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Research Article

Earthworm diversity in an unexplored Himalayan landscape: Patterns across forest, orchard and crop field ecosystems

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Abstract

The present study was undertaken to explore the earthworm diversity in the Bani Valley, situated at an elevation range of 1200-2000 m above sea level, in the western Himalayan Region. Over the course of two years (March 2021 to January 2023), eight earthworm species were documented in three distinct habitat-types (forest, orchard and crop field), characterised by varying levels of anthropogenic interference. Notably, the crop field habitat exhibited highest earthworm density as well as biomass, while the forest habitat was observed to exhibit least earthworm abundance despite negligible human interference. Year-wise comparison showed that *Octolasion tyrtaeum* exhibited the highest mean density during both the years [34.31± 2.54 m^{-2} (2021-22) and 27.91 ± 1.88 m^{-2} (2022-23)], while the least density was recorded for *Amynthas corticis* (2.84 ± 1.06 m^{-2}) during 2021-22, but for *Drawida nepalensis* (1.60 ± 0.63 m^{-2}) during 2022-23 period. Moreover, an aggressive dominance of exotic earthworm species was observed in the study area with the occurrence of only one native species i.e. *Drawida nepalensis*. Maximum Likelihood Phylogram analysis of different earthworm species revealed three major clades, largely consistent with classical taxonomy. However, intergeneric clustering between *Drawida nepalensis* and *Octolasion tyrtaeum* suggests a potential case of cryptic similarity warranting further investigation. Analysis of Variance followed by multivariate ordination through canonical correspondence analysis suggested that the earthworm community structure was governed by the interactive effects of different soil physico-chemical properties. Despite the valuable insights with regard to earthworm diversity of the Bani Valley, further investigations are required in other unexplored patches to develop a comprehensive inventory of the earthworm fauna of the Himalayan Region.

Keywords

soil fauna, earthworm, diversity, Bani Valley, Western Himalayas, habitats, anthropogenic pressure

Introduction

India is one of the 17 globally-recognised mega-diverse countries, supporting an exceptionally rich biota with over 150,000 recorded species (Chandra et al. 2022). The Himalayan Region, comprising approximately 50% of the country's total forest cover, contributes substantially to the biodiversity and is considered one of the most significant biodiversity hotspots of the world (Dar and Khuroo 2020). This region spans over 2,400 km across the northern part of India (bordering Pakistan in the west to Myanmar in the east) and covers an area of about 0.53 million km^2, constituting 16.2% of the total geographical area of India (Dikshit et al. 2020, Tripathi et al. 2022). This region encompasses a broad range of altitudinal and ecological gradients, making it a critical zone for biodiversity research. While numerous studies have explored the diversity patterns of different floral and above-ground faunal communities, research focusing on underground soil fauna, especially earthworms, is comparatively limited (Kumari 2013, Thakur et al. 2020, Singh et al. 2021).

Earthworms are amongst the most ecologically significant invertebrates in the underground ecosystems (Edwards 2004). They play a pivotal role in soil formation, nutrient cycling, organic matter decomposition and enhancement of soil fertility. Often referred to as “ecosystem engineers’’, their activity influences structure, moisture dynamics and microbial communities in the soil (Decaens et al. 2002). Despite their critical ecological roles, comprehensive data on earthworm diversity are sparse in many mountainous landscapes, particularly in the Himalayan Region. Consequently, earthworm fauna of this region is under-represented in the current biodiversity records. Therefore, a comprehensive documentation and taxonomic characterisation of earthworm fauna in this under-investigated landscape is essential to enhance our understanding of the regional biodiversity patterns, ecological dynamics and potential species endemism.

Given their sensitivity to ecological changes, earthworm distribution is strongly influenced by plantation type, seasonal fluctuations and land-use patterns. Variations in vegetation cover across different habitats support different earthworm species, while seasonal changes in temperature and moisture directly regulate their activity and reproduction (Liu et al. 2025). Recognising their ecological significance, the present study was undertaken to expand the current understanding of earthworm diversity in the Himalayan Region and to provide a baseline for future ecological and conservation research. Specifically, the current study was done across three different habitats (forest, orchard and crop field) in the unexplored Bani Valley, situated in the north-western part of the Himalayan Region of Jammu and Kashmir (J&K), India with the aim to update earthworm diversity of the study area.

Material and methods

Study Area

The study was conducted in Bani Valley, situated in the District Kathua of the erstwhile state of J&K, between latitude 32°41'23"-32°43'15" N and longitude 75°43'59"-75°48'11" E (Fig. 1). This Valley lies in the western Himalayan Region and is situated at the bank of the Sewa River. The climate of the study area ranges from subtropical to temperate in the inhabited zone, while alpine conditions prevail at the snow-bound higher reaches. During the summer season, the temperature varies between 18 and 45˚C, while during winter, the temperature ranges from 0–15˚C. Rainfall data for the entire study period was obtained from National Hydroelectric Power Corporation (NHPC) Power Station (Sewa-II), Bani (Table 1).

Table 1.

Rainfall data of Bani Valley during the study period (March 2021-January 2023).

Month	**Rainfall observed (mm)**	
	(2021-22)	**(2022-23)**
March	75.40	3.40
May	190.20	150.40
July	641.60	409.40
September	173.20	216.80
November	4.00	74.60
January	484.20	364.00

Survey of the vegetation cover revealed that pine (*Pinus roxburghii* Sargent), Oak (*Quercus oblongata* D.Don) and Deodar [*Cedrus deodara* (L.) G.Don] trees were the dominant tree species in forests. For the present study, oak-dominated forests were selected due to their widespread occurrence. In orchards, apple (*Malus pumila* Mill) plantation was the most prevalent and thus chosen as the representative site, although small scale cultivation of pear (*Pyrus communis* L.), peach (*Prunus persica* L.) and walnut (*Juglans regia* L.) was also observed. Similarly, in the crop fields, maize (*Zea mays* L.)

and mustard (*Brassica juncea* L.) were the primary crops cultivated in rotation, reflecting the typical land-use practices of the region.

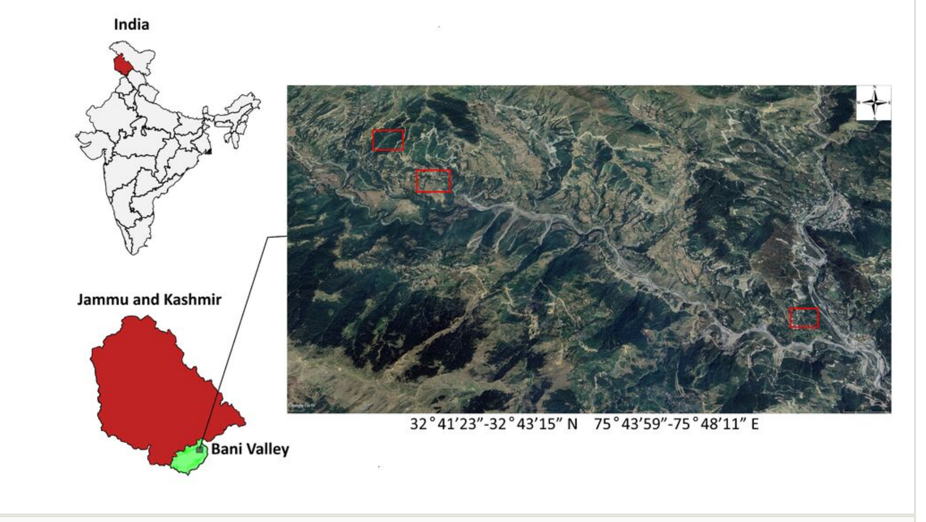

Figure 1.

Location map of the study area. Selected habitats highlighted in red boxes.

Earthworm sampling and identification

Earthworm sampling was done on a bimonthly interval, for two consecutive years (2021-22 and 2022-23) starting from March 2021 till January 2023 according to the Tropical Soil Biology and Fertility (TSBF) method (Swift and Bignell 2001). During every sampling, three square plots of 100 m^2 area each from the forest, orchard and crop field habitats were selected and five monoliths of area 25 cm × 25 cm (length × width) and 30 cm depth were sampled from each of these plots. It was ensured that no area was re-sampled in the subsequent samplings. Adult worms were extracted, counted and weighed to determine fresh biomass. After uniform contraction, representative worms of each species were carefully preserved in 5% formaldehyde solution for further taxonomic studies. Earthworm density was calculated as the number of individuals per m^2 (no. m^{-2}) and biomass as grams per m^2 (g m^{-2}) by converting the area of unit monolith to m^2 as explained by Gudeta et al. (2022). Additionally, Standard monographs of Stephenson (1923), Sims and Easton (1972), Julka (1988) and Blakemore (2012) were followed for identification of the earthworms up to species level.

Phylogenetic Analysis

To understand the evolutionary relationship between the reported species, a phylogenetic tree was constructed using partial nucleotide sequences of mitochondrial Cytochrome c oxidase subunit I (COX1) gene, retrieved from NCBI database. The sequences were aligned in MEGA X with default parameters and subjected to phylogenetic reconstruction using the Maximum Likelihood (ML) method and Tamura-

Nei-model (Tamura and Nei 1993). To evaluate the reliability of the inferred tree, non-parametric bootstrapping using 1000 bootstrap replicates was performed (Felsenstein 1985, Tamura et al. 2021). Branches with bootstrap values greater than 50% were considered moderate to strong support in phylogenetic tree analysis.

Physico-chemical analysis of soil

Soil temperature at each site was recorded using a soil probe thermometer, while pH and electrical conductivity (EC) were measured using a digital kit (Multi 340i/ SET) from the suspension of soil in distilled water (1:10 ratio). The soil moisture was determined through gravimetric method in the laboratory and was calculated as weight loss after drying 10 g soil in an oven for 24 hours at 105°C. The soil texture and organic carbon (OC) were estimated by using the methods of Bouyoucos (1962) and Nelson DW (1996), respectively. The Kjeldahl method (Bremner 2018) was used for Nitrogen (N) estimation, the method of JOHN (1970) was used for estimation of phosphorus (P) and concentration of Potassium (K), was analyzed by Microwave Plasma Atomic Emission Spectrophotometer (MP-AES) 4200 series (Agilent technologies) following the di-acid digestion method ($HClO_4$:HNO_3 in ratio 1:4).

Statistical analysis

SPSS software was used for two-way analysis of variance (ANOVA) for different soil parameters, while PAST software (version 4.03) was used for calculation of diversity indices, analysis of distribution patterns in earthworm density, biomass and their correlation with different soil properties. Moreover, multivariate ordination through canonical correspondence analysis (CCA) was performed to understand the diversity pattern with respect to different physico-chemical properties of the soil.

Results

Community structure

A total of eight earthworm species representing three families and six genera were recorded from the study area (Table 2). The family Lumbricidae dominated the earthworm community with the occurrence of five species: *Aporrectodea caliginosa caliginosa* (ACC), *Aporrectodea caliginosa trapezoides* (ACT), *Octolasion tyrtaeum* (OT), *Dendrodrilus rubidus* (DR) and *Bimastos parvus* (BP). In contrast, the family Moniligastridae was represented by two species, *Drawida japonica* (DJ) and *Drawida nepalensis* (DN), while *Amynthas corticis* (AC) was the sole representative of the family Megascolecidae. Moreover, BP and AC were the representative worms of epigeic and epi-endogeic categories, respectively, while the remaining six worms were endogeic. The entire study area was observed to be aggressively dominated by exotic species, with the record of only one native species i.e. DN. The mean density and biomass of different earthworm species across the two study years (2021-22 and 2022-23) is presented in **Fig. 2**. OT exhibited the highest mean density during both the years [34.31 ± 2.54 m^{-2} (2021-22) and 27.91 ± 1.88 m^{-2} (2022-23)]. In contrast, AC exhibited the lowest earthworm density during 2021-22 (2.84 ± 1.06 m-²), while DN was the least dense species during 2022-23 (1.60 ± 0.63 m-²). Comparing biomass, OT again dominated during both the years [16.47 ± 1.22g m-² (2021-22) and 13.40 ± 0.90g m-² (2022-23)], while the least biomass was recorded for BP during both the years [0.96 ± 0.23g m-² (2021-22) and 0.83 ± 0.19g m-² (2022-23)].

Table 2.

Running key to the earthworm species of the Bani Valley. Bold text represent species identified from the study area.

1	Setae lumbricine, 8 on each segment	2
1’	Setae perichaetine, more than 8 on each segment	11
2	Male pores before segment 11	3
2’	Male pores in segment 13 or 15	4
3	Genital markings present, spermathecal atrium small pear shaped	***Drawida japonica*** **(Michaelsen, 1892)**
3’	Genital markings rarely present, spermathecal atrium large sac like	***Drawida nepalensis*** **Michaelsen, 1907**
4	Male pores on segment 13	*Eiseniella tetraedra* (Savigny, 1826)
4’	Male pores on segment 15	5
5	First dorsal pore at intersegmental furrow 4/5 or 5/6	6
5’	First dorsal pore at or behind intersegmental furrow 9/10	9
6	Pale or pink colour worms	*Aporrectodea rosea rosea* (Savigny, 1826)
6’	Red colour worms	7
7	Yellow stripes on body present	*Eisenia fetida* (Savigny, 1826)
7’	Yellow stripes absent	8
8	Clitellum on segments 26–31	***Dendrodrilus rubidus*** **(Savigny, 1826)**
8’	Clitellum on segments 24–30	***Bimastos parvus*** **(Eisen, 1874)**
9	Clitellum on segments 27–33,34	10
9’	Clitellum on segments 30–35	***Octolasion tyrtaeum*** **(Savigny, 1826)**
10	Tubercula pubertatis smooth	***Aporrectodea caliginosa trapezoides*** **(Dugès, 1828)**
10’	TP interrupted slightly at segment 32	***Aporrectodea caliginosa caliginosa*** **(Savigny, 1826)**
11	Spermathecal pores two pairs in intersegmental furrows 5/6 and 6/7	*Amynthas morrisi* (Beddard, 1892)
11’	Spermathecal pores more than two pairs	12
12	Spermathecal pores three pairs in intersegment al furrows 5/6 –7/8	*Amynthas gracilis* (Kinberg, 1867)
12’	Spermathecal pores four pairs in intersegment al furrows 5/6 – 8/9	***Amynthas corticis*** **(Kinberg, 1867)**

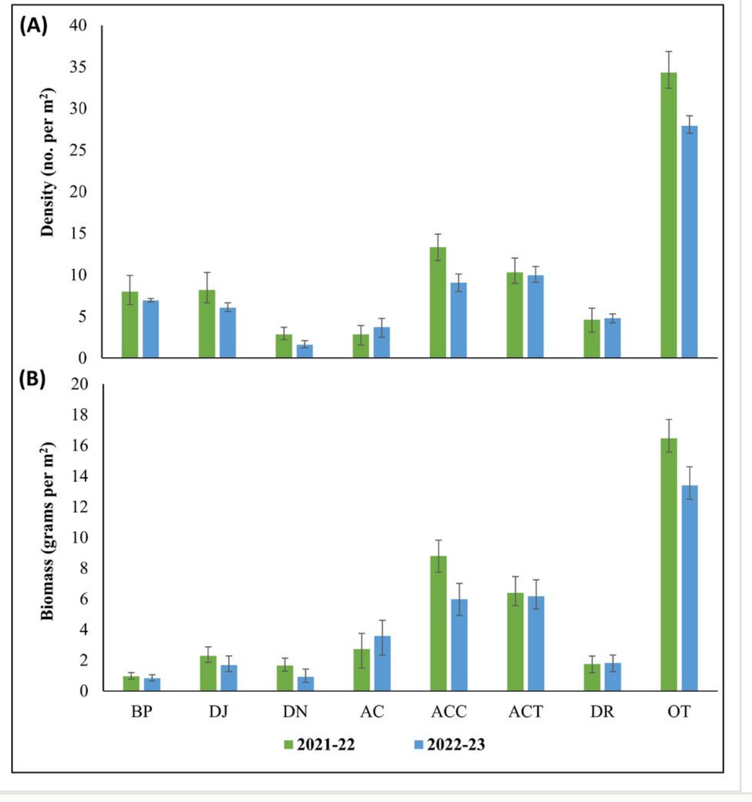

Figure 2.

Mean values of different earthworm species for **(A)** density and **(B)** biomass during the period 2021-22 and 2022-23. BP; *Bimastos parvus*, DJ; *Drawida japonica*, DN; *Drawida nepalensis*, AC; *Amynthas corticis*, ACC; *Aporrectodea caliginosa caliginosa*, ACT; *Aporrectodea caliginosa trapezoides*, DR; *Dendrodrilus rubidus*, OT; *Octolasion tyrtaeum*.

Phylogenetic relationships amongst earthworm species

Maximum Likelihood (ML) phylogram of eight earthworm species, based of the COX1 sequences of their representative isolates, revealed three major clades that were supported by varying levels of bootstrap confidence (Fig. 3). The first clade comprised *Aporrectodea trapezoides* and *Aporrectodea calignosa*, both belonging to family Lumbricidae. The second clade include *Drawida nepalensis*, *Octolasion tyrtaeum* and *Drawida japonica*. Although *Drawida nepalensis* and *Octolasion tyrtaeum* belong to different families (Moniligastridae and Lumbricidae, respectively), their presence in the same clade may suggest either convergent mitochondrial evolution or unresolved divergence due to limited COX1 variability. The third clade include *Dendrodrilus rubidus*, *Amynthas corticis* and *Bimastos parvus*. Overall the phylogenetic reconstruction is largely consistent with classical taxonomy at genus level, yet the intergeneric clustering between *Drawida nepalensis* and *Octolasion tyrtaeum* suggests potential cases of cryptic similarity and requires further investigation.

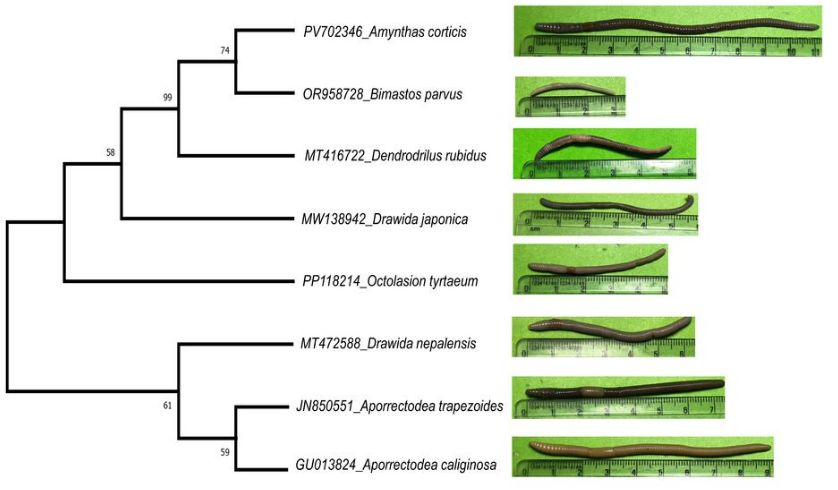

Figure 3.

Maximum Likelihood phylogenetic analysis of COX1 sequences of representative isolates of eight earthworm species. Numbers at nodes indicated bootstrap values from 1000 replicates.

Spatio-temporal distribution pattern

The monsoon season (July-September) was observed as the most favourable period for earthworms, as maximum density and biomass were recorded during this time. Amongst the studied habitats, crop field exhibited the highest earthworm density throughout the study period, followed by orchard and forest habitats, respectively. A similar pattern was observed for earthworm biomass as well. Further, comparison of the two-year data suggested that the first sampling (2021-22) recorded significantly higher density as well as biomass than the subsequent sampling year (2022-23) (Table 3).

Table 3.

Variation in mean density (No. m^{-2}) and biomass (g m^{-2}) of earthworms in the selected habitats of the study area. Bold text represents the highest value, bold italics represent the lowest value.

Habitat	**Month**	**Density (No. m^{-2})**		**Biomass (g m^{-2})**	
		2021-22	2022-23	2021-22	2022-23
Forest	March	***32.00***	***32.00***	16.96	17.98
	May	80.00	67.20	**47.04**	41.34
	July	**96.00**	83.20	46.27	44.35
	September	86.40	67.20	37.76	32.19
	November	57.60	41.60	32.00	23.62
	January	38.40	***32.00***	20.93	***16.26***
Orchard	March	48.00	54.40	23.04	22.02

Habitat	Month	Density (No. m^{-2})		Biomass (g m^{-2})	
		2021-22	2022-23	2021-22	2022-23
	May	92.80	60.80	49.86	35.71
	July	**137.60**	118.40	**70.53**	63.74
	September	102.40	99.20	42.30	44.54
	November	67.20	60.80	32.90	28.03
	January	32.00	***28.80***	16.51	***15.17***
Crop field	March	64.00	67.20	26.43	27.26
	May	99.20	67.20	44.29	***25.92***
	July	**188.80**	150.40	**93.63**	73.02
	September	124.80	96.00	57.09	45.95
	November	118.40	80.00	51.84	33.60
	January	***54.40***	***54.40***	29.50	28.74

In the forest habitat, the highest earthworm density (96.00 m^{-2}) was observed in July 2021, while its lowest value (32.00 m^{-2}) was recorded during March of both years (2021 and 2022) and January of 2023. Highest earthworm biomass (47.04 g m^{-2}) in the forest was recorded during May 2021, while its lowest value (16.26 g m^{-2}) was recorded in January 2023.

In the orchard habitat, peak values for density (137.60 m^{-2}) and biomass (70.53 g m^{-2}) were recorded during July 2021, while their lowest values (28.80 m^{-2}, 15.17 g m^{-2}) occurred in January 2023. Similarly, in the crop field, the highest density (188.80 m^{-2}) was recorded during July 2021, while the lowest density (54.40 m^{-2}) occurred in January of both years (2022 and 2023). Biomass followed a similar trend, with the maximum value of 93.63 g m^{-2} in July 2021 and the minimum (25.92 g m^{-2}) in the month of May 2022.

Diversity indices across the selected habitats

The Kruskal-wallis test revealed a significant variation ($p < 0.05$) in the index of dominance (D), Simpson’s index (1-D) and Shannon-wiener diversity index (H’) across different habitats during different months; however, the difference was non-significant for the evenness index. Post hoc analysis through multiple pairwise Mann-Whitney U tests further revealed that the variation in diversity indices was significant between forest-orchard and forest-crop field groups, while the difference was non-significant between orchard-crop field.

In the forest habitat, the index of dominance (D) was highest (0.68) during the month of January 2023, while it was lowest (0.21) in July 2022. The highest D value in the orchard (0.68) was recorded in January 2022, while it was lowest (0.16) in July 2022. Similarly, in the crop field, the D value peaked during the month of January 2023 (0.54), while it dropped to the lowest (0.17) in July 2022.

Simpson’s index (1-D) ranged between 0.32 (January, 2023) and 0.79 (July 2022) in the forest habitat, 0.32 (January 2022) and 0.84 (July 2022) in the orchard and 0.46 (January 2023) to 0.83 (July 2022) in the crop field. The Shannon-wiener diversity index (H’) peaked during the month of July 2022, while it dropped to the lowest in January 2023. It ranged from 0.50 to 1.67 in the forest, 0.64 to 1.97 in the orchard and 0.80 to 1.92 in the crop field habitat. Similarly, the evenness Index ranged between 0.74 [crop field (March 2022)] to 0.96 [forest (November 2022)] (Fig. 4).

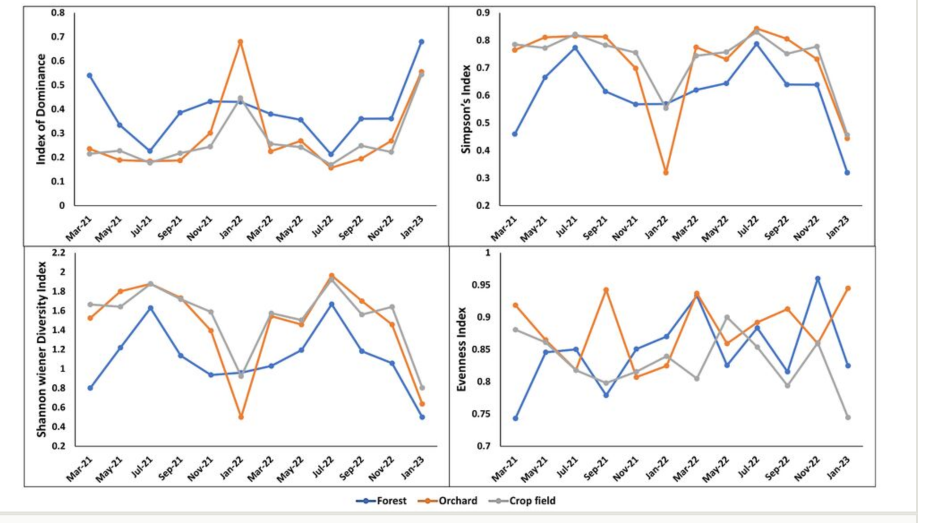

Figure 4.

Diversity Indices for the earthworm population across different habitats during the sampling period (March 2021- January 2023).

Physico-chemical properties of soil

Two-way ANOVA revealed a significant variation ($p < 0.05$) in soil properties across different habitats during both the years (2021-22 and 2022-23) (Tables 4, 5and Suppl. material 1). Notably, the correlation between habitat type and sampling month was highly significant ($p < 0.001$) for OC, K, temperature and EC, indicating the combined influence of ecological and temporal variables on soil nutrient dynamics.

Table 4.

Physico-chemical properties of soil observed during 2021-22. *p < 0.05; **p < 0.01; ***p < 0.001.

Month	Sites	Temperature	Moisture	pH	EC
March	**Forest**	15.8±0.20	28.4±0.40	6.9±0.30	48.5±2.13
	Orchard	15.8±0.20	29.6±0.80	7.3±0.12	114.9±7.75
	Crop field	15.2±0.30	28.2±0.95	6.9±0.49	120.5±1.22
May	**Forest**	18.7±0.20	24.1±0.27	6.8±0.23	62.9±1.83

Month	Sites	Temperature	Moisture	pH	EC
	Orchard	19.5±0.06	25.8±0.40	7.2±0.17	106.2±3.42
	Crop field	20.9±0.15	24.2±0.30	7.1±0.17	125.5±0.99
July	**Forest**	21.6±0.20	36.8±0.80	6.8±0.31	77.4±1.55
	Orchard	22.2±0.20	37.4±0.40	7.0±0.30	97.5±1.12
	Crop field	22.9±0.21	38.4±0.40	6.9±0.25	130.5±1.27
September	**Forest**	16.9±0.15	30.1±0.31	6.7±0.29	84.3±1.20
	Orchard	17.9±0.17	28.9±0.42	7.1±0.10	82.1±0.44
	Crop field	18.9±0.11	32.2±0.50	7.0±0.34	181.3±3.23
November	**Forest**	16.2±0.40	23.6±0.81	6.8±0.31	91.2±0.87
	Orchard	16.6±0.15	28.4±0.40	7.1±0.25	66.7±1.11
	Crop field	17.6±0.15	26.6±0.40	6.9±0.31	232.0±5.22
January	**Forest**	9.2±0.15	20.6±0.35	6.6±0.25	69.8±1.50
	Orchard	10.2±0.15	20.8±0.50	7.1±0.17	90.8±4.02
	Crop field	11.9±0.20	20.8±0.40	7.2±0.23	176.3±2.69
Summary of Two-way ANOVA					
Month		3623.82^{***}	1054.24^{***}	0.27	183.35^{***}
Site		260.92^{***}	29.40^{***}	7.71^{***}	4519.37^{***}
Month *Site		25.91^{***}	16.96^{***}	0.50	334.95^{***}

Table 5.

Physico-chemical properties of soil observed during 2022-23. *p < 0.05; **p < 0.01; ***p < 0.001.

Month	Sites	Temperature	Moisture	pH	EC
March	**Forest**	15.5±0.31	26.5±0.31	6.6±0.10	42.6±1.27
	Orchard	15.6±0.20	26.2±1.01	7.0±015	133.3±5.62
	Crop field	15.8±0.20	32.0±0.35	7.3±0.12	120.9±1.88
May	**Forest**	18.3±0.15	23.9±0.42	6.7±0.10	58.7±1.74
	Orchard	19.1±0.17	24.5±0.23	7.1±0.30	106.4±1.64
	Crop field	20.1±0.12	26.3±0.23	7.0±0.31	126.4±4.81
July	**Forest**	21.4±0.20	34.4±0.40	6.9±0.42	74.9±3.11
	Orchard	22.4±0.20	34.6±0.85	7.2±0.35	99.6±2.35
	Crop field	22.4±0.30	34.8±1.60	6.8±0.75	131.9±8.06
September	**Forest**	19.8±0.06	29.0±0.46	7.1±0.30	66.8±2.38
	Orchard	20.1±0.12	30.6±0.35	7.5±0.26	103.0±0.39
	Crop field	20.2±0.06	32.4±0.35	7.4±0.45	129.1±6.42
November	**Forest**	16.6±0.2	25.2±1.06	7.1±0.30	175.7±4.20
	Orchard	17.4±0.3	26. 5±2.01	6.9±0.29	92.8±2.05

Month	Sites	Temperature	Moisture	pH	EC
	Crop field	18.9±0.21	31.0±1.20	6.6±0.10	130.9±2.40
January	**Forest**	9.3±0.15	22.3±0.23	6.6±0.23	109.2±1.87
	Orchard	10.1±0.21	25.0±1.04	6.9±0.11	103.1±3.80
	Crop field	11.4±0.21	26.3±0.23	7.2±0.17	125.9±1.57
Summary of Two-way ANOVA					
Month		3894.98^{***}	2.84^{*}	2.404	148.42^{***}
Site		198.79^{***}	4.43^{**}	3.59^{*}	535.02^{**}
Month *Site		17.95^{***}	1.02	1.600	194.80^{***}

Soil temperature was highest in the crop field during July [22.9 ± 0.21˚C (2021), 22.4 ± 0.20˚C (2022)] and the lowest in forest habitat during January [9.2 ± 0.15˚C (2022), 9.3 ± 0.20˚C (2023)]. Soil moisture peaked in the crop field habitat during July of both the years [38.4 ± 0.40 % (2021), 34.8 ± 0.40 % (2022)], while it was lowest in forest, during January [20.6 ± 0.35% (2022), 22.3 ± 0.23% (2023)]. Soil pH remained slightly acidic to slightly alkaline, ranging from 6.6 ± 0.35 [forest (January 2022)] to 7.5 ± 0.26 [orchard (September 2022)]. Similarly, electrical conductivity (EC) showed significant spatial variation, with the highest value in crop field [232.0 ± 5.22 µS/cm (November 2021)] in crop field and the lowest in forest [42.6 ± 1.27 µS/cm (March 2022)].

OC was generally higher in the forest soils reaching a peak during November 2021 (7.73 ± 0.67), while least values were observed in crop field during the month of January [3.09 ± 0.67 (2022)]. Nitrogen (N) content remained relatively stable, with the highest value in the crop field [1.36 ± 0.04 (July 2021)] and the lowest in Orchard [0.90 ± 0.08 (March 2022)]. Potassium (K) ranged between 0.87 ± 0.10 g/kg [forest (March 2021)] to 3.08 ± 0.14 g/kg [forest (November 2021)]. Similarly, Phosphorus (P) content was highest (0.19 ± 0.02 g/kg) in the forest during July 2021, while its lowest value (0.10 ± 0.01 g/kg was recorded in the orchard during the month of March 2022.

Interaction between soil properties and earthworm abundance

Canonical Correspondence Analysis (CCA) elucidated the influence of soil parameters on the distribution of different earthworm species across different habitats (Fig. 5). The CCA plot, based on earthworm density (5A), showed that canonical axis 1 (CCA 1) explained 53.47% of the total variance due to temperature, moisture and pH, suggesting positive correlation of these propeties with *Drawida nepalensis* (DN), *Dendrodrilus rubidus* (DR), *Drawida japonica* (DJ), *Bimastos parvus* (BP) and *Amynthas corticis* (AC). Similarly, CCA 2 explained 21.57 % of the total variance primarily due to OC and Nitrogen (N) content of the soil, reflecting a fertility-driven influence on the distribution of *Aporrectodea caliginosa caliginosa* (ACC) and *Aporrectodea caliginosa trapezoides* (ACT). Moreover, *Octolasion tyrtaeum* (OT) showed consistently negative associations with both axes (CCA 1 and CCA 2), suggesting its tolerance to stress conditions arising due to the change in ecological conditions throughout the study period.

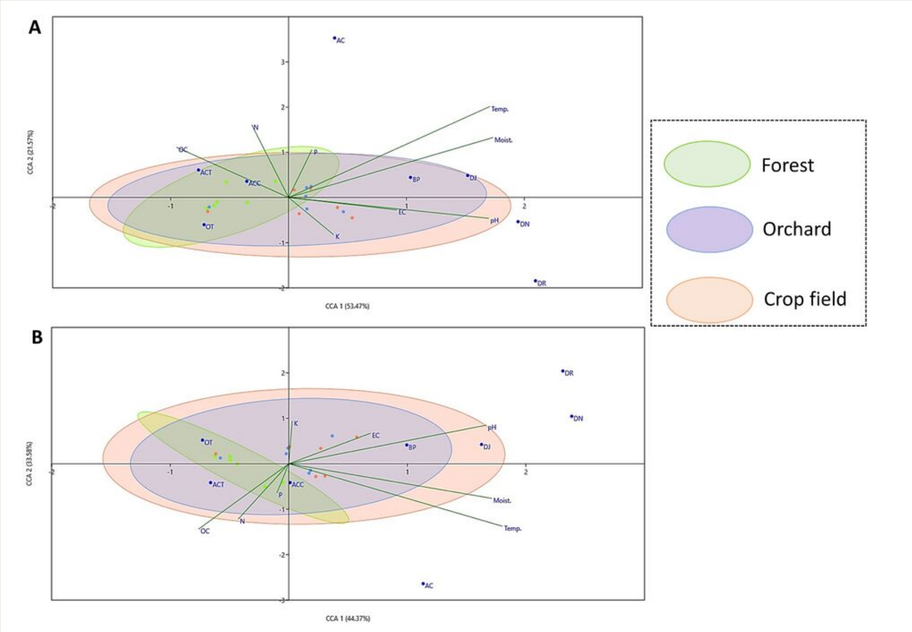

Figure 5.

CCA ordination plot showing the influence of different soil properties on earthworm density **(A)** and biomass **(B)** at different study sites.

The CCA plot, based on earthworm biomass (5B), explained 77.85% variance along the first two axes (CCA 1 and 2). Earthworm species like BP, DJ, DR and DN ordinated near the vectors of pH and EC, while AC was observed aligning with temperature and moisture along the axis 1. On the other side, ACC and ACT remained aligned with P, OC and N, suggesting their positive association with these properties. Moreover, OT showed isolated ordination in the same way as for density, based the CCA plot, owing to its abundance throughout the year.

Discussion

The present study offers valuable insights into the earthworm community structure and distribution pattern across three distinct habitats (forest, orchard and crop field) in the Bani Valley, an unexplored region of the Western Himalayas. A total of eight earthworm species were recorded from the selected area, indicating a moderate species richess, consistent with previous findings from other parts of the Himalayan Region (Sinha et al. 2003, Sharma et al. 2019, Rajwar et al. 2021). Notably, the present study offers novel insights by documenting these species as new records for the District Kathua of Jammu and Kashmir, thereby contributing significantly to the regional faunal inventory. Moreover, the presence of only one native species i.e. *Drawida nepalensis*, suggests the dominance of exotic species in the region supporting previous study reports from the adjoining Himalayan belt of Himachal Pradesh (Sharma et al. 2019, Ahmed et al. 2022).

However, when compared with the species diversity in the adjacent areas of the Western Himalayan Region, *Dendrodrilus rubidus* appears to occur exclusively in Bani Valley and is being reported for the first time, but further investigation is suggested in this regard.

In terms of habitat-based distribution, crop fields supported the highest earthworm density and biomass possibly due to traditional farming practices with no input of synthetic chemicals in the form of fertilisers and pesticides. This observation aligns with the findings of Bhadauria et al. (2012) in the central Himalayas, where agricultural soils with organic amendments and traditional irrigation practices favoured higher population densities despite of the higher anthropogenic interference. On the other hand, the lowest earthworm density was recorded in the forest habitat, possibly due to slightly acidic conditions. Hale et al. (2006) reported that the undisturbed temperate forests, although ecologically stable, often support fewer earthworms due to dense litter layers, acidic soils and low soil disturbance, thus limiting oxygen availability and organic matter penetration into the mineral soil layers. The occurrence of *Drawida nepalensis* and *Dendrodrilus rubidus* under the warm and moist conditions of crop field and orchards was consistent with some previous reports from Kumaon and Garhwal Regions (Bhadauria and KG 2018 , Bora et al. 2024) where these species were found to flourish in organically rich and aerated soils.

Reports pertaining to different landscapes have revealed an upsurge in earthworm population density and biomass during the rainy season (Reddy and Pasha 1993, Blanchart and Julka 1997, Rossi and Blanchart 2005, Suthar 2012, Jing et al. 2025). The present study corroborated these findings with the highest density, biomass and species richness recorded during July of both years. In contrast, during harsh winters, earthworm activity drops due to low temperatures and reduced biological activity, as a result of which least density as well as biomass was observed in January , during both years. Additionally, the abundance of earthworms are affected by various edaphic features, of which soil moisture and temperature are the most important (Edwards and Arancon 1996, Singh et al. 2020a). In the present study, species like *Bimastos parvus*, *Dendrodrillus rubidus* and *Drawida nepalensis* showed positive association with moisture, while the species, *Amythas corticis* positively correlated with that of temperature and was observed during hot weather conditions.

Species diversity of earthworms recorded in Bani Valley (current study), when compared with an earlier report by Singh et al. (2020b) from the plain areas of District Kathua, suggests that earthworm diversity varies notably between plain and hilly terrains. Bora et al. (2021) pointed out that the earthworms exhibit migratory behaviour twice a year, showing uphill movement during summer and downhill movement during the autumn season. During such migrations, some earthworm strains may die of desiccation before reaching suitable shelter sites, which may explain why certain species occur in specific habitats within plain areas, but are absent in similar habitats of the hilly terrain. Findings of the current study support this observation with the report of new species records from this unexplored landscape of the North-West Himalayan Region. Although the updated earthworm species diversity of District Kathua has reached 18 through this study report, further exploration is also recommended in adjoining land patches to develop a more comprehensive inventory of earthworm species of this region.

Conclusions

The study provides a first comprehensive record of the earthworm diversity in the unexplored Bani Valley, situated in the northwest Himalayan Region of Jammu and Kashmir, India, by documenting eight species across the three major habitat types (forest, orchard and crop field). An aggressive dominance of exotic species was observed with only one native species, i.e. *Drawida nepalensis*. The crop field habitat supported the highest earthworm density and biomass, likely due to organic farming practices, while the lowest earthworm density was recorded in forests. Overall, the earthworm community structure in this region was shaped by a complex interplay of soil properties (temperature, moisture, pH, organic carbon and nitrogen), climatic conditions and human interference. Although the present study reports valuable input with regard to earthworm diversity in Bani Valley, further investigations are recommended in other unexplored patches to develop a comprehensive inventory of the earthworm fauna of the Himalayan Region.

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Author contributions

Arvinder Kaur and Madan Lal contributed to study conceptualisation and design. Sampling, Data collection and analysis were performed by Madan Lal and Ankeet Bhagat. Shakoor Ahmed contributed in identification of earthworm species. All authors proof-read and approved the final manuscript.

Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary material

Suppl. material 1: Supplementary Tables doi

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Data type: Tables
Brief description: Earthworm Diversity in an Unexplored Himalayan Landscape: Patterns Across Forest, Orchard and crop field ecosystems
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