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Relationship between species richness, taxonomic distinctness, functional diversity, and local contribution to β diversity and effects of habitat disturbance in the riparian spider community of the Ganga River, India

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Abstract

Background In the riverine riparian ecosystem, particularly in India, the knowledge of the effects of habitat disturbance on taxonomic distinctness, functional diversity, and local contribution to β diversity (LCBD) of spider community is elusive. The present study examined the relationships between the index of taxonomic distinctness (Δ^+), index of variation in taxonomic distinctness (λ^+), functional evenness (FEve), functional divergence (FDiv), functional dispersion (FDis), and LCBD of spider community of the Ganga River and the effects of habitat disturbance on these indices. A total of 27 sampling sites were selected along the bank of the Ganga River. Based on the rating of the disturbance scores, the sites were classified into lowly, moderately, and highly disturbed sites. To understand the relationships between species richness, Δ^+, λ^+, FDis, FDiv, FEve, LCBD, and habitat disturbance score, Pearson's correlation was calculated, followed by the linear regression model. The one-way multivariate analysis of variance was used to find differences in taxonomic distinctness and functional diversity in the different disturbed sites.

Results Significant relationships were found between λ^+ and Δ^+, FDis and Δ^+, FDis and λ^+, FDiv and species richness, FEve and species richness, FEve and λ^+, FEve and habitat disturbance, LCBD and FEve, and LCBD and habitat disturbance. A significant difference was present in the indices of functional diversity between the lowly, moderately, and highly disturbed sites. Agriculture, garbage dump, human settlement, and created embankment influenced the spider community's λ^+, FEve, and LCBD.

Conclusion Unrestrained anthropogenic activities exacerbate habitat disturbance by affecting ecological processes. Thus, understanding linkages between ecosystem disturbance, taxonomic, functional, and β diversity can be fundamental to managing and conserving natural resources. This work highlights the importance of including taxonomic and functional diversity to comprehend the impact of habitat disturbance on riverine riparian spiders beyond just the number of species. An integrated taxonomic and functional diversity approach coupled with β diversity can be used to support environmental assessment, restoration, and conservation planning of the biological resources of the Ganges River.

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Keywords Habitat disturbance, Taxonomic distinctness, Functional evenness, Functional divergence, Functional dispersion, Local contribution to beta diversity, Spider community, Riparian area, Ganga River

Introduction

The rank of species is prominent in most biodiversity studies (Gaston 2000). But in recent years, scientists have come to believe that the biodiversity of a region does not depend solely on the number of species. Instead, they trust the taxonomic surrogacy method because the species and higher taxonomic ranks, such as genera and families, have predictable relationships (Campbell et al. 2010). This method does not directly count species but counts them indirectly by higher ranked taxa, such as genera, families, orders, classes, etc. (Campbell et al. 2010). Taxonomic surrogate measures such as the index of taxonomic distinctness (Δ^+) and the index of variation in taxonomic distinctness (λ^+) (Warwick and Clarke 1995; Clarke and Warwick 1998; Clarke and Warwick 2001) can be derived using hierarchical taxonomic tree information such as Linnaean classification or phylogenetic distances matrix (Campbell et al. 2010), and these indices are not susceptible to sample size effects like other diversity indices (Warwick and Clarke 1995). They may be helpful tools for studying diversity beyond the simple species count (Bevilacqua et al. 2009).

Functional diversity is the component of biodiversity that influences the dynamics, productivity, stability, and other aspects of ecosystem functioning through organismal traits (Tilman 2001). The goal of measuring functional diversity is to quantify the diversity of functional characteristics in species assemblages (Mason and Mouillot 2013). There are several methods proposed by scientists for the quantification of functional diversity, such as functional evenness (FEve)—the evenness of abundance distribution in filled trait space, functional divergence (FDiv)—the degree to which abundance is distributed toward the extremities of filled trait space (Mason and Mouillot 2013; Laliberté and Legendre 2010) and functional dispersion (FDis)—the mean distance in multidimensional trait space of individual species to the centroid of all species in the community (Laliberté and Legendre 2010). The values of FEve range between 0 and 1, where values close to 0 indicate most species are packed tightly in a portion of the trait space, and values close to 1 show the species are evenly spread along the trait space. The values of FDiv also range between 0 and 1, where values approaching 1 indicate the dominancy of a few numbers of species. The values of FDis have a lower limit of 0 (for the communities composed of only one species) but have no upper limit. As functional diversity reflects the diversity of morphological, ecological, and physiological traits within biological communities (Petchey and Gaston 2006), it has been exhibited to illustrate ecosystem functioning better than other traditional estimations of diversity (Hooper et al. 2005).

The degree of community differentiation or the extent of change in community structure in response to complex environmental gradients is referred to as β diversity (Whittaker 1960). There have been significant advances in how β diversity is interpreted in terms of its constituent components over the last few decades. Because it represents the link between local communities and the regional species pool, β diversity is considered a prime property of ecological communities that can aid in furnishing inferences about community assembly mechanisms (Marathe et al. 2021). Though most research on β diversity and its components has concentrated on taxonomic diversity (Chao et al. 2019), a better understanding of ecological processes can also be provided by β diversity across functional groups (Zarabska-Bożejewicz and Kujawa 2018).

Legendre and De Cáceres (2013) introduced a concept of local contribution to β diversity (LCBD), which is the uniqueness of the sampling units to community composition throughout the study area. The LCBD values range from 0 to 1, and an increasing LCBD value indicates a species composition with a higher degree of uniqueness. As LCBD is a comparative indicator of the ecological uniqueness of the sampling units (Legendre and Gauthier 2014), it can be used to prioritize sites for ecological assessment and conservation of freshwater ecosystem (Heino and Grönroos 2016; Gavioli et al. 2019; Li et al. 2020).

With more than 50,000 species worldwide (WSC 2023), spiders are among the most common and abundant predatory animals. It was estimated that the global spider community consumes over 400 million metric tons of prey per year (Nyffeler and Birkhofer 2017). Most of these preys are insects, especially pests of agricultural and forestry systems. Thus, spiders play an essential role in the architecting of food webs in the ecosystem by restraining the population of insects in forests and around human habitation. The spiders are also an important food source for higher trophic level animals (Milano et al. 2021). Spider populations tend to decline due to habitat degradation, especially by agroforestry practices, climate change, urbanization, and pollution (Branco and Cardoso 2020).

Forest age, agricultural management, livestock grazing, invasive plants, landscape structure, seasonal changes, and vegetation structure play a significant role in determining the taxonomic and functional diversity of the spider community (Schirmel et al. 2012; Leroy et al. 2014; Gomes 2017; Joseph et al. 2017; Gallé et al. 2018a, b; Melliger et al. 2018; Kaltsas et al. 2019; Morel et al. 2019; Baldissera et al. 2020; Delgado de la flor et al. 2020; Picchi et al. 2020). The conceptual connections between species diversity, functional diversity, and ecosystem disturbance are critical for resource management and conservation planning, but our understanding of these relationships is limited (Diaz et al. 2007). The colossal river systems, such as the Ganga River, provide crucial water resources for the environment and society, but they frequently face serious challenges associated with environmental and anthropogenic impacts (Richards et al. 2022). But no research has been done to understand the outcome of anthropogenic disturbance on the taxonomic and functional diversity of the riparian invertebrate community of the Ganga River until now. In this study, spiders are used to investigate the effects of anthropogenic disturbance on their taxonomic and functional diversity in the Gangetic riparian zone as they are diversified predators that constitute a crucial ecological component in aquatic and terrestrial food webs, and their diversity is highly influenced by the anthropogenic disturbances (Ávila et al. 2017; Sanchez-Ruiz et al. 2017; Tajthi et al. 2017).

The present study focused on (1) understanding the relationship between species richness, taxonomic distinctness, functional diversity, and LCBD and habitat disturbance; (2) determining whether there are differences in taxonomic distinctness and functional diversity between lowly, moderately, and highly disturbed sites; and (3) identifying the best disturbance combination that affects taxonomic distinctness, functional diversity, and LCBD in the spider community of the riparian habitat of the Ganga River, India.

Methods

The work was conducted in the Ganga River, the largest river basin in India, with a channel length of about 2974 km and a basin area of about 965,936 km^2 (Khan et al. 2018). The complexity of glacier and snow melt, monsoon runoff, groundwater resources, and several dams, barrages, and canals influence the hydrology of the Ganga River system. It is estimated that the discharge size of the Ganga River varies from less than 1000 m^3 s^{-1} in the non-monsoon period to more than 20,000 m^3 s^{-1} in the monsoon period (Khan et al. 2018; Rai et al. 2021), and it experiences a tremendously high suspended sediment load of 356×10^6 t year^{-1} (Khan et al. 2018).

For the work, 27 study sites with an interval of ~ 75 km along the Ganga River from Bijnour (in Uttar Pradesh, India) to Nischintapur (in West Bengal, India) were chosen (Fig. 1). A detailed portrayal of the study sites is available in Ali et al. (2019).

The data collection was performed in the summer (May and June) of 2018 and 2019 and in the winter (November and December) of 2018 and 2019. At each site, depending on accessibility, a 50 m by 100 m plot was selected alongside either on the left or right bank of the river, and a total of 15 quadrats of 4 m by 4 m were employed per plot (5 across the length and 3 across the width) for spider collection. The spiders were collected by aerial hand collection, ground hand collection, sampling in the litter, vegetation beating, sweep netting, and pitfall trapping (Coddington et al. 1996). In the pitfall trapping process, a plastic bottle of 10 cm in diameter, 11 cm in depth (Churchill and Arthur 1999) was placed overnight in the middle of each quadrat, filled with preservatives (30% ethyl acetate, 1% detergent and 69% water). Other methods involved spending 30 min per quadrat for spider collection during the daytime. After collecting, the spiders were preserved in 70% ethanol and identified up to at least genus level using literature (Pocock 1900; Tikader 1973, 1980, 1982a, b, 1987; Tikader and Patel 1975; Tikader and Malhotra 1980; Tikader and Biswas 1981; Sethi and Tikader 1988; Barrion and Litsinger 1995; Agnarsson 2004; Sebastian and Peter 2009; Platnick et al. 2011).

Nine habitat disturbances, namely agricultural activities, boats, effluent discharge, garbage dump, ghats (a series of steps leading into a water body), grazing, human settlement, created embankment, and sand mining, were recorded at each site. Among 15 quadrats employed, if disturbances occurred in 0–5 quadrats, a score of 1 was given, if disturbances occurred in 6–10 quadrats, a score of 2 was given and if disturbances occurred in 11–15 quadrats, a score of 3 was given (Gezie et al. 2017). Then, each site's overall disturbance score was calculated by adding individual values from nine different factors. The overall disturbance scores (sum of disturbance scores of each site) ranged from 9 to 22 for each site. These disturbance scores were used to categorize the sites into three types, namely lowly disturbed sites (disturbance score between 9 and 12), moderately disturbed sites (disturbance score between 13 and 16), and highly disturbed sites (disturbance score between 17 and 22).

For all of the statistical analyses, the presence–absence data of spiders for each sampling site were used. The presence–absence data were used because it provides a natural ground to understand the relationships between several indicators of biological diversity at a large geographical scale (Arita et al. 2008),

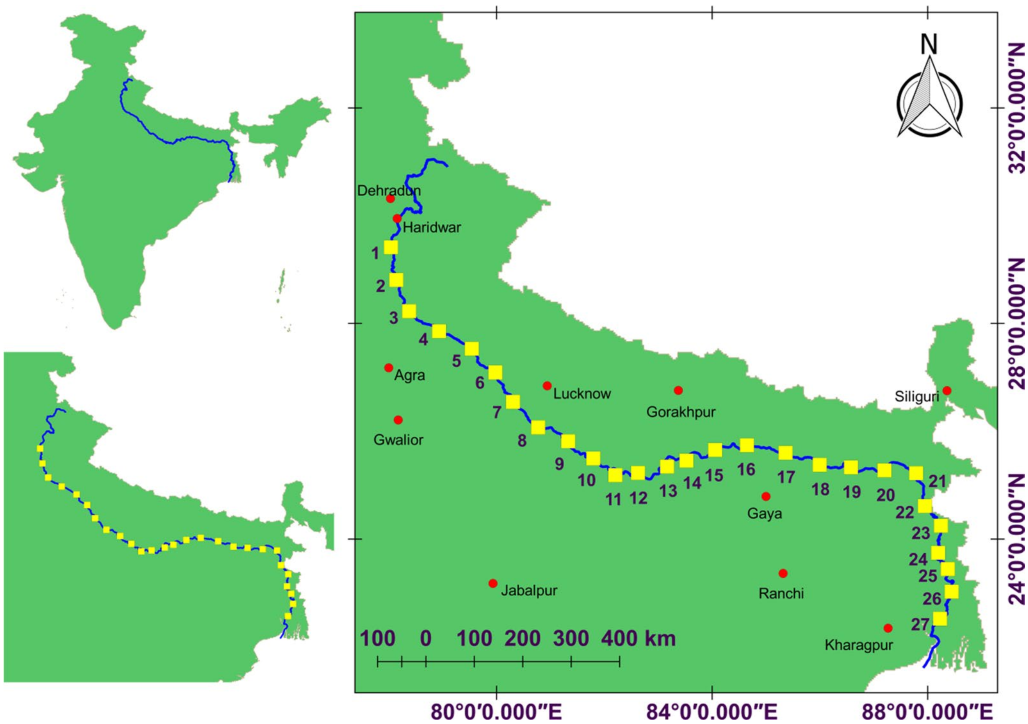

Fig. 1 Location of 27 spider sampling sites studied along the Ganga River, India

it is appropriate to study communities containing mobile species (Dorazio et al. 2011), and it is worthy of describing ecological patterns (Dai et al. 2018). For analysis, summed species matrix (i.e., pooled across all seasons) for each site was used (De et al. 2021). The R language and environment for statistical computing version 4.0.0 (R Core Team 2020) were used for the statistical analyses.

For taxonomic distinctness analysis, five taxonomic categories (infraorder, clad, family, genus, and species) of spiders were used. The Δ^{+} and λ^{+} were calculated by the 'taxa2dist' and 'taxondive' functions of the R package 'vegan' (Oksanen et al. 2019). For functional diversity analysis, the spiders were classified by their ecological guild (Cardoso et al. 2011) and their stratum of hunting (Gallé et al. 2018a). The FDis, FDiv, and FEve were calculated by the 'dbFD' function of the R package 'FD' (Laliberté and Legendre 2010; Laliberté et al. 2014). The LCBD values for each site were calculated after using Hellinger transformation for presence–absence data (Legendre and De Cáceres 2013) by the package 'adespatial' (Dray et al. 2019). Before the analysis, the species richness, Δ^{+}, λ^{+}, FDis, FDiv, FEve, LCBD, and habitat disturbance scores were normalized (mean = 0 and SD = 1) (Miyazono and Taylor 2013; Datry et al. 2016). To understand the relationship between species richness, Δ^{+}, λ^{+}, FDis, FDiv, FEve, LCBD, and habitat disturbance score, Pearson's correlation was calculated, followed by the linear regression model.

The multivariate Kruskal–Wallis test was used to determine whether there was any difference in taxonomic distinctness and functional diversity in the lowly, moderately, and highly disturbed sites by the 'multkw' function of the R package 'UTL' (Maugoust 2023). If any difference was found, then Games–Howell test for pairwise comparison (Games and Howell 1976) with Tukey adjusted *p*-value was used using the R package 'rstatix' (Kassambara 2020) to find the pair of sites (from three disturbance groups) had a significant difference in values of indices.

Two-step approaches were used to find the best combination of disturbances that affected the spider community's taxonomic distinctness, functional diversity, and LCBD. First, an automated generalized linear model (GLM) selection with subsets of the supplied global models was performed by the R package 'MuMIn' (Barton 2020), where the set of models was generated with all possible combinations and Akaike Information Criterion with a correction for small sample sizes (AICc) was used to rank the models. Then, among these ranked models, the significant model was chosen based on the *p*-value (<0.05), where this *p*-value was obtained from *t*-distribution. Thus, the model was considered best, with the lowest AICc value and significant *p*-value (<0.05). To get the importance of each predictor variable of each model, the absolute value of the *t*-statistic (the ratio of coefficient and its standard error, where the standard error provides an estimation of variation of the predictor variable) was calculated using the 'varImp' function of the R package 'caret' (Kuhn 2020).

Results

Across study sites, the species richness ranges from 17 to 58 (mean = 32.852, SD = 10.801), Δ^+ ranges from 70.530 to 76.557 (mean = 73.253, SD = 1.322), λ^+ ranges from 178.526 to 391.286 (mean = 295.995, SD = 54.634), FEve ranges from 0.114 to 0.294 (mean = 0.182, SD = 0.051), FDiv ranges from 0.754 to 0.879 (mean = 0.798, SD = 0.033), FDis ranges from 0.218 to 0.362 (mean = 0.303, SD = 0.035) and habitat disturbance score ranges from 9 to 22 (mean = 15.074, SD = 4.132) (Fig. 2; Table 1).

Pearson's correlation test indicated significant correlations ($p < 0.05$) between λ^+ and Δ^+ ($r = -0.517$) (Table 2; Fig. 3), FDis and Δ^+ ($r = 0.609$), and FDis and λ^+ ($r = -0.394$) (Table 2; Fig. 4A, B). Significant correlations ($p < 0.05$) were found between FDiv and species richness ($r = 0.449$) (Table 2; Fig. 5), FEve and species richness ($r = -0.855$), FEve and λ^+ ($r = -0.494$) FEve and habitat disturbance ($r = 0.889$) (Table 2, Fig. 6A–C), LCBD and FEve ($r = -0.734$), and LCBD and habitat disturbance ($r = -0.681$) (Table 2; Fig. 7A, B). The Kruskal–Wallis test revealed that the species richness had significant differences among lowly, moderately, and highly disturbed sites (Kruskal–Wallis $\chi^2 = 18.062$, $df = 2$, $p < 0.05$). There was no statistically significant difference in Δ^+ and λ^+ between the lowly, moderately, and highly disturbed sites (for Δ^+ Kruskal–Wallis $\chi^2 = 0.984$, $df = 2$, $p > 0.05$; for λ^+ Kruskal–Wallis $\chi^2 = 2.024$, $df = 2$, $p > 0.05$) (Fig. 8).

There was no statistically significant difference in FDis between the lowly, moderately, and highly disturbed sites (for FDis Kruskal–Wallis $\chi^2 = 2.840$, $df = 2$, $p > 0.05$). Still, there was a statistically significant difference in FDiv and FEve between the lowly, moderately, and highly

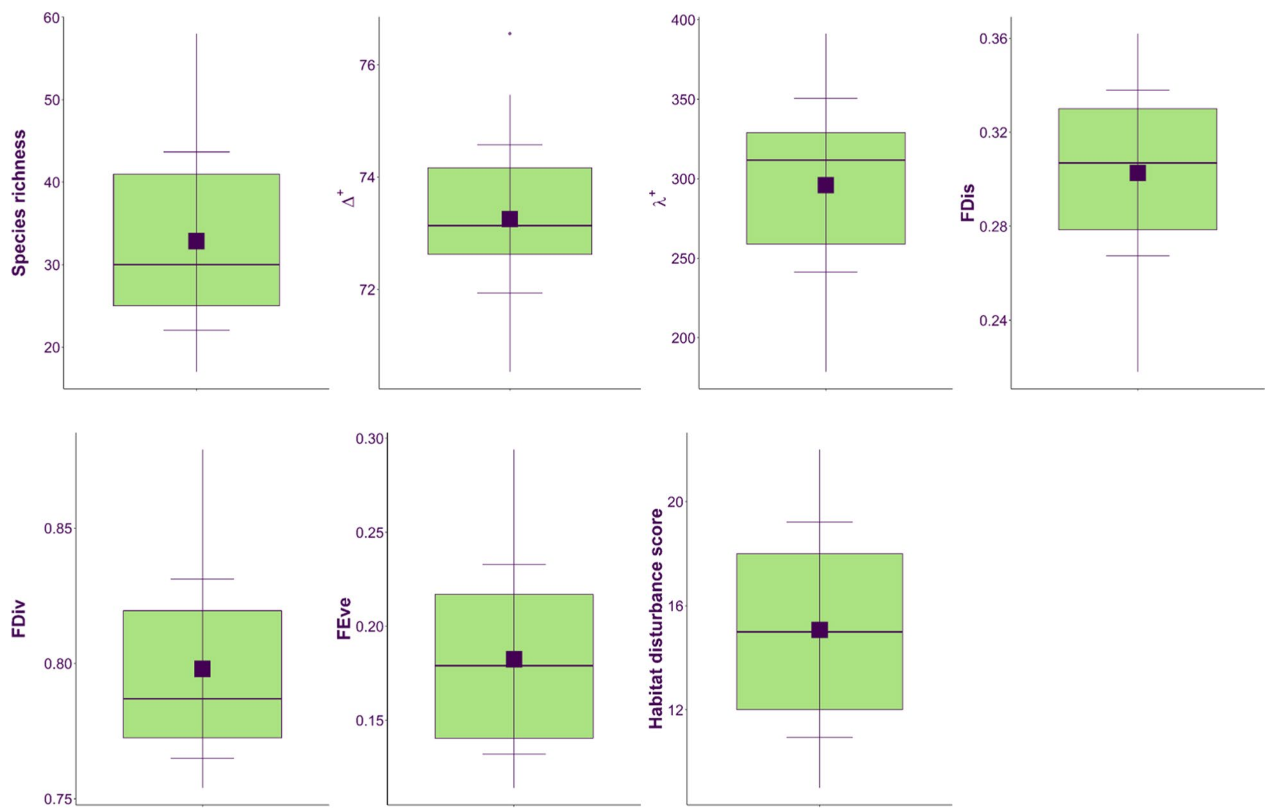

Fig. 2 Boxplots represent a comparative account of species richness (mean ± SD = 32.852 ± 10.801, median = 30), index of taxonomic distinctness (Δ^+) (mean ± SD = 73.253 ± 1.322, median = 73.138), index of variation in taxonomic distinctness (λ^+) (mean ± SD = 295.995 ± 54.634, median = 311.785), functional dispersion (FDis) (mean ± SD = 0.303 ± 0.035, median = 0.307), functional divergence (FDiv) (mean ± SD = 0.798 ± 0.033, median = 0.787), functional evenness (FEve) (mean ± SD = 0.182 ± 0.051, median = 0.787) of the spider community and habitat disturbance score (mean ± SD = 15.074 ± 4.132, median = 15) of the 27 sites studied along the Ganga River. Each box represents the 25%/75% quartiles. The mean is shown with a dark square symbol, and the median is shown with a horizontal line. The standard deviation values are shown with short horizontal lines

Table 1 Minimum value, maximum value and mean ± standard deviation of species richness, index of taxonomic distinctness (Δ^+), index of variation in taxonomic distinctness (λ^+), functional evenness (FEve), functional divergence (FDiv), functional dispersion (FDis) of the spider community and habitat disturbance score of the 27 sites studied along the Ganga River

Indicator	Minimum value	Maximum value	Mean ± standard deviation
Species richness	17	58	32.852 ± 10.801
Δ^+	70.530	76.557	73.253 ± 1.322
λ^+	178.526	391.286	295.995 ± 54.634
FEve	0.114	0.294	0.182 ± 0.051
FDiv	0.754	0.879	0.798 ± 0.033
FDis	0.218	0.362	0.303 ± 0.035
Habitat disturbance score	9	22	15.074 ± 4.132

Table 2 Pearson's correlation between species richness, index of taxonomic distinctness (Δ^+), index of variation in taxonomic distinctness (λ^+), functional evenness (FEve), functional divergence (FDiv), functional dispersion (FDis), local contribution to β diversity (LCBD) and habitat disturbance score of the 27 sites studied along the Ganga River, India

	Species richness	Δ^+	λ^+	FEve	FDiv	FDis	LCBD
Δ^+	0.046						
λ^+	0.191	**− 0.517***					
FEve	**− 0.855***	0.201	**− 0.494***				
FDiv	**0.449***	− 0.033	− 0.037	− 0.186			
FDis	0.205	**0.609***	**− 0.394***	− 0.088	0.094		
LCBD	**0.702***	− 0.031	0.272	**− 0.734***	0.045	0.152	
Habitat disturbance score	− 0.911	0.006	− 0.283	**0.889***	− 0.275	− 0.217	**− 0.681***

Significant ($p < 0.05$) values are indicated by boldface and * mark

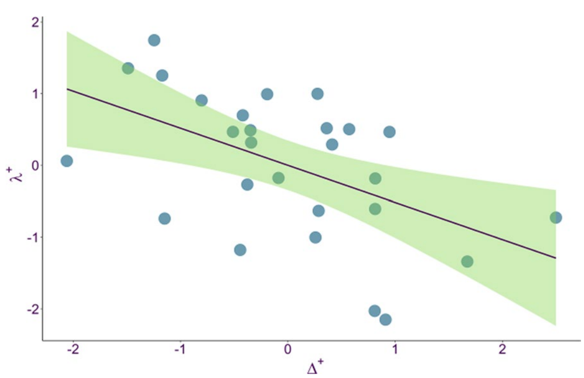

Fig. 3 Scatter plots of the relationship between taxonomic distinctness (Δ^+) and the index of variation in taxonomic distinctness (λ^+) (multiple $R^2 = 0.267$, $r = -0.517$, $p < 0.05$) of spider community in the 27 sites studied along the Ganga River

disturbed sites (for FDiv Kruskal–Wallis $\chi^2 = 8.154$, $df = 2$, $p < 0.05$, for FEve Kruskal–Wallis $\chi^2 = 17.392$, $df = 2$, $p < 0.05$) (Fig. 9). The Games–Howell test indicated that FDiv significantly differed between lowly and moderately disturbed sites (estimate = − 1.39, Tukey adjusted $p = 0.015$). FEve differed between lowly and highly disturbed sites (estimate = − 1.75, Tukey adjusted $p < 0.0001$) and between moderately and highly disturbed sites (estimate = − 1.27, Tukey adjusted $p = 0.002$).

Habitat disturbances significantly affected the λ^+, FEve, and LCBD. The GLM suggested that the garbage dump and created embankment were important disturbances that affected the λ^+, agriculture, human settlement and created embankment were important disturbances that affected the FEve and agriculture and created embankment were important disturbances that affected the LCBD of the spider community (Table 3; Fig. 10A–C).

Discussion

Taxonomic distinctness measures taxonomic relatedness between species (Ellingsen et al. 2005). Functional diversity assesses the response of species assemblages to natural or anthropogenic pressures by measuring the characteristics of organisms that relate to their interactions with their environmental components (Leaver et al. 2019; Torres-Bejarano et al. 2021). The LCBD measures the uniqueness of the sites in terms of species composition and indicates local contributions to species replacement and richness differences (Heino and Grönroos, 2016). The present study attempted to determine the

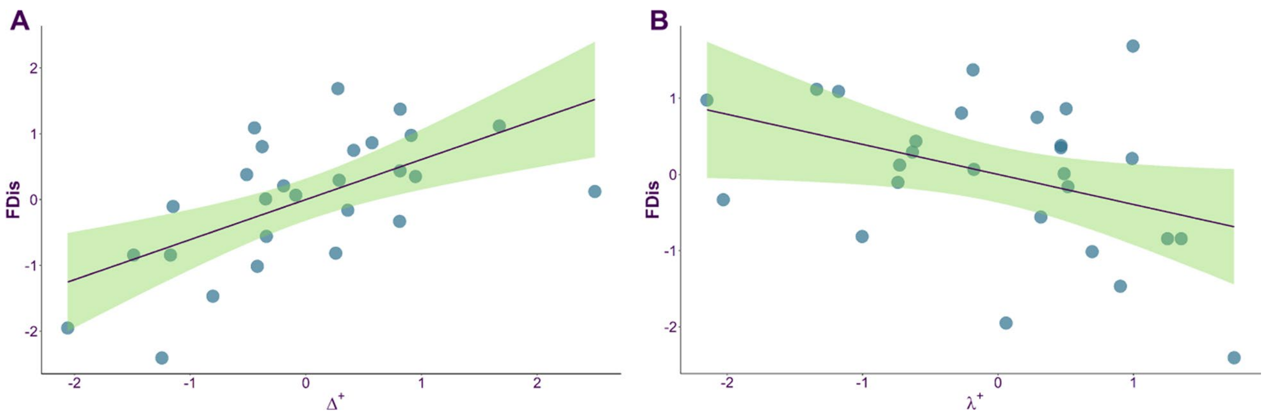

Fig. 4 Scatter plots of the relationship between **A** functional dispersion (FDis) and taxonomic distinctness (Δ^+) (multiple $R^2 = 0.371$, $r = 0.609$) and **B** functional dispersion (FDis) and the index of variation in taxonomic distinctness (λ^+) (multiple $R^2 = 0.155$, $r = -0.394$) of spider community in the 27 sites studied along the Ganga River

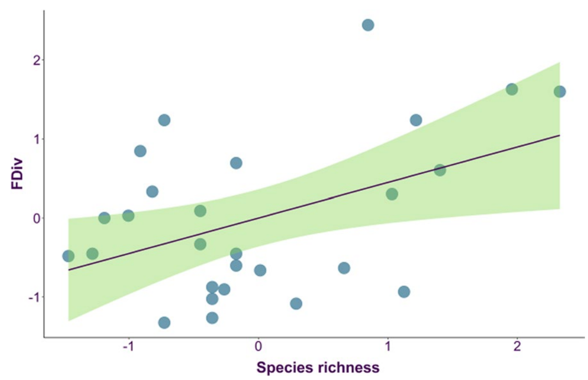

Fig. 5 Scatter plot of the relationship between functional divergence (FDiv) and species richness (multiple $R^2 = 201$, $r = 0.449$) of spider community in the 27 sites studied along the Ganga River, India

relationship between taxonomic distinctness, functional diversity, and LCBD of the riparian spiders of the Ganga River and to find out the effect of habitat disturbances on such diversity measurements.

As ecological and evolutionary forces shape the functional traits of species, which reflect variation in survivorship and fitness across differing environments (Swenson and Enquist 2007; Thomas et al. 2015), the close taxonomic relatives similarly utilize resources, and they share similar functional traits. As a higher value of Δ^+ reflects high taxonomic diversity (so that low relatedness among species) and a higher value of λ^+ reflects low taxonomic diversity (as the presence of some genera with many species would tend to increase λ^+), the Δ^+ and λ^+ have an inverse relationship (Clarke and Gorley 2001; García-Martínez et al. 2015). In this study, a similar association was observed. As higher values of FDis indicates, higher dispersion of functional traits in multivariate space and higher values of Δ^+ suggests the establishment of different taxa with a large ecological niche. The present study observed a positive relationship between them. Mason et al. (2005) predicted that there would be no relationship between FDiv and species richness. But as the higher values of FDiv indicates a higher degree of complementarity species niche and low competition for resources (Villéger et al. 2008) that supports higher species richness, a positive relationship was found in the present study. Farias and Jaksic (2009) observed a negative relationship between species richness and FEve, and the current study found a significant negative relationship between them. Higher FEve values indicate high utilization efficiency of the niche space that can be achieved through high taxonomic diversity, and higher λ^+ means low taxonomic diversity (Mason et al. 2005; Villéger et al. 2008; García-Martínez et al. 2015). FEve and λ^+ have a negative relationship, which was found in this study. Present work found that the FEve was positively correlated with habitat disturbance; LCBD was negatively correlated with FEve and habitat disturbance. These findings indicate that when few species become dominant in the ecosystem due to increasing habitat disturbance, these species will be more evenly distributed in the sites, leading to a decrease in the uniqueness of the species composition in the sites. As species richness had a significant difference between the three types of disturbed sites and FEve and FDiv were significantly correlated with species richness, it was observed that FEve and FDiv also had a difference between the three types of disturbed sites.

The contribution of aquatic insects to the diets of different families of riparian spiders can vary from less than 20% to above 60%, but it may reach 100% also (Stenroth et al. 2014; Kelly et al. 2019; Hunt et al. 2020). Variations in primary productivity in the riparian area can alter higher trophic levels, including aquatic insects (de

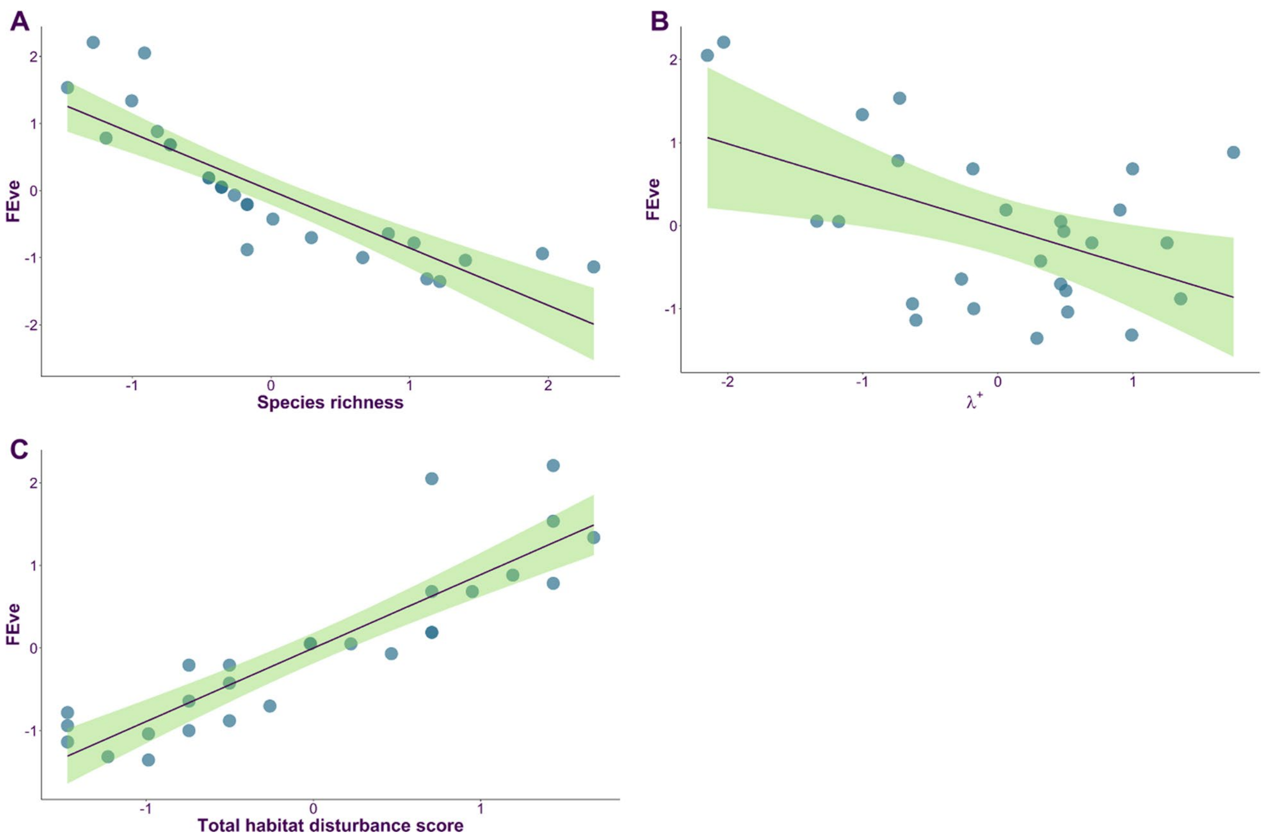

Fig. 6 Scatter plots of the relationship between **A** functional evenness (FEve) and species richness of spider community (multiple $R^2 = 0.731$, $r = -0.855$) **B** functional evenness (FEve) and index of variation in taxonomic distinctness (λ^+) of spider community (multiple $R^2 = 0.244$, $r = -0494$) and **C** functional evenness (FEve) of spider community and total habitat disturbance score (multiple $R^2 = 0.789$, $r = 0.889$) in the 27 sites studied along the Ganga River, India

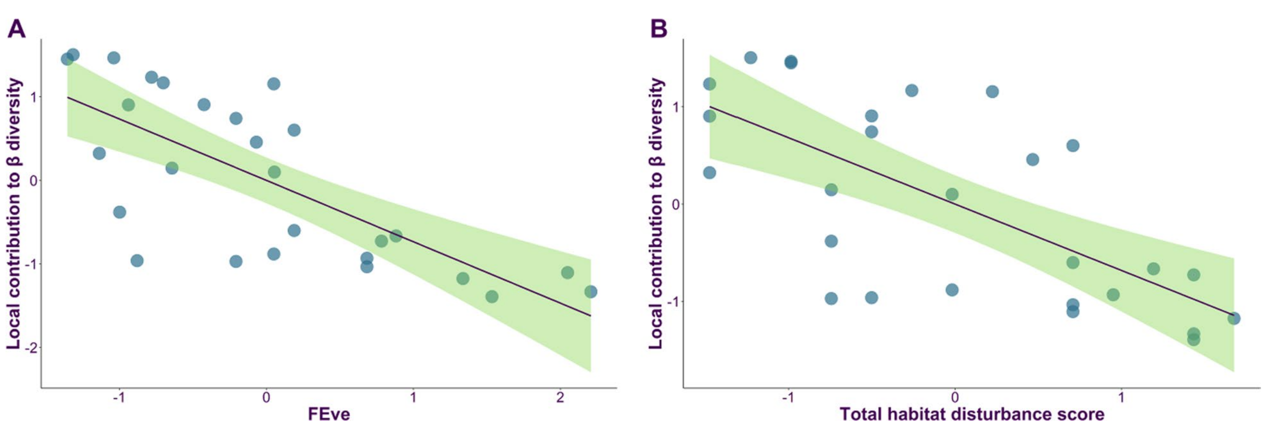

Fig. 7 Scatter plots of the relationship between **A** local contribution to β diversity (LCBD) and functional evenness (FEve) of spider community (multiple $R^2 = 0.539$, $r = -0.734$) and **B** local contribution to β diversity (LCBD) of spider community and total habitat disturbance score (multiple $R^2 = 0.464$, $r = -0.681$) in the 27 sites studied along the Ganga River, India

Jesús-Crespo and Ramírez 2011) that can affect the distribution, abundance, and diet of riparian consumers such as spiders (Tagwireyi and Sullivan 2016). In the Ganga River, the primary productivity is enhanced by the increasing supply of dissolved organic carbon to the river due to the atmospheric deposition of nutrients such as

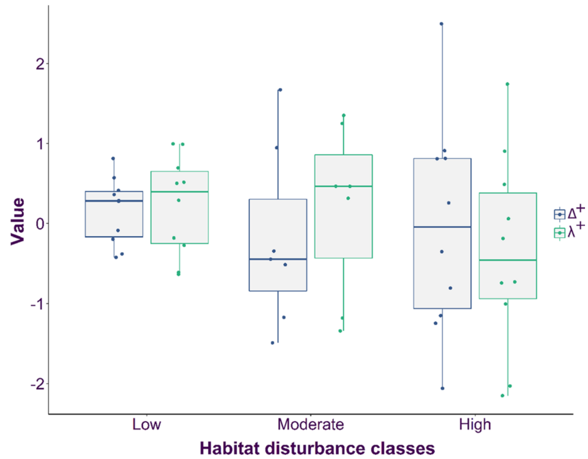

Fig. 8 Boxplot comparing taxonomic distinctness (Δ+) and index of variation in taxonomic distinctness (λ+) of spider community between the lowly, moderately, and highly disturbed sites along the Ganga River, India (for Δ+ Kruskal–Wallis $\chi^2 = 0.984$, $df = 2$, $p > 0.05$; for λ+ Kruskal–Wallis $\chi^2 = 2.024$, $df = 2$, $p > 0.05$). Each box represents the 25%/75% quartiles, and the median is shown with a horizontal line

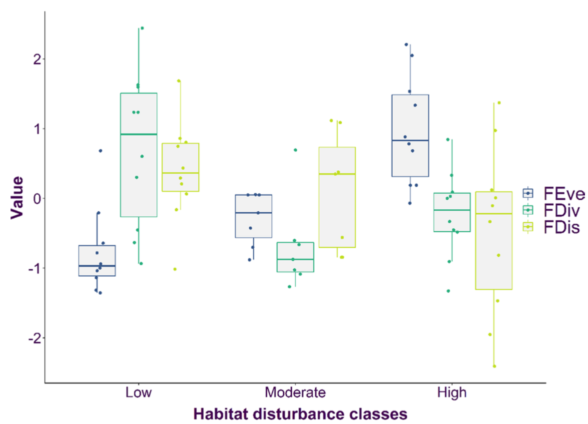

Fig. 9 Boxplot comparing functional evenness (FEve), functional divergence (FDiv), and functional dispersion (FDis) of spider community between the lowly, moderately, and highly disturbed sites along the Ganga River, India (for FEve Kruskal–Wallis $\chi^2 = 17.392$, $df = 2$, $p < 0.05$; for FDiv Kruskal–Wallis $\chi^2 = 8.154$, $df = 2$, $p < 0.05$; for FDis Kruskal–Wallis $\chi^2 = 2.840$, $df = 2$, $p > 0.05$). Each box represents the 25%/75% quartiles, and the median is shown with a horizontal line

phosphate and nitrate (Pandey et al. 2014; Siddiqui et al. 2020). It was estimated that riparian spiders obtain more than 50% of their body carbon from aquatic production (Collier et al. 2002). Thus, nutritional enrichment may become a key factor driving the ecology of the Ganga River, which may shift the phenology of riparian producers leading to a mismatch of resources reaching higher consumers in the food chain, such as spiders.

Additionally, the pollution level in the Ganges River has become a matter of deep concern because water-polluting chemicals enter the ecosystem's food chain and cause immense damage to the associated biota. In recent years, harmful chemicals such as polychlorinated biphenyls (PCBs) and heavy metals have been detected in the Ganga River (Dwivedi et al. 2018; Ghirardelli et al. 2021). Emerging aquatic insects are contaminated with chemicals such as mercury (Hg) and polychlorinated biphenyls (PCBs) in polluted water bodies, and the presence of such contaminants in riparian spiders correlates with the proportion of emerging aquatic insects in their diet (Chumchal et al. 2022). Consuming such contaminated insects negatively affects species richness and abundance of insectivore riparian spiders (Bundschuh et al. 2022). This means that chemical pollutants in river water can negatively affect the biodiversity of riparian spiders, which occupy the apex of the invertebrate food chain. Studies on the effect of the river water's chemical (nutrients and pollutants) enrichment on the riparian spiders were beyond the scope of the present study. However, the present study found that physical habitat disturbances such as agriculture, garbage dump, human settlement, and created embankment can influence the variation in taxonomic distinctness, functional diversity, and LCBD of the spider community, which is similar to the findings by De et al. (2021) who found that the agriculture, human settlement, embankment, and sand mining affects riparian spider assemblage in the Ganga River.

Information on species' diversity and distribution patterns in the riparian region is critical because conservation management in this region is based on this baseline data. But, as the scientific community has limited but constantly progressive knowledge about the variety and ordination of organisms, particularly invertebrates, an alteration in conservation stratagem will occur with the increase of information and knowledge about the ecology of any species (Abellán et al. 2005). This statement applies to the river ecosystem as the geomorphology of any river is constantly changing because climatic factors such as rainfall and temperature and topographic factors such as vegetation cover and land use affect river hydrology, which is often seasonal, and this change directs changes in the river-dependent organisms (De et al. 2021).

Conclusion

The current study was the first on any Indian river system to observe that anthropogenic habitat disturbance can affect the taxonomic distinctness, functional diversity, and LCBD of the spider community in riverine riparian habitat. Though the present study did not include factors like landscape structure, topography, prey availability, and vegetation patterns that have the potential to

Table 3 Effects of habitat disturbance types (best predictors) on the index of variation in taxonomic distinctness (λ^+), functional evenness (FEve), and local contribution to β diversity (LCBD) of the spider community of the 27 sites studied along the Ganga River, India

Indicator	Coefficient	R^2	β	SE	p	Variable importance
λ^+	Intercept	0.332	-1.072×10^{-6}	0.164	0.999	
	Garbage dump		0.512	0.255	0.056	2.005
	Created embankment		− 0.857	0.255	0.003	3.357
FEve	Intercept	0.869	1.551×10^{-7}	0.074	1.00	
	Agriculture		0.305	0.081	0.001	3.739
	Human settlement		0.641	0.113	9.82×10^{-6}	5.634
	Created embankment		0.389	0.119	0.004	3.252
LCBD	Intercept	0.565	-9.378×10^{-7}	0.132	1.00	
	Agriculture		− 0.355	0.137	0.016	2.590
	Human settlement		− 0.733	0.137	1.74×10^{-5}	5.345

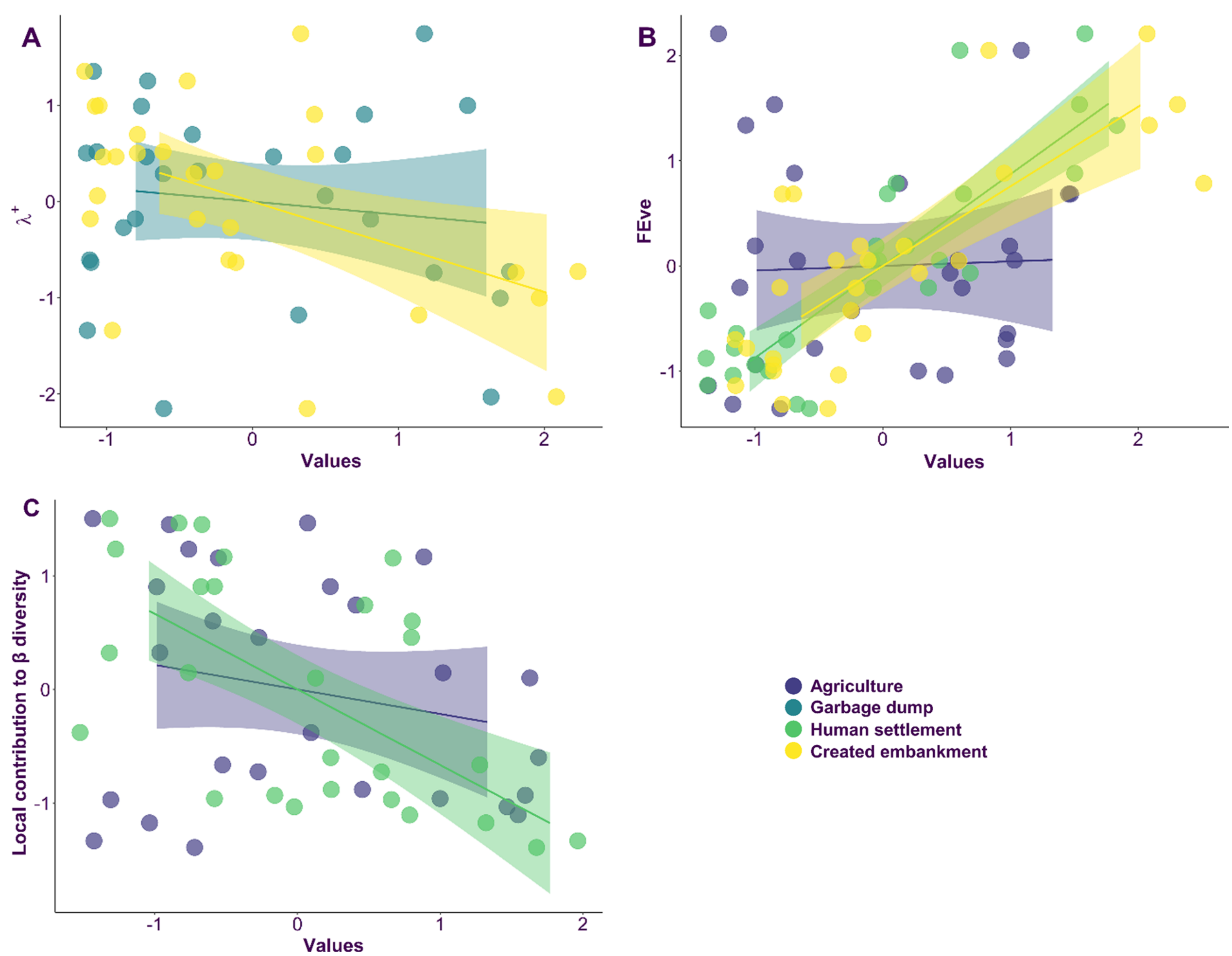

Fig. 10 Scatter plots of the multiple linear regression (best predictor combination) between **A** index of variation in taxonomic distinctness (λ^+) of spider community, **B** functional evenness (FEve) of spider community, and **C** local contribution to β diversity of spider community with habitat disturbance in the 27 sites studied along the Ganga River, India

shape the taxonomic and functional diversity of any community, particularly in heterogeneous lotic ecosystems where regional biodiversity changes with spatial gradients of environmental conditions, our work on the spider community should be considered as the initial step in the process of enhancing our fundamental knowledge on the effect of habitat disturbance on the spider community of the Ganga River, which should be recursive with new information generated through further research.

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Author contributions
KD: conceptualization, data curation, formal analysis, methodology, software, validation, visualization, writing—original draft; APS: data curation; AS: data curation; KS: data curation; MS: supervision, validation, writing—review and editing; VPU: project administration, resources, supervision, validation, writing—review and editing; SAH: funding acquisition, project administration, resources, supervision, validation, writing—review and editing. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used for the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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