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Research article

Odonate diversity and community turnover along elevational gradients in the Karnali River Basin, Nepal

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Abstract

Odonates are bioindicators, and understanding their species composition pattern along elevational gradients is essential for conservation initiatives. This study investigates the diversity and distribution patterns of Odonata along an elevational gradient (544–2987 m above sea level (asl)) in the Karnali River basin of western Nepal. Sampling was conducted across 15 sites during pre-monsoon, monsoon, and post-monsoon seasons of 2022 using the belt transect method in lentic and lotic habitats. The Shannon Diversity Index, Simpson's Index, and beta (β) diversity (both incidence-based and abundance-based) were used to describe the odonate assemblages. A total of 90 species representing 54 genera and 12 families (five Anisoptera and seven Zygoptera) were recorded. Libellulidae and Coenagrionidae emerged as the most species-rich families among dragonflies and damselflies, respectively. Diversity indices fluctuated with elevation, with the Shannon (3.58) and Simpson (0.96) indices peaking at 646 m and declining sharply at higher altitudes. Polynomial regression revealed a significant negative correlation ($r = -0.81$, $p < 0.001$) between species richness and elevation. β-diversity analysis showed high dissimilarity and turnover among sites, with incidence-based dissimilarity (mean $\beta_{sor} = 0.572$) and abundance-based dissimilarity (mean dBC = 0.664) both driven primarily by species turnover. Lentic habitats showed higher β-diversity (mean $\beta_{sor} = 0.607$) than lotic habitats (mean dBC = 0.595). Most species exhibited narrow elevational ranges, primarily below 1600 m, while a few were widespread, including *Pantala flavescens,* which were recorded from lower to higher elevation ranges. These findings highlight significant spatial variation in odonate assemblages across elevations, underscoring the ecological sensitivity of montane aquatic habitats to altitudinal and potentially climatic gradients.

Keywords: Zygoptera and Anisoptera; Lentic and lotic habitats; β-diversity; Altitudinal zonation; Bioindicators

1 | Introduction

The amphibious attributes of dragonflies and damselflies (Insecta: Odonata) make them a versatile tool for biodiversity assessment (Harisha 2016). They are widely distributed across diverse habitats, including forests, lakes, gardens, farmlands, rivers, houseyards, and urban environments. However, the abundance and distribution of odonates are influenced by several factors, such as the vegetation along the edges of water bodies (Corbet 1999; Cordoba-Aguiler 2008), land use patterns, anthropogenic activities (Luke et al. 2017; Wijesooriya et al. 2022), and seasonal changes (Renner et al. 2017). Besides taxonomic studies, biological diversity across spatial and environmental gradients has become a major focus of research in spatial ecology in recent decades. Species richness along elevational gradients exhibits three broad patterns: a mid-elevation peak, a monotonic decline, or an increase with elevation, depending on the various taxonomic groups (Rahbek 1995). Most studies on altitudinal gradients mainly focused on species diversity (α-diversity and γ-diversity) (Rana et al. 2019), and community composition and dissimilarities in species composition (taxonomic beta diversity) are poorly understood along elevational gradients. Beta (β)-diversity provides the link between α-diversity at local scales and γ-diversity at more regional scales (Anderson et al. 2011). To quantify the variation in species composition, β-diversity is partitioned into its turnover and nestedness components (Baselga 2010, 2013). The turnover component of β-diversity denotes species replacement by other species from site to site due to environmental filtering, while nestedness occurs when species present at relatively species-poor sites constitute proper subsets of those present at more species-rich sites (Fontana et al. 2020).

Elevation effects have been the focus of various studies on butterflies (Khanal 2013), mammals (Poulton 2019), amphibians (Khatiwada et al. 2019), birds (Pandey et al. 2020), ants (Subedi & Budha 2020) and larval odonata (Mahato & Edds 1993) in Nepal. Despite being an important bioindicator species, odonatological studies are scanty in Nepal. The elevational distribution pattern of adults of Odonata is still not well established. Therefore, the present study aimed to assess the diversity and community composition of Odonata along the elevational gradient of the Karnali River basin.

2 | Materials and methods

2.1 | Study area

The Karnali River basin comprises tributaries of the Bheri River (Sani Bheri, Thuli Bheri), Seti River (Budhiganga, Kailash), and Karnali River (Humla Karnali, Mugu Karnali, Tila, Sinja Khola, Karwadi). This basin has 936 lakes and 1128 glacier lakes (Bajracharya et al. 2020). Forests, bare land, agriculture, grassland, and shrubland are major-land use types of this river basin. The summer monsoon brings roughly 80% of the region's precipitation,

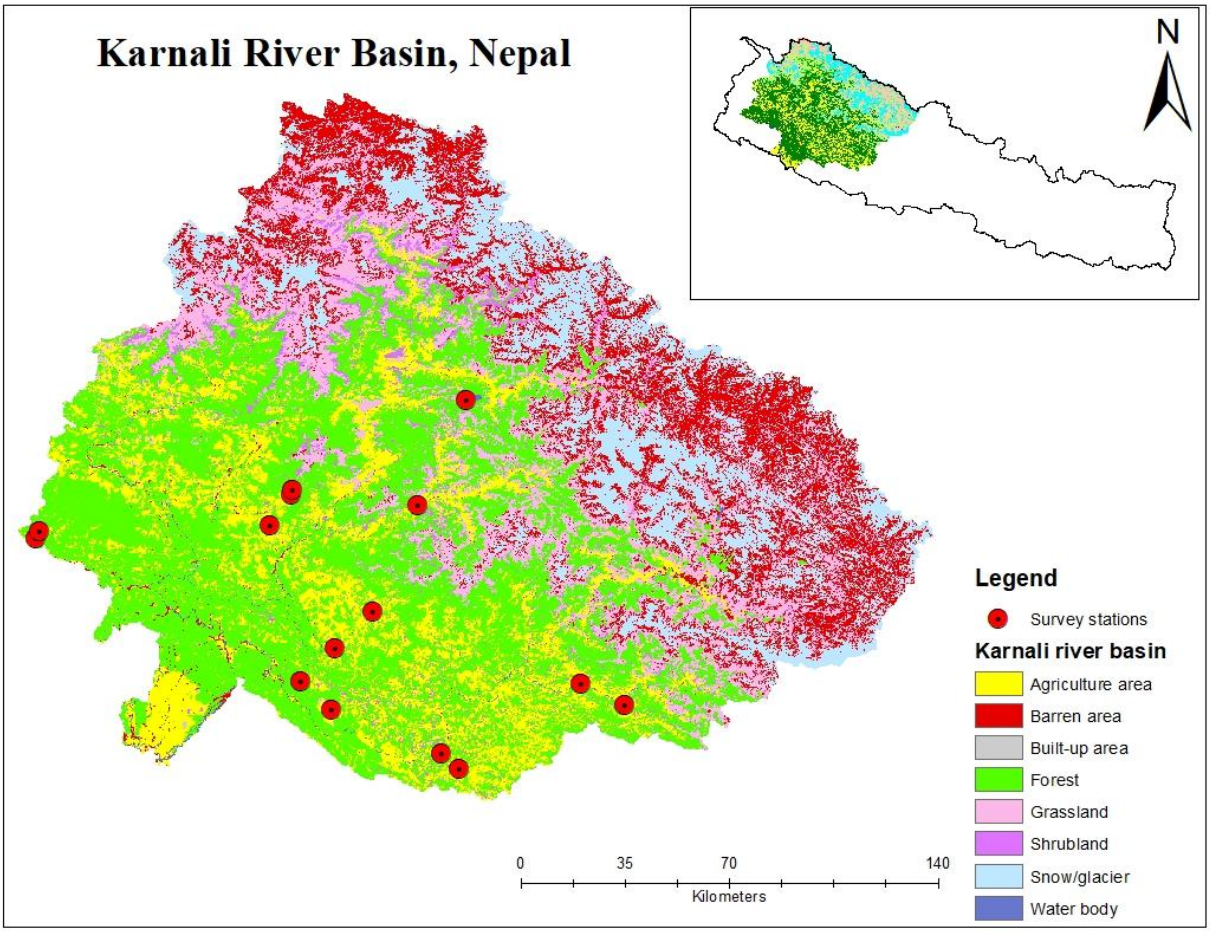

Figure 1. Map of the study area showing survey stations.

with winter droughts being the most common (Aryal et al. 2023). The biologically significant Karnali River is the home of nationally and globally endangered flora, vertebrates, and macro-invertebrates, which is possibly explained by the broad elevational distribution of varied aquatic ecosystems, ranging from hot and humid lowlands to cold alpine habitats (Khatiwada et al. 2021).

The sampling sites in the study area were located in an elevation range from 450 m to 2980 m of the Karnali River basin (Fig. 1, Table 1).

2.2 | Field data sampling

Sampling was carried out in the pre-monsoon, monsoon, and post-monsoon seasons of 2022, and winter was excluded due to lack of activity of adults at low temperatures. Sampling sites were established considering habitat potentiality and accessibility. A total of 15 transects were established covering various elevation and vegetation types in lentic habitat and lotic habitat (Table 1) and a total of six sampling events were conducted throughout the study period. Belt transects of 500 × 10 m were used to survey Odonata to quantify the fluctuation in Odonata richness and abundance along the elevational gradient (Koparde et al. 2015). The transects were mostly continuous belt transects, but in a few sampling sites, interrupted belt transects with 2–3 quadrats were created within the total length depending on accessibility. At each site, odonata were observed and photographed, and their abundance was also recorded on sunny days from 08:00 to 12:00 h in the morning and 15:00 to 17:00 h in the evening (due to their diurnal and crepuscular behavior).

The *in-situ* identification was done with the help of field guides (Subramanian 2009; Nair 2011; Singh 2022) and taxonomic keys (Fraser 1933, 1934, 1936). In cases where instant identification

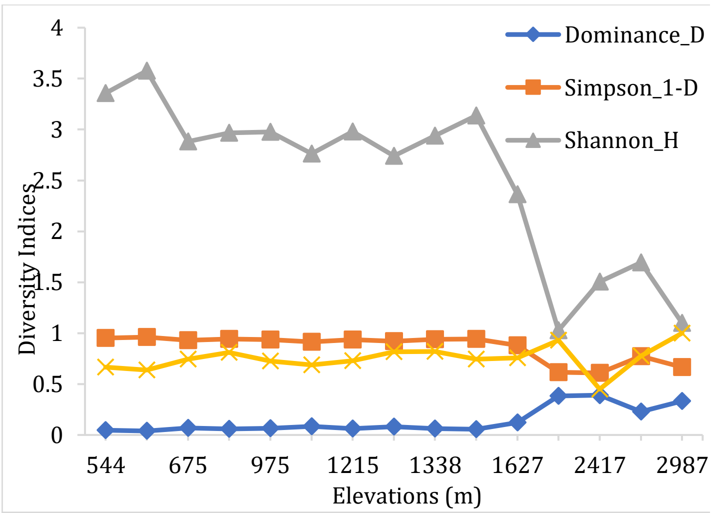

Figure 2. Variation of species diversity indices along the altitudinal gradient in the Karnali River basin.

Table 1: Spatial attributes of sampling locations with geomorphological features.

S.N.	Location	Coordinates	Elevation	Habitat Descriptions
1.	Baluwa Sangrahi	28.45796°N, 82.00121°E	544 m	The paddy field, along with the river, has hanging shrubby vegetation and partially submerged large stones.
2.	Bulbule lake	28.58226°N, 81.61955°E	646 m	Shrub-dominated wetland with slow-running water channel.
3.	Rati Khola	28.76799°N, 81.62795°E	675 m	Fast-flowing water channels with hanging shrubby vegetation and partially submerged large stones.
4.	Hurke	28.66824°N, 81.51376°E	783 m	Small brook dominated by shrubby vegetation.
5.	Chinkhet	28.67499°N, 82.47299°E	975 m	The terraced agricultural field, along with a fast-flowing river and submerged large stones.
6.	Kupinde Daha	28.41067°N, 82.05898°E	1127 m	Reservoir with rocky area and trees.
7.	Chatiwan Lake	29.08001°N, 80.58695°E	1215 m	The lake with riparian vegetation, surrounded by terraced agricultural fields.
8.	Budar Waterfall	29.10189°N, 80.59987°E	1315 m	Stream inside the dense forest.
9.	Dailekh Khola	28.88084°N, 81.75322°E	1338 m	The paddy field, along with the river, has hanging shrubby vegetation and partially submerged large stones.
10.	Kamal Daha	28.61270°N, 82.62418°E	1564 m	Wetland dominated by shrubs, especially Lotus.
11.	Santada	29.13895°N, 81.39468°E	1627 m	Rivulet with submerged stones and riparian vegetation.
12.	Nagmagad	29.20829°N, 81.90488°E	2137 m	Tributes of river without vegetation.
13.	Jingale Lake	29.23362°N, 81.46738°E	2417 m	Ramaroshan Lake Complex: wetland inside a forested area.
14.	Roshan River	29.24527°N, 81.46829°E	2430 m	Ramaroshan Lake Complex: wetland inside a forested area.
15.	Rara Lake	29.5288°N, 82.06548°E	2987 m	Lake surrounded by coniferous forest.

based on morphological characteristics was not possible, the specimen was caught using a hand-held insect sweeping net, then killed and kept in triangular envelope paper for further identification. The identified species were then enlisted following the systematic arrangement and taxonomy of Paulson et al. (2024).

Further, the species recorded at ±40–50 m distance from the sampling points were enlisted at the nearest elevational ranges to enhance a comprehensive checklist of Odonata of the Karnali River basin, Nepal.

2.3 | Data analysis

Odonata species richness was computed from pooled data from all seasons for each site. The diversity indices were calculated for each elevation gradient, and graphs were plotted for comparison. Additionally, a polynomial regression plot was created to evaluate the variation in species richness along altitudinal gradients.

Pairwise, β-diversity was evaluated using both incidence-based and abundance-based dissimilarity measures (Baselga 2010, 2013). On an incidence-based dissimilarity measure, similar weights were given for all species. And to recompense for such bias, abundance-based dissimilarity measures were calculated. For incidence-based β-diversity, the Sorenson dissimilarity index (βsor), Simpson dissimilarity (=turnover component of Sorenson dissimilarity) (βsim), and the nestedness-resultant component of Sorenson dissimilarity (βnes) components were calculated. Similarly, for abundance-based dissimilarity, the Bray-Curtis dissimilarity index (dBC), balanced variation (=turnover component, in which individuals of one species are substituted by the same number of individuals but of other species from site to site) (dBC-bal), and abundance gradient components (=nestedness component and is caused by individuals being lost from one site to another without the species being replaced) (dBC-gra). To detect major transitions and diversity patterns in the odonata community along the elevational gradient, stepwise β-diversity was analyzed, which compares one elevational zone with its adjacent elevational zone along the elevation gradient (Wang et al. 2012; Fontana et al. 2020).

Table 2. Species status according to the levels assigned to frequency of occurrence, abundance.

Occurrence % of total sites, Abundance	Level	Score	Status
Below 10 %, low	1-1	2	Rare
Below 10 %, Medium	1-2	3	Uncommon
10-50 %, Low	2-1	3	Uncommon
Below 10 %, High	1-3	4	Common
10-50 %, Medium	2-2	4	Common
Above 50 %, Low	3-1	4	Common
10-50 %, High	2-3	5	Common
Above 50 %, Medium	3-2	5	Common
Above 50 %, High	3-3	6	Abundant

Family-wise elevation range was also computed. The elevation range profile of each species was estimated from the presence of the species at the lowest and highest altitudes, assuming the presence of that species at all intermediate altitudes (Bota-Sierra et al. 2021).

The population status of odonates in the study area was categorized as rare, uncommon, common, and abundant based on frequency of occurrence and abundance (Table 2) (Gaston 1994). The frequency of occurrence of each species (i.e., the number of sites in which each species was sampled) was divided into three parts, i.e., below 10%, 10 – 50%, and above 50% of total sites, and levels as 1, 2, and 3, respectively.

For abundance, the formula is As = Ns/Fs (where Ns is the total number of species s in all sampled sites and Fs is the frequency of sites in which species s was sampled). Later, abundance was categorized as low (below 50 individuals in a single calendar year), medium (50–100 individuals in a single calendar year), and high (above 100 individuals in a single calendar year), levels 1, 2, and 3, respectively (Gaston 1994).

All collected data was entered into the Microsoft Excel 2019 spreadsheet and analyzed in PAST software (Version 4.08, Hammer et al. 2001). To quantify the sampling effort, a species rarefaction curve on both sample-based (total transect number) and individual-based on the elevation gradient was prepared.

3 | Results

A total of 3,812 individuals of odonates belonging to 90 species (52 dragonflies and 38 damselflies), 54 genera, and 12 families (five anisopterans and seven zygopterans) were recorded from 15 different sampling sites along the elevational gradient of the study area (Table 1).

A total of 74 odonate species were uncommon, nine were common, while seven species were rare (Supplementary file 1).

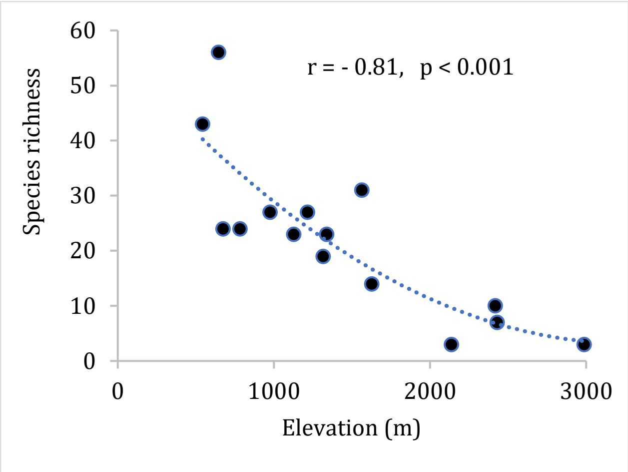

Figure 3. The scatter plot shows a decline in observed species richness with altitude.

Among dragonfly species, *Crocothemis servilia* has the highest abundance (n=274), while *Gynacanthaeschna sikkima* (n=2) and *Watanabeopetalia atkinsoni* (n=2) were the least abundant species. Likewise, the damselfly species with the highest abundance was *Ceriagrion coromandelianum* (n=290), and the least abundant damselfly species were *Lestes viridulus*, *Anisopleura subplatystyla*, *Coeliccia renifera*, and *Aciagrion approximans*, with only four individuals of each one (Annex 1).

The abundance, species richness, and diversity of Odonata varied between study sites. Among anisopterans, Libellulidae (n=33) was the dominant family, while Chlorogomphidae was the family with the least species richness (n=1). For zygopterians, family Coenagrionidae (n=19) has high species richness, while family

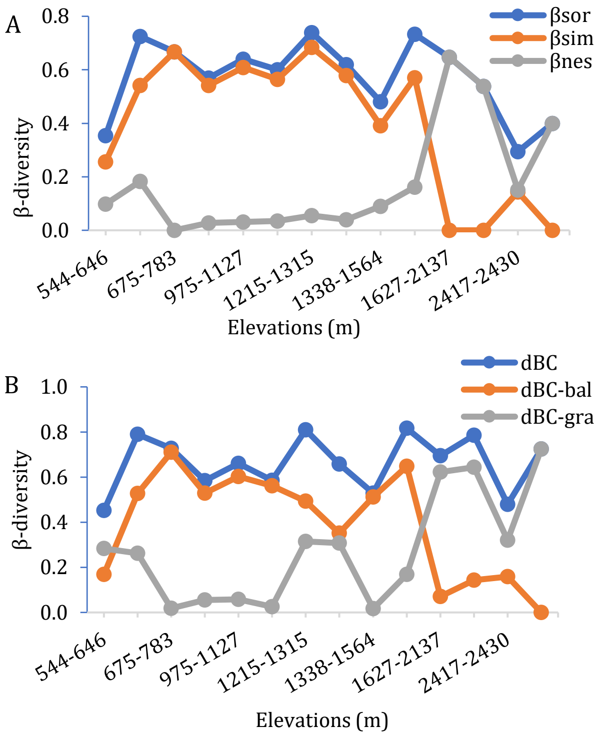

Figure 4. Overall pairwise (A) incidence-based and (B) abundance-based β-diversity of odonata along the elevation gradient in the Karnali River basin. Bsor = Sorenson dissimilarity index; βsim = turnover; βnes = nestedness; dBC = Bray-Curtis dissimilarity index; dBC-bal=balanced variation; dBC-gra=abundance gradient.

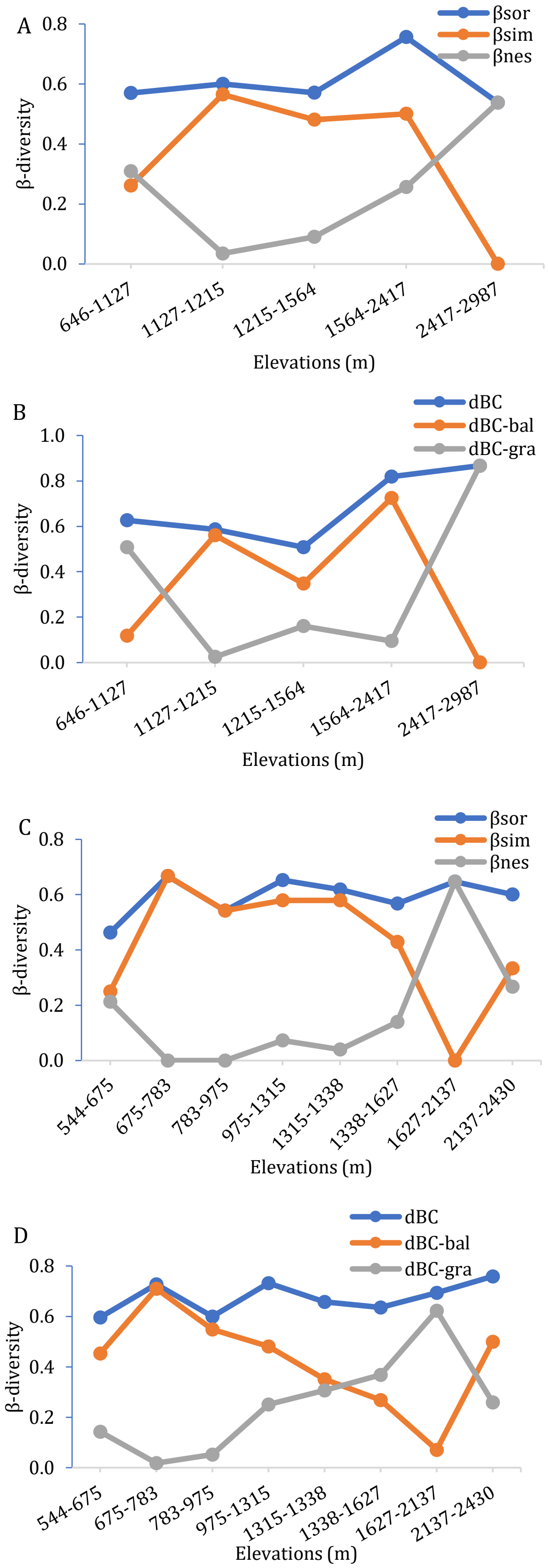

Figure 5. Pairwise (A) incidence-based and (B) abundance-based β-diversity of odonata for lentic habitat and pairwise (C) incidence-based and (D) abundance-based β-diversity of odonata for lotic habitat along the elevation gradient in the Karnali River basin.

Table 3. Family-wise species richness and abundance of odonata observed in the Karnali River basin.

Families (abbreviation)	Species richness	Abundance
Synlestidae (Synl.)	1	9
Lestidae (Lest.)	2	28
Calopterygidae (Calo.)	2	143
Chlorocyphidae (Chlc.)	4	86
Euphaeidae (Euph.)	4	91
Platycnemididae (Plat.)	6	158
Coenagrionidae (Coen.)	19	942
Aeshnidae (Aesh.)	7	55
Chlorogomphidae (Chlg.)	1	2
Gomphidae (Gomp.)	9	70
Macromiidae (Macr.)	2	19
Libellulidae (Libe.)	33	2209
Total	**90**	**3812**

Table 4. Mean, SD, minimum (Min), and maximum (Max) range of the overall incidence-based and abundance-based dissimilarities of odonata of the Karnali River basin.

Beta diversity indices and their components	Mean	SD	Min	Max
βsor	0.572	0.142	0.294	0.739
βsim	0.396	0.262	0.000	0.684
βnes	0.176	0.205	0.000	0.647
d_{BC}	0.664	0.122	0.452	0.816
$d_{BC\text{-}bal}$	0.391	0.236	0.000	0.710
$d_{BC\text{-}gra}$	0.273	0.243	0.017	0.725

Synlestidae has the lowest species richness (n=1) (Table 3, supplementary file 1).

Most of the species (n=56) shared both lentic and lotic habitats, while 17 species were confined to lentic and 18 species were inhabitants of lotic habitats. The *Bradinopyga geminata* was recorded in urban areas near both lentic and lotic habitats.

Odonata species diversity indices show fluctuations along the elevational gradients. The Shannon and Simpson diversity indices were maximum at 646 m asl, scoring 3.58 and 0.96, respectively. However, the minimum Shannon diversity index (1.03) was at 2137 m, and the minimum Simpson diversity index (0.61) was at 2417 m. The Shannon diversity index was moderate to high at lower elevations while low at higher elevations. The dominance of odonata species was low in the study area. The species evenness of the study area ranges from 0.45 to 1. The species were more stable in all communities except at 2417 m altitude, with a score of 0.45 (Fig 2). A scatter plot with a polynomial curve showed a significant decline ($r = -0.81$, $df = 14$, $p < 0.001$) in species richness with an increase in altitudinal gradient (Fig 3).

Odonata communities showed high dissimilarity among sites and strong patterns of turnover along the elevational gradient (Fig. 4, 5). The mean pairwise dissimilarity was 0.572 for all incidence-based sites and 0.664 for all abundance-based sites (Table 4). Partitioning β-diversity (incidence-based) returned a higher contribution of βsim (turnover) compared with βnes (nestedness) in the overall β-diversity. Mean βsim and βnes are 0.396 and 0.176, respectively. Likewise, for abundance-based dissimilarity, the dBC-bal (balance variation) with a mean value of 0.391 was higher than the dBC-gra with a mean value of 0.273. High turnover indicates that the number of shared species among sites was low (Fig. 4).

The composition of species living in lentic and lotic habitats exhibited similar variation in richness, but beta diversity was larger in lentic habitat (mean βsor = 0.607) than in lotic habitat (mean dBC = 0.595) along the elevation gradient. Two major peaks of turnover in mid and upper elevation, i.e., between 1127 and 1215 m, and 1564 and 2417 m, were observed in lentic habitat, while in lotic habitat, turnover at lower and upper elevation, i.e., between 675 and 783 m, and 1627 and 2137 m, was observed for both incidence-based and abundance-based sites (Fig. 5).

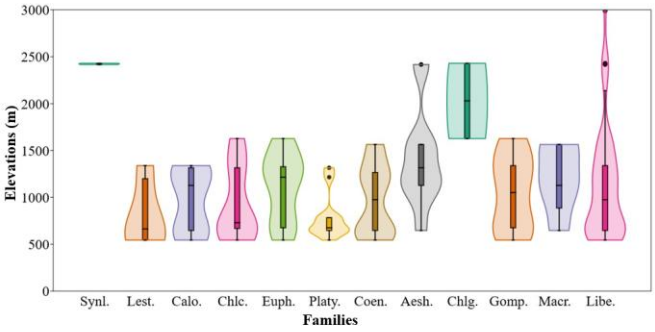

Figure 6. The elevation distribution of odonata families recorded in the Karnali River basin. Violin and boxplots represent the median, 3rd quartiles, and outliers. Abbreviations in Table 3.

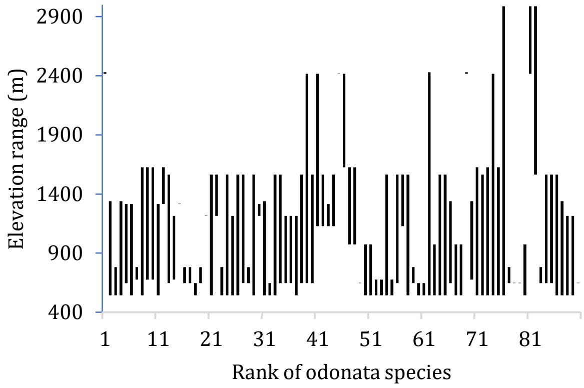

Figure 7. Elevational range profiles of Odonata in the Karnali River basin. Each bar represents the maximum and minimum elevational limits of a single species.

Most odonate families were recorded at lower elevations, except for the families Synlestidae (above 2400 m) and Chlorogomphidae (above 1600 m). Libellulidae was the dominant family from lower to higher elevations with a high elevational range profile, but species richness was very low at higher elevations. The violin and box plots indicate higher species richness at lower elevation (below 1000 m), though families have a wide elevation range (Fig. 6). Most Odonata species showed narrow elevational ranges along the gradient and occurred below 1600 m asl, while four species were recorded only above 2400 m (Fig. 7). *Pantala flavescens* was recorded from lower to higher elevation (larger range size).

The individual-based rarefaction curve based on individual numbers revealed that the highest species abundance (1100) with maximum species richness (56) was at 646 m, while the least abundance (7) of the three species was at the 2987 m elevation zone (Fig. 8). Likewise,

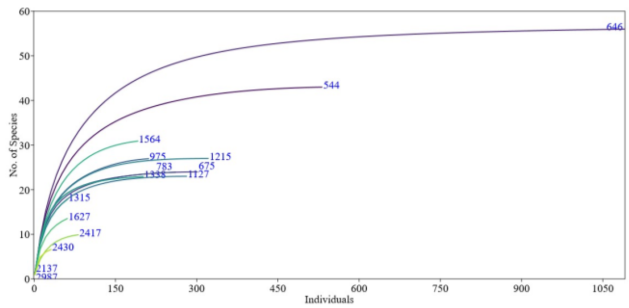

Figure 8. Individual-based rarefaction curves for different elevation gradients of the Karnali River basin.

the rarefaction curve based on sampling transects (Fig. 9) shows that an adequate sampling effort was conducted. In the curve at 95% confidence intervals, the upper and lower curves did not match the transect curve, indicating the presence of more odonate species in the study area.

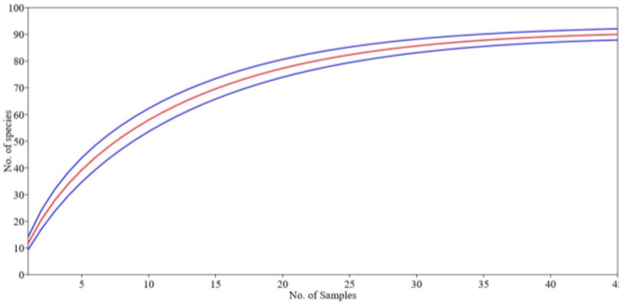

Figure 9. The rarefaction curve based on sampling efforts in the Karnali River basin. The red line represents the number of transects sampled, and the blue lines represent the 95% confidence intervals, upper and lower.

4 | Discussion

Nearly half (90 species) of the total number of species recorded from Nepal (Kalkman et al. 2020; Sharma et al. 2024) are dominated by the family Libellulidae, and Coenagrionidae in Karnali river basin reflects the general pattern in Asian countries (Arulprakash & Gunathilagaraj 2010) as they are found in the widest habitat, have a short life cycle, and are more tolerant towards a wide array of habitats (Dalzochio et al. 2011; Harisha 2016). Their wide habitat range and greater abundance are supported by their aggressive behavior and their feeding behavior, where they consume almost all insects; even cannibalism was seen (Sharma & Joshi 2007).

This study also revealed a higher abundance of anisopterans compared to zygopterans. These differences are likely attributable to the greater dispersal ability of anisoptera (Corbet 1999) and the thermoregulatory behavior exhibited by odonata to acquire energy for sustained flight (Seidu et al. 2017). In contrast, zygopterans are smaller, weaker fliers (Corbet 1999) and are generally regarded as thermoconformers (May 1976). This study affirms that the Libellulidae and Coenagrionidae showed strong associations to lentic habitat, while the Calopterygidae, Chlorocyphidae, Euphaeidae, Platycnemididae, and Gomphidae families were mostly recorded from lotic habitats. This coincides with the findings of Wijesooriya et al. (2022) in Sri Lanka and Seidu et al. (2019) in Ghana, as species belonging to these families are highly adapted to fast-flowing water characterized by rocky substrates and shady environments that provide good ecological habitat for their different behavioral activities (Dijkstra & Clausnitzer 2014; Seidu et al. 2019). Current research also shows the strong affinity of species belonging to the family Aeshnidae to lentic habitat. In contrast, Seidu et al. (2019) reported Aeshnidae being associated with lotic habitat. *Coeliccia renifera* was recorded only from forest habitat in mid-hill because this species depends on forest streams for breeding (Dow 2010).

Shannon diversity index values up to mid-elevation sites were above 2.0, which was an indication of a stable habitat structure, while in high-elevation sites, values were greater than 1.0, indicating that alteration in habitat or degradation of the habitat structure (Shannon 1948). The values obtained from the evenness index (almost above 0.5) at the different study sites show that odonate fauna were well distributed in lower elevations of the Karnali River basin (Shannon 1948).

As expected, odonate species richness decreased along with an increase in elevation gradient, showing a significant negative correlation with elevation ($r = -0.81$, $p < 0.001$), which is a common pattern shared by several species throughout the world (Corbet 1999; Acharya & Vijayan 2015; Peters et al. 2016; Rahbek et al. 2019; Bota-Sierra et al. 2021; Dewan et al. 2022). Although species richness declined, notable differences in community composition were observed across the study area. Many rare and unique species were recorded at higher elevations, consistent with the findings of Stefani-Santos et al. (2021). The declining trend observed in this study may be attributed to climatic conditions and vegetation types, as also suggested by Peters et al. (2016), and the mid-elevation peak in species richness indicates that elevational gradient alone did not influence the richness. Changes in climate, heterogeneity of habitat, and environmental conditions may be major factors that influence species diversity along elevation gradients (Yu et al. 2013).

The patterns of β-diversity of the odonata community along the elevational gradient were examined, and both incidence-based dissimilarity (turnover) and abundance-based dissimilarity (balanced variation) were similar. So, to explain the trends of β-diversity, both can be used side by side. This research shows multiple elevational peaks in pairwise β-diversity of odonates, with increasing elevational gradient denoting maximum dissimilarity in the composition of odonata in the study area. Such fluctuations in both turnover and balanced variation indicate that odonate species assemblages and their populations were being replaced by different species and populations from site to site (Baselga 2010, 2013). Despland (2014) suggests that the edge effect, which takes place at ecotone borders, may be the cause of the high β-diversity observed between them. The turnover also indicates the assemblages of unique species site-wise from lower to higher elevations. High turnover was observed during the change of species assemblages from lotic and lentic habitats. Further, turnover was observed by the same habitat types in different locations. This conforms to the findings of Clausnitzer (2003) that Odonate species assemblages are often altered by altered environments, which favor generalist species that can adapt to a variety of habitat types. Similarly, Aynekulu et al. (2012) also concludes that high turnover denotes notable differences in species composition among sites and vegetation types. Likewise, smaller subsets of larger communities are indicated by nestedness, which is more likely to rise where α-diversity decreases (Baselga 2010). The findings of the present study reveal high nestedness at higher elevations, a pattern that has also been documented in various studies worldwide (da Silva et al. 2018; Flores et al. 2018).

We may thus presume that the high regional diversity of odonate species in the study area is primarily driven by community turnover. Many studies have emphasized the significant role of turnover in shaping β-diversity patterns across various taxonomic groups, including dung beetles (da Silva et al. 2018), ants (Flores et al. 2018), butterflies (Dewan et al. 2021), and odonates (Gómez-Anaya et al. 2011). Legendre et al. (2005) conclude that geographical restrictions and environmental filtering influence the patterns of β-diversity along environmental gradients. The findings of this research indicate that the β-diversity of the study area is influenced by environmental filtering rather than geographical restrictions.

The data indicate that most odonata species occupy a narrow elevational range, highlighting their sensitivity to environmental variables associated with altitudinal changes. Heiser & Schmitt (2010) suggested that the dispersion ability of species is associated with environmental factors, particularly temperature and climate. Given their amphibious life cycle and often habitat-specific requirements, odonate species are especially vulnerable to habitat alteration, which can act as a barrier to their distribution (Renner 2018).

5 | Conclusions

In the Karnali River basin, Odonata species richness is highest at lower elevations, and declines progressively with increasing altitude. Despite this decline, higher elevations harbor unique odonate species. Due to their relatively narrow altitudinal ranges, odonata serve as valuable bioindicators of environmental change. Therefore, conservation efforts should prioritize odonate diversity across the entire altitudinal gradient of the Karnali River basin to ensure the protection of both widespread and elevation-restricted species.

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Authors' contributions

M.S. conceptualized the research, collected data from the field, identified specimens and wrote the original draft; B.R.O. assisted with field data collection, specimen preservation and preparing the original draft. I.G. designed and supervised the research. All authors read and approved the final version of the manuscript. Text

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Conflicts of interest

The authors declare no conflict of interest.

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Annex 1. list of odonata with their families, abundance, DBI and Indicator species based on OVI value

Families	Species	Abundance	DBI	Habita Indicator (OVI)
Synlestidae	*Megalestes major*	9	5	Pristine
Lestidae	*Lestes praemorsus*	34	3	Degraded
	Lestes viridulus	4	3	Altered
Calopterygidae	*Neurobasis chinensis*	118	3	Generalist
	Vestalis gracilis	16	5	Generalist
Chlorocyphidae	*Aristocypha quadrimaculata*	40	3	Generalist
	Aristocypha spuria	23	5	Generalist
	Aristocypha trifasciata	6	4	Generalist
	Rhinocypha unimaculata	5	4	Pristine
Euphaeidae	*Anisopleura comes*	7	4	Generalist
	Anisopleura lestoides	10	3	Generalist
	Bayadera indica	42	3	Generalist
Platycnemididae	*Calicnemia eximia*	18	4	Generalist
	Copera marginipes	41	3	Degraded
	Copera vittata	57	3	Degraded
	Prodasineura autumnalis	6	4	Degraded
	Pseudocopera ciliata	32	5	Degraded
Coenagrionidae	*Aciagrion approximans*	4	5	Altered
	Aciagrion occidentale	16	5	Generalist
	Aciagrion pallidum	11	4	Generalist
	Agriocnemis clauseni	20	4	Generalist
	Agriocnemis femina	21	3	Generalist
	Agriocnemis lacteola	14	3	Generalist
	Agriocnemis pygmaea	113	2	Generalist
	Amphiallagma parvum	35	3	Degraded
	Ceriagrion cerinorubellum	16	4	Generalist
	Ceriagrion coromandelianum	282	2	Generalist
	Ceriagrion fallax	4	4	Altered
	Ischnura forcipata	22	3	Degraded
	Ischnura nursei	18	3	Generalist
	Ischnura rubilio	110	1	Generalist
	Paracercion calamorum	9	2	Generalist
	Pseudagrion decorum	96	2	Generalist
	Pseudagrion microcephalum	18	2	Generalist
	Pseudagrion rubriceps	74	2	Altered
	Pseudagrion spencei	44	2	Generalist
Aeshnidae	*Anax guttatus*	7	2	Generalist
	Anax immaculifrons	15	3	Generalist
	Anax nigrofasciatus	15	4	Generalist
	Cephalaeschna viridifrons	5	5	Generalist
	Gynacantha bayadera	2	5	Pristine
	Gynacantha incisura	5	5	Generalist
	Gynacanthaeschna sikkima	2	5	Pristine
Chlorogomphidae	*Watanabeopetalia atkinsoni*	1	5	Pristine
Gomphidae	*Anisogomphus bivittatus*	3	4	Pristine
	Anisogomphus occipitalis	3	3	Generalist
	Ictinogomphus rapax	6	2	Degraded
	Lamelligomphus biforceps	7	3	Generalist
	Lamelligomphus risi	10	4	Generalist
	Nepogomphus modestus	5	4	Generalist
	Paragomphus lineatus	9	3	Generalist
	Scalmogomphus bistrigatus	9	3	Altered

	Scalmogomphus schmidti	5	4	Generalist
Macromiidae	*Epophthalmia frontalis*	14	2	Degraded
	Macromia moorei	5	2	Generalist
Libellulidae	*Acisoma panorpoides*	125	0	Generalist
	Brachydiplax sobrina	21	0	Generalist
	Brachythemis contaminata	15	0	Generalist
	Bradinopyga geminata	4	1	Generalist
	Crocothemis servilia	250	0	Generalist
	Diplacodes nebulosa	12	1	Generalist
	Diplacodes trivialis	39	1	Altered
	Neurothemis fulvia	54	1	Generalist
	Neurothemis intermedia	17	1	Degraded
	Neurothemis tullia	32	2	Generalist
	Orthetrum glaucum	10	2	Altered
	Orthetrum internum	15	1	Pristine
	Orthetrum luzonicum	19	5	Generalist
	Orthetrum pruinosum neglectum	220	0	Generalist
	Orthetrum sabina sabina	126	0	Generalist
	Orthetrum taeniolatum	62	0	Generalist
	Orthetrum triangulare triangulare	62	0	Generalist
	Palpopleura sexmaculata	68	1	Generalist
	Pantala flavescens	150	0	Generalist
	Potamarcha congener	4	2	Generalist
	Rhodothemis rufa	3	4	Degraded
	Rhyothemis triangularis	3	2	Degraded
	Rhyothemis variegata	11	2	Generalist
	Sympetrum speciosum	7	5	Pristine
	Sympetrum striolatum commixtrum	84	2	Pristine
	Tetrathemis platyptera	15	4	Generalist
	Tholymis tillargra	51	1	Generalist
	Tramea basilaris	22	2	Generalist
	Trithemis aurora	233	0	Generalist
	Trithemis festiva	116	0	Generalist
	Trithemis pallidinervis	29	1	Generalist
	Urothemis signata signata	23	3	Generalist
	Zyxomma petiolatum	10	4	Degraded