuri barrage (S1), Chahlarighat (S2), Elgin bridge (S3), Saryughat Gonda (S4) and Faizabad (S5) with S1 and S2 in upstream, S3 in midstream while S4 and S5 in the lower stream. Assistance of experienced and skilled local fishermen was taken in carrying out investigational fishing. For collecting fish species, gill nets of different sizes (mesh size 2.5 x 2.5, 3 x 3, 7 x 7 cm; LxB 75 x1.3, 50x1 m), cast nets (mesh size 6 x 6 mm), drag nets (mesh size 7 x 7 mm, L x B 80 x 2.5m) and fry collecting nets (indigenous nets using nylon mosquito nets tied with bamboo at each ends) were used. Four gill-nets were set up overnight at study sites. Fish sampling was done in channel and near shoreline following Bain and Knight [14]. The fish samples caught were fixed in 10% formaldehyde, transferred to the laboratory and stored in glass bottles.

After counting all samples, their total length (TL), standard length (SL), fork length (FL), and body weight (BW) were measured. Identifications done were based on keys for fishes of the Indian subcontinent [15, 16]. We also visited fish markets and landing centers associated with the river system to examine and search for the presence of any such species, which were not found during our investigational fishing. During study of existing threats faced by ichthyofauna were obtained from both primary and secondary sources i.e. by direct observations and interactions with local stakeholders and fishermen. In the present study, the conservation status of the fishes was assessed as per Lakra et al. [17] and according to World Conservation Union or International Union for the Conservation of Nature and Natural Resources [18] criterion**.**

3) RESULTS AND DISCUSSION

3.1. Water quality assessment

The physic-chemical parameters like pH, turbidity, total dissolved solid and conductivity were varying considerably from site to site. The pH showed definite seasonal trend and it ranged from 7.5 to 8.0 with mean value of 7.8 which suggests the alkaline nature of the Ghaghara River water. Turbidity varied from 8.1 to 24.2 NTU being highest in middle and lowest in the upper stretch. Water conductivity was high in S1 and S5 indicating higher concentration of dissolved materials and average in rest of the sites and it varied from 270.7 to 623.4 µS/cm. Overall, water depths were averaging from 2.8-7.6 m.

Depth was high in lower stretch and upper region of upper stretch (S1), moderate at middle stretch while lower at lower region of upper stretch (S2).The concentration of dissolved oxygen (DO) showed a range of 4.5–7.4 in the survey sites being higher in upstream and lower in downstream. The maximum D.O. was observed during the post-monsoon season and minimum value in pre-monsoon. Water velocity varied from 0.17 ms^{-1} to 0.38 ms^{-1} among the sites. Alkalinity ranged between 110.1-254 mgL^{-1} and higher values were found at the sites S3 (217-254 mgL^{-1}) and S5 (231-278.1 mgL^{-1}) throughout the year. Substrates ranged from slightly coarser (≥6.5 mm) than pure sand (0.06–1 mm) to a mixture of largely pebbles (16–63 mm) and cobble (64–256 mm). Mean substrate was slightly larger than gravel. Water temperature (12.1–26.8°C) varied as expected with seasonal climates and averaged 23.8°C. The total dissolved solid (TDS) was generally high along the upper and lower stretch (176.2–419.9 ppm) and low in the middle stretch. The total hardness varied from 172.5 to 271.3 mgL^{-1} and it was higher (271.3) at downstream. High concentration of orthophosphate (0.14 mgL^{-1}) and ammonia (0.8) were recorded in the downstream (S4). Major source of phosphate in water are domestic sewage, agriculture effluents and industrial waste waters. The average annual concentration of NO_3 fluctuated from 0.55 to 2.8 mgL^{-1}. The concentration of NO_2 was negligible in all the sites. The

Table: 2 Average ranges of selected hydro biological characteristics (annual mean with standard deviation in parenthesis) of the Ghaghara River at sampling sites

Parameters	Sampling zones				
	S1	S2	S3	S4	S5
Depth (m)	6.35 (±1.3)	2.80 (±1.49)	4.3 (±1.49)	6.7 (±3.2)	7.6 (±3.7)
Flow (m/sec)	0.17 (±0.3)	0.2 (±0.1)	0.19 (±0.1)	0.38 (±0.2)	0.2 (±0.17)
Water temp. (°C)	26.3 (±0.1)	23.3 (±2.60)	26.6 (±1.49)	27.9 (±3.7)	24.9 (±1.7)
Turbidity (NTU)	8.1 (±0.7)	16.6 (±5.63)	24.2 (±12.3)	19.1(±12.2)	16.5 (±6.4)
TDS (ppm)	176.2 (±14.2)	129.5 (±20.2)	147.8 (±30.7)	206.7 (±30.2)	419.9 (±93.7)
pH	7.5 (±0.3)	7.9 (±0.57)	8.0 (±0.8)	7.8 (±0.4)	7.9 (±0.3)
Conductivity (µS/cm)	623.4 (±45.6)	276.9 (±10.50)	293.4 (±19.7)	270.7 (±69.6)	487 (±150.7)
D.O (ppm)	7.4 (±0.7)	5.8 (±1.4)	5.1 (±0.8)	4.6 (±0.6)	4.5 (±2.2)
Alkalinity (mg/l)	150.6 (±14.4)	147 (±69.8)	233.5 (±61.4)	110.1 (±55.9)	254 (±23)
Total hardness (mg/l)	222.5 (±23)	172.5 (±4.7)	186.7 (±21.1)	271.3 (±39.2)	207.1(±28.2)
Ammonia (mg/l)	0.02 (±3.7)	0.16 (±0.08)	0.4 (±0.3)	0.8 (±1.49)	0.57 (±0.05)
Orthophosphate (mg/l)	0.06 (±0.1)	0.03 (±0.03)	0.03 (±0.01)	0.14 (±0.09)	0.07 (±0.01)
NO_2 (mg/l)	0.03 (±0.01)	0.04 (±0.02)	0.05 (±0.05)	0.06 (±0.07)	0.05 (±0.05)
NO_3 (mg/l)	1.1 (±0.2)	0.55 (±0.64)	1.7 (±0.5)	2.8 (±0.6)	2.7 (±0.7)
Fine substrate (%)	24.2 (±19.9)	36.2 (11.2)	42.2 (±7.9)	32.2 (±10.8)	54.2 (24.7)
Sand substrate (%)	26.6 (±14.1)	56.3 (11.1)	17.6 (±9.2)	20.6 (±11.1)	32.6 (±13.1)
Fine gravel (%)	19.04 (±13.4)	29.04 (±17.4)	39.04 (±16.4)	20.04 (±16.2)	17.04 (±14.5)
Coarse gravel (%)	16.2 (±7.3)	23.3 (±8.3)	45.2 (±13.3)	22.3 (±10.3)	16.3 (±9.3)
Cobble substrate (%)	6.87 (±1.9)	3.87 (±2.9)	17.87 (±10.9)	4.87 (±2.9)	9.87 (±3.9)
Overhanging vegetation (presence/absence)	0.2 (±0.1)	0.6 (±0.2)	0.4 (±0.2)	0.8 (±0.2)	0.2 (±0.1)

Table: 3 Principal component (PC) loadings from principal component analysis of physical habitat structure, physic-chemical and adjacent land use environmental variables from 50 sampling sites.

Variables	PC1	PC2	PC3
Water flow (m/sec)	**-0.33**	-0.18	0.17
Depth (m)	**0.33**	-0.16	0.18
Water temp (°C)	-0.03	-0.01	**0.45**
DO (mgl^{-1})	**0.36**	-0.03	0.01
pH	0.09	**-0.46**	0.30
Turbidity (mgl^{-1})	**-0.31**	-0.15	0.21
Conductivity ($\mu S/cm^{-1}$)	0.19	-0.07	**-0.40**
TDS(ppm)	**-0.25**	**-0.39**	-0.06
Fine substrate (%)	0.01	0.17	0.23
Sand substrate (%)	**-0.33**	-0.14	0.17
Fine gravel (%)	**0.35**	-0.10	0.11
Coarse gravel (%)	**0.27**	-0.01	**0.29**
Cobble substrate (%)	**0.32**	-0.19	0.19
Overhanging vegetation (%)	0.001	**0.31**	0.16
Row crop land use (presence/absence)	0.07	0.08	-0.03
Rangeland land use (presence/absence)	0.02	**-0.48**	-0.13
Rip-rap (presence/absence)	-0.02	**0.29**	**0.38**
Eigenvalue	7.19	1.81	1.55
Per cent variance explained	42.33	10.65	9.12
Cumulative variance explained	42.33	52.98	62.10

average concentration of phosphate was highest (0.14 mgL^{-1}) at the Saryughat Gonda site (S4) and lowest with 0.00 (±0.01) at site S3. The data on various physical habitat characteristics and morphology of selected sites are shown in **Table 1** and **Table 2**.

3.2. Species composition in relation to environmental variables

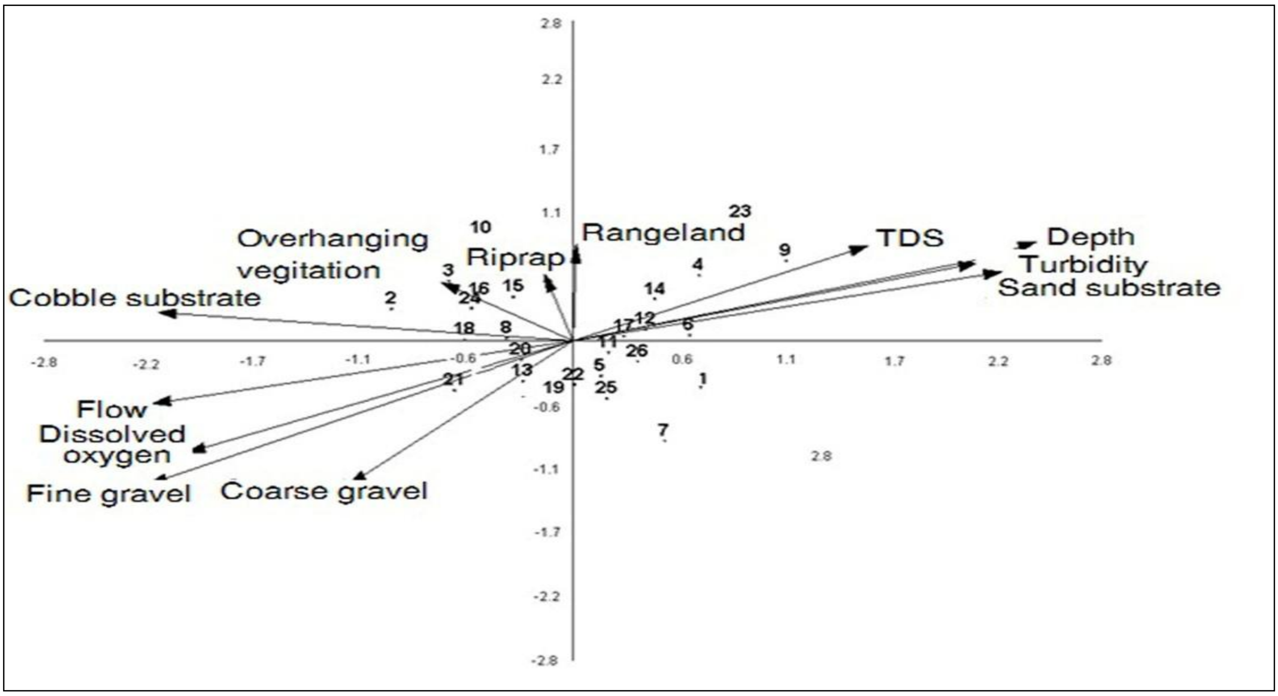
A total of 62 fish species were collected and identified from the five sampling locations of river Ghaghara. The PCA produced three axes that cumulatively explained 62.1% of the environmental variation in sites **(Table 3)**.

The first axis had high loadings for water flow, depth, dissolve oxygen, turbidity and substrates (per cent sand, coarse gravel and cobble). The second axis had high loadings for pH, total dissolve solids (TDS), per cent overhanging vegetation cover and rangeland land use. The third axis had high loadings for water temperature, conductivity and riprap land use (**Table 4**).

Table: 4 Canonical correspondence analysis summary statistics for the fish and environment sampled in River Ghaghara. Tolerance of Eigen analysis set at 1E-009

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigen values	0.265	0.194	0.166	0.120
Species-environment. Correlations	0.917	0.860	0.900	0.736
Cumulative percentage variance				
Explained by species only	9.14	15.83	21.57	25.70
Explained by species + environmental variables	20.95	36.29	49.45	58.91
Interset correlations with axis				
Flow (m/sec)	-0.733	-0.169	-0.184	-0.018
Depth (m)	0.767	0.238	0.096	-0.003
D.O (mgl^{-1})	-0.673	-0.301	-0.328	-0.011
Turbidity (mgl^{-1})	0.747	0.186	0.196	-0.011
TDS (ppm)	0.524	0.261	0.243	0.078
Sand substrate (%)	0.704	0.209	0.179	0.030
Fine gravel (%)	-0.740	-0.386	-0.123	0.090
Coarse gravel (%)	-0.391	-0.388	-0.191	-0.005
Cobble substrate (%)	-0.722	0.076	-0.325	0.010
Overhanging vegetation (presence/absence)	-0.229	0.157	0.026	0.164
Rangeland (presence/absence)	0.006	0.260	0.145	0.233
Rip-rap (presence/absence)	-0.050	0.181	-0.032	0.132

Fig.3: Canonical correspondence analysis (CCA) showing correlation between species composition and environmental variables. ID: 1=*Mystus tengara;* 2=*Nandus nandus*; 3=*Nemacheilus botia;* 4=*Notopterus notopterus;* 5=*Ompok bimaculatus*; 6=*Ompok pabda*; 7=*Puntius sarana*; 8=*Puntius sophore*; 9=*Labeo bata*; 10=*Rita rita*; 11=*Bagarius bagarius*; 12=*Catla catla*; 13=*Chitala chitala*; 14=*Channa marulius*; 15=*Clupisoma garua*; 16=*Sperata aor*; 17=*Wallago attu*; 18=*Cirrihinus mrigala*; 19=*Cirrihinus reba*; 20=*Eutropiicthys vacha*; 21=*Crossocheilus latius*; 22=*Labeo gonius*; 23=*Labeo calbasu*; 24=*Chagunius chagunio*; 25=*Labeo rohita*; 26= *Mastacemblus armatus.*



Fifteen variables (water flow, depth, dissolved oxygen, turbidity, pH, TDS, water temperature, conductivity, overhanging vegetation, substrates and land use) of 17 total environmental variables had high loadings on at least one of the principal component axis interpreted. The primary gradients include water temperature, pH, conductivity and rangeland land use. In contrast, percent sand substrate and rowcrop land use did not have high loadings on any of the first three axes. The MANOVA on the habitat variables indicated a significant difference in habitat structure among sampling sites ($F = 8.55$, $p < 0.05$). The forward selection procedure for the CCA resulted in the retention of 12 variables as significant contributors to variation in the ordination. The first ordination axis accounted for 9.14% of the variance of the species data, whereas the second axis accounted for 15.83% of this variance; we did not attempt to interpret the third and fourth ordination axes (**Fig 3**). Species and their abundances were significantly correlated with the environmental factors

Table 5: Major types of fish habitat and dominant genera of Ghaghara River recorded during May 2009 to May 2011.

Major Habitat types	Fish types	Dominant fish genera	Total no. of fish species in study areas				
			S1	S2	S3	S4	S5
Fast flowing water	Cat fishes & carps	*Rita, Ompok, Sperata, Bagarius, Labeo, Clupisoma, Eutropiichthys, Wallago* and *Mystus.*	29	16	17	14	22
Backwater and shallow pools	Medium sized species	*Rita, Sperata, Notopterus, Wallago, Cirrhinus, Mystus* and *Ompok.*	21	10	15	9	19
Deep pools	Large sized species	*Chitala,Wallago,Cyprinus, Sperata, Labeo, Ompok, Notopterus* and *Clarias.*	26	11	0	11	15
Channel confluence	Mixed assemblage	*Clupisoma, Notopterus, Puntius, Labeo* and *Channa.*	37	5	26	18	20
Open river	Mixed assemblage	*Channa, Cyprinus, Mystus, Sperata, Labeo, Notopterus, Clupisoma* and *Salmostoma.*	13	8	10	9	11
Floodplain	Mixed assemblage	*Notopterus, Wallago, Cirrhinus, Mystus, Ompok, Rita, Sperata*	17	0	15	0	5
Slow water	Mixed assemblage	*Catla,Channa,Mystus,Puntius,Chitala,Heteropneustes,Wallago,Macrognathus, Notopterus,*	9	2	7	0	8

Fig. 4: Distribution of families, genera and species in sampling sites.

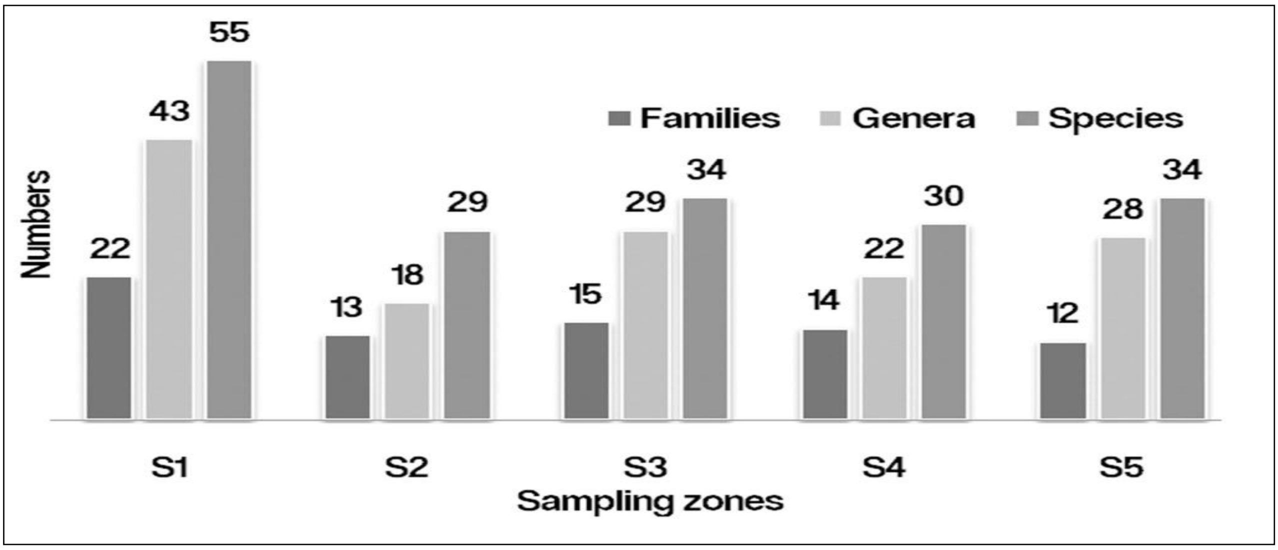


Table 6: Site wise representation of prevailing threats for valuable fish fauna

Name of site	Threats	Important genera
Girijapuri barrage	Small dams, over fishing	*Channa punctatus, Cirrhinus mrigala, Rita rita, Ompok bimaculatus, Ompok pabda, Labeo calbasu, Labeo rohita, Labeo bata, Eutropiichthys vacha, Chitala chitala, Catla catla , Notopterus notopterus, Rita rita*
Chahlarighat	Weirs, discharge of sewage, over fishing, deforestation, siltation	*Cirrhinus mrigala, Eutropiichthys vacha, Chitala chitala, Catla catla, Labeo calbasu, Labeo rohita, Ompok bimaculatus, Ompok pabda, Notopterus notopterus, Rita rita*
Elgin bridge	Domestic pollution, semi urban, discharge of sewage	*Eutropiichthys vacha, Chitala chitala, Labeo calbasu, Labeo rohita, Ompok bimaculatus, Ompok pabda, Ompok pabo*
Saryughat Gonda	Domestic pollution, semi urban, discharge of sewage, over fishing	*Eutropiichthys vacha, Chitala chitala, Ompok bimaculatus, Ompok pabda, Labeo calbasu, Labeo rohita*
Faizabad	Temple, cremation, discharge of sewage and other domestic wastes, factories, over fishing	*Eutropiichthys vacha, Chitala chitala, Catla catla, Labeo calbasu, Labeo rohita, Notopterus notopterus, Ompok bimaculatus, Ompok pabda*

(P=0.001 along axes one and two, Monte Carlo test with 1,000 permutations).

Depth, turbidity, sand substrate, and TDS were positively correlated (average r=0.72) with first ordination axis, whereas water flow, dissolved oxygen (DO), overhanging vegetation, fine gravel and coarse gravel substrates were negatively (average r=-0.58) correlated. Rangeland land use and riprap were positively correlated with second ordination axis. The species–environment correlations of each axis were 0.91 (Axis 1) and 0.86 (Axis 2). Each significant environmental factor increased along a vector away from the origin with its length being a measure of magnitude. Sites containing deep waters with slow water current and low dissolved oxygen, higher percentage of sandy substrate and turbid water with high dissolve solids were associated with a group of five species (*Labeo bata, Mystus tengara, Notopterus notopterus, Ompok pabda* and *Channa marulius*). On the other hand, sites with fast water with shallow depth and high dissolve oxygen, higher percentage of fine to coarse gravel substrate and presence of overhanging vegetation were associated with another group of six species (*Nandus nandus*, *Nemacheilus botia*, *Crossocheilus latius* ,*Cirrihinus mrigala*, *Chgunius chagunio* and *Sperata aor*). Axis 2 on the CCA biplot contrasted species associated with presence of rangeland and riparap land use pattern (e.g. *Rita rita* and *Labeo calbasu*) from species (e.g. *Puntius sarana, Cirrhinus reba,* and *Labeo rohita*) with the absence of these land use patterns. For the remaining species (e.g. *Catla catla, Mastacemblus armatus, Wallago attu, Bagarius bagarius, Puntius sophore, Eutropiicthys vacha, Clupisoma garua, Labeo gonius, Chitala chitala* and *Ompok bimaculatus*) in this study habitat conditions was mostly about average for the site sampled.

3.3. Habitat types and fish assemblage

The categorization of fish habitat based on water flowing velocity and water depth recognized five major types habitat in different studied sites of the river as recorded during two years period as fast flowing, back water and shallow pools, deep pools, channel confluence, open river, flood plain and slow water regions. Altogether we collected 62 fish species belonging to eight orders, 24 families and 48 genera. The site wise number of families, genera and species has been shown in **Fig 4**.

The habitat situated at the junction of two rivers is an ideal place for fish habitat. Maximum 37 species were recorded from this meandering of river and channel confluence habitat of site 1 (S1) as shown in Table 5 wherein the information regarding occurrence of dominant genera are also given. The dominant genera of fishes occurring therein are indicated in Table 5. Among all the sites, the fish species richness (FSR) of the dominant genera ranged from 29 (S2) to 55 (S1) (**Fig 4**) with an average value of 36.4.

The prevailing threats for valuable fish fauna at sites studied during study were found to be several anthropogenic activities like formation of barrages, small dams or weirs and over fishing particularly at Girijapuri barrage and Chahlarighat whereas discharge of domestic pollutant and sewage were observed as the potential alarm for fish diversity at Chahlarighat, Elgin bridge, Saryughat Gonda and Faizabad. The discharge of temple waste and cremation were found to have adverse effect on the richness of fish fauna in the river Ghaghara **(Table 6)**.

Habitat is a place that provides the physical, chemical and biological support for species diversity and productivity. Habitat and species are inseparable [19]. Important environmental factors have been identified for some river and lake dwelling fishes, particularly in temperate regions of the world [20, 21] and represent an important step in the identification of suitable water quality and critical habitat. The quality of water depends on its physic-chemical and biological characteristics [9]. The abundance and distribution of a fish species, therefore, depends entirely on its facility to accommodate itself to a variety of environmental conditions and degree of vitality by which it is enabled to survive under more or less sudden changes [22].

In the present study we observed a significant structure of fish community in a complex, comprehensive dataset and identified certain environmental factors such as depth, flow and dissolved oxygen as major components. This study revealed that the physical habitat variables play a leading role in the distribution of fishes in River Ghaghara and the habitat alteration brought about in various rivers contribute significantly to the endangerment of freshwaters in the rivers of Gangetic plains. Habitat use pattern across assemblages of fish in flowing waters has been reported several times but almost always for streams and small rivers. Though moving water is the distinguishing feature of the rivers, we observed that depth, current velocity and substrate in the Ghaghara River are key habitat features for many fish assemblages and found the most important variables in shaping fish distributions. A study of Sheldon [23] shows that in flowing waters number of fish fauna is strongly correlated with the water depth. In this study we noticed that species richness depends on the various other factors like channel confluence, availability of water and water depth etc. The rich number of species (55) found at the site S1 (Girijapuri barrage) might be due to confluence of a canal that brings some other species from the other larger rivers. At this site there were found a few species that have not been noticed in any other site. The least number of species was reported at site S2 (Chahlarighat) which may be due to seasonal availability of water, low depth and narrow channel width. We have also observed that some of the large sized fish genera of conservation importance such as *Chitala* and *Wallago* showed preference to deep pool habitat in River Ghaghara. The other fish habitat groups indicate a similar pattern of swift waters supporting distinct but limited number of species. Our key habitat groups were derived with data from one river although there are few other intact rivers in the Ganga basin with abundant and varied species of conservation interest. Our habitat conservation classes were formed to encompass groups of species with different habitat needs, and this generalization may make the specific groups more widely applicable.

Ichthyodiversity is a vital component of aquatic ecosystems which refers to variety of fish species. The occurrence of 62 fish species indicates rich species diversity in this river. In our study cumulative fish abundance in group three was greater than that in each of the other four groups. Species in this group (9 species) appear to be attracted to deep waters with slow water current and higher percentage of fine substrate. Indian major carps (*Cirrhinus mrigala* and *Labeo rohita*) and other species of Bagarids and Cyprinids (*Aorichthys seenghala* and *Labeo gonius*) associated themselves only with slower and deeper water in richness. This association was also noted in other fishes by Lamouroux et al. [24], Lamouroux and Souchon [25] and Carter et al. [26]. Sarkar and Bain [27] have reported the habitat preference of *Labeo rohita* towards slow water current. Other species studied, did not respond much to speed of flow, except for striped catfish (*Rita rita*), which preferred fast flowing river habitats in large number. Assessment of fish biodiversity and aquatic resources are important in order to develop strategic plan for the proper conservation, management and sustainable utilization of fish germplasm resources.

Many livelihoods are dependent on the fishery resources and therefore there is a need to adopt conservation strategy different from conventional approaches. In this connection, stocking of indigenous fish yearlings (from wild population) for ranching year after year in rivers and associated perennial reservoirs will be helpful for restoration of threatened and disappeared fish species. Ranching with hatchery bred individual should not be carried which may cause inbreeding and genetic erosion. Strong management strategies fixing total harvestable catch (THC), through the use of quotas are needed to reduce overall collection pressure and maintaining status quo with regard to the collection and trade of local species from the river. Strong management strategies fixing total harvestable catch (THC), through the use of quotas are needed to reduce overall collection pressure and maintaining status quo with regard to the collection and trade of local species from the river. Fisheries scientists are developing approaches to fisheries management that are consistent with the ecosystem approach, such as whole ecosystem modeling, including insights into the human dimension of fisheries management. Such approaches aim to provide for fisheries management to contribute towards ecosystem restoration, including provision for the involvement of stakeholders and the reduction of uncertainties in ecosystem simulation techniques [28].

Fish conservation management of the state of Uttar Pradesh is possible if it is taken up in a comprehensive manner, defining conservation areas, adopting ecohydrological approach, involving the wider public and different research organizations, state fisheries and other stakeholders for wider environmental benefits. The ecohydrological approach primarily demands the study of system in natural conditions and investigate its dynamics and also to use communities (fish/invertebrates) as indicators of ecosystem health. The findings of this study furnish specific guidance on channel habitats with inclusive ranges of depth, substrate and current velocity needed to support the threatened fish species of the River and therefore to include in conservation planning. Furthermore, our results suggest the importance of local environmental influences towards conservation of ichthyofauna of the river by making restoration efforts of the fish habitat. It is recommended that further studies should be made to expand research on the enhancement of indigenous fish species by adopting habitat restoration and species rehabilitation at local scale. The river ecosystem of the Ghaghara is said to be immensely important in maintaining considerable freshwater diversity. Management measures should be planned keeping in view the habitat requirements and associated relationship with the fish assemblage at local scale. This study on the fish diversity, habitat parameters in relation to species distribution may provide current relevant information for fisheries department as well as to the other stakeholders for proper conservation of aquatic biodiversity in this important tributary of the Ganga River.

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