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ORIGINAL RESEARCH

Studies on earthworm diversity with respect to soil properties in different land use systems in Koraput region of the Eastern Ghats, India

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Abstract

To understand the impact of soil properties and land use systems on earthworm diversity in the biodiversity-rich Eastern Ghats Highlands of India, the present study was carried out in six land use systems i.e., moist deciduous forest, dry deciduous forest, fallow land, cropland, compost pit, and, sewage soil. The study area has been divided into $10 \times 10\ km^2$ grids and 25% grids were randomly selected for sampling from April to December 2022. A total of 16 species of earthworms under 14 genera and 8 families were recorded, out of which 15 species are new records for the region. The most taxonomically rich family was the Megascolecidae. The most abundant species are endogeic followed by epigeic and anecic. Based on Hill numbers, the highest values of Shannon index ($^1D = 9.89$) and Simpson diversity ($^2D = 9.14$) were found for the fallow land. Earthworm abundance showed a significant difference among six land use systems [$F_{(5,84)} = 3.256$, $p < 0.05$] and seasons [$F_{(2,87)} = 46.463$, $p < 0.01$]. Furthermore, earthworms showed a significant positive relationship with moisture ($r = 0.538$, $p < 0.01$), organic carbon ($r = 0.560$, $p < 0.01$), available Nitrogen ($r = 0.525$, $p < 0.01$), and clay content ($r = 0.535$, $p < 0.01$), whereas negatively correlated with sand content ($r = -0.513$, $p < 0.01$) of soil. Cropland showed high species richness, and fallow land exhibited increased diversity due to elevated moisture, moderate edaphic factors, and proximity to pristine forests. The presence of a high number of native species urges their conservation in this region through land management.

Keywords Koraput · Odisha · Oligochaeta · Species assemblage · Edaphic factors · Hill numbers

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Introduction

In tropical and temperate regions, earthworms are the most widespread of invertebrate animals and are mostly found in the soils of forests, woodlands, shrublands, and grasslands, which together occupy around 80 million km^2, or about 54% of the earth's surface (Whittaker and Likens 1973). Earthworms are commonly referred to as soil "ecosystem engineers" for maintaining 'good' soil structure through increased soil physical qualities (infiltration, water retention, and erosion resistance) as well as enhancing soil fertility through plant litter decomposition, enhancing microbial activities, regulation of biological population, nutrient cycling and soil organic carbon cycles (Julka 1988; Blanchart et al. 1999; Lavelle et al. 2007; Kooch and Jalilvand 2008). They alter soil profiles by burrowing, moving particles within and across horizons, creating and dissolving aggregates, and modifying porosity, aeration, water infiltration, and retention capacity (Blanchart et al. 1999). Depending on their borrowing capacity earthworms are broadly classified into three ecological categories: epigeic, endogeic and anecic (Bouché 1972; Lavelle 1983; Fragoso et al. 1997; Cameron et al. 2021). Epigeic species living on the topsoil surfaces in leaf litter have a diverse spectrum of enzymatic activities due to the ingestion of microflora (Curry and Schmidt 2007). Furthermore, epigeic earthworms may improve soil drainage by accelerating the breakdown of organic forest floors (Hale et al. 2005), which have a higher water-holding capacity than the underlying mineral soil (Gupta and Larson 1979). Endogeic species move deeper into the soil to feed on the soil organic matter while anecic worms make vertical burrows and feed on plant litter and organic residues (Lavelle et al. 1997). Endogeic species may boost N_2O generation (Augustenborg et al. 2012), increase soil porosity and nutrient leaching (Shipitalo and Le Bayon 2004), and enhance soil NO_3^- concentrations (Speratti and Whalen 2008). Casts of endogeic species like *Pontoscolex corethrurus* have highly enriched carbon in their casts showing higher mineralization of ingested soils (Coq et al. 2007). The larger body-sized anecic earthworm has greater potential to increase soil nutrient leaching (Van Schaik et al. 2014) and GHG emissions (Borken et al. 2000). The presence of earthworms irrespective of different ecological categories helps in increasing the inorganic nitrogen (Cortez et al. 2000).

Earthworm acts as bioindicator of soil quality due to their species-specific preference and tolerance towards soil quality, climate, and food (Kale and Karmegam 2010; Fründ et al. 2011). The physical i.e., texture, depth, coherence, structural stability (tillage) and chemical condition i.e., pH, EC, oxygen supply, toxic elements and chemicals of the habitat is determined by the soil quality which regulates the earthworm assemblages (Bhadauria and Ramakrishnan 1989; Fründ et al. 2011; Edwards and Arancon 2022). Their populations are being decimated by climate i.e., temperature, precipitation climatic water balance time course, and stochasticity, which initiates the recovery phase (Fründ et al. 2011; Edwards and Arancon 2022). Furthermore, climatic factors contribute to seasonal variations, with earthworms displaying the greatest fluctuation in the monsoon season, driven by favourable conditions such as heightened moisture levels that facilitate activities like breeding, cocoon production, hatching, and mass migration (Kale and Karmegam 2010). Soil temperature has an impact on earthworm dynamics since it helps in regulating the activities like metabolism, growth, and respiration of earthworms and becomes lethal below 5 °C and above 38 °C (Edwards and Arancon 2022). Earthworm activity and fecundity are also influenced by soil moisture (Julka 1988). Singh et al. (2019) reported a catastrophic decline in the earthworm population after extreme drought or freezing events. Prolonged dryness results in the migration of earthworms deeper into the soil surface (Edwards and Arancon

2022). Maximum population size and carrying capacity are determined by the availability of food which includes litter fall, root turnover, rhizodeposition, manure and organic matter additions (Fründ et al. 2011; Edwards and Arancon 2022). The ecological structure, specifically the ratio of anecic to endogeic species and the percentage of non-vulnerable species should be utilized as indicators of contaminated soils while endogeics appear to be good indicators in non-contaminated (cultivated) sites (Pérès et al. 2011).

The tropical terrestrial environment has recently suffered substantial degradation due to global integration, which is dominated by intense permanent agriculture, industrial logging, and associated fires and fragmentation (Lewis et al. 2015). Land conversion to man-made uses, such as large-scale commercial and subsistence farming, entails considerable removal of natural vegetation, resulting in a reduction in soil quality manifested in physical and biochemical features (Veldkamp et al. 2020). The current intensification of agricultural practices is a key contributor to soil degradation, which includes organic matter loss and the release of greenhouse gases, fertilizer overuse, erosion, contamination, acidification, salinization, and genetic diversity loss (Kopittke et al. 2019). Subsequently, a sharp decrease in earthworm biomass, richness, and diversity has occurred (Decaëns and Jiménez 2002). Furthermore, a decrease in native species, exotic and endogeic domination, and lack of recovery of disappearing populations were reported in various studies (Fragoso et al. 1997, 1999; Decaëns and Jiménez 2002; Hale et al. 2005; Huang et al. 2020; Cameron et al. 2021). However, soil moisture availability and increased nitrogen application in the agroecosystem stimulate organic matter inputs into the soil food web which enhances the earthworm population (Curry et al. 2008; Edwards and Arancon 2022). In addition, earthworm abundance and ecological groups (e.g., epigeic, endogeic, and anecic) are influenced by the geographic-phylogenetic components, followed by the influence of soils, history of a particular terrain and local agricultural practices and type of agroecosystem (Fragoso et al. 1999). Fragoso et al. (1999) reported that natural ecosystems (all savannas and most tropical rainforest sites) are species-rich communities with low abundance values but ecologically diverse native earthworm fauna, whereas agroecosystems (fallows, crops, pastures, and tree plantations) are characterised by depauperate earthworm communities with low species richness and abundance and also dominated by exotic endogeics. However, in India's agroecosystems, earthworm populations are dominated by native species, which are abundant and biomass-rich (Fragoso et al. 1999). Senapati and Sahu (1993) reported that natural grassland showed higher species diversity than man-interfered grassland and crop field in different agroecosystems of Odisha. An overall rise in population density and activity with increasing fallow age could be attributed to more favourable temperature, moisture, and humidity conditions, which result in greater organic matter and nutrient accumulation (Bhadauria and Ramakrishnan 1989).

Among the 15 agro-climatic zones of India, Eastern Ghats fall under the category of the eastern plateau and hills and eastern coastal plains and hills, with significant biodiversity and natural resources (Rawat 1997; Mahata and Palita 2023). Koraput district in the Eastern Ghats of India is an economically underdeveloped region, with 84% of the inhabitants living in rural regions and 50.56% of the scheduled tribes relying only on traditional farming and the gathering of non-timber forest products (Adhikary et al. 2019). Nearly the entire Eastern Ghats is covered by forest, severely rocky mountains, and narrow intermontane valleys. The main topography of the Eastern Ghats can be divided into five categories: high slope rainfed upland (Dongar), rainfed medium land (Pada), rainfed medium land surrounding habitation (Beda), flat medium land surrounded by two streams (Saria), and stream-fed terraced low land (Jhola) (Dash et al. 2018). From Jhola land to Donger, the potentiality of land for agriculture declines. Donger is high altitudinal land (1200–1500 m) characterised by forest and shrubs followed by Pada (900–1200 m) which is fallow land and land for shifting cultivation. Beda (900–1100 m) upland cultivation area used for agroforestry, Saria (800–1000 m) used for conservation agronomy i.e., vegetable cultivation and Jhola (<900 m) used for intensive cultivation (Panda et al. 2011; Dash et al. 2018). Thus agricultural areas are closely associated with forested land (Dash et al. 2018) and partially deposited sediments brought down from the forested hills alter the physical, chemical properties and nutrient status of the soils (Panda et al. 2011). Traditional farming system i.e., ploughing the soil 6–7 times with a pair of bullocks, 25–30 cm deep in a crisscross pattern, mechanical weeding and no use of the chemical substance for plant growth and protection, is practised by tribal people in the most of the lands in this region (Adhikary et al. 2015). In addition, farmers of the Eastern Ghats of Koraput region practising organic farming supported by the Govt of Odisha with several NGOs for the last two decades (Sahu and Nayak 2007; Chaudhury et al. 2014). The works on earthworms in Odisha (part of Eastern Ghats) date back to 1910 (Michaelsen 1910). As of date, there is very limited information available on earthworms from this region. However, subsequent works have been also carried out on earthworm diversity in western Odisha (Dash and Patra 1977; Julka 1978; Senapati and Dash 1983). Julka and Senapati 1987 reported a systematic account of 30 species so far from Odisha and 11 species from Telangana (Ahmed and Chandra 2021). A total list of ten species belonging to five different families was documented from the North-Eastern Ghats of Odisha (Sankar and Patnaik 2018). Much of the existing research has primarily focused on taxonomy and distribution (Julka and Senapati 1987; Ahmed and Chandra 2021), and there is a notable scarcity of literature addressing earthworm ecology based on soil properties and land use systems in the Eastern Ghats region (Sankar and Patnaik 2018). Addressing these knowledge gaps, our study aims to (1) comprehend earthworm diversity based on land use systems and (2) investigate how edaphic factors impact earthworm diversity and seasonal abundance fluctuations. To achieve these objectives, we assessed earthworm diversity by comparing various land use systems and analysed the influence of edaphic factors on their assemblages. Our hypotheses were (1) earthworm diversity varies according to their specific requirements of edaphic factors in different land use systems and (2) seasonal fluctuations in earthworm abundance occur across different seasons.

Materials and methods

Study area

The Koraput district (18° 12′ 59.76″ to 19° 9′ 59.76″ N latitudes and 82° 4′ 59.88″ to 83° 22′ 59.88″ E longitudes) of Odisha (Fig. 1), is characterised by undulating mountainous terrain of the northern Eastern Ghats of India. The total area of the district 8807 km^2 with elevation ranging from 121 to 1672 m above mean sea level. The study area is categorised with subtropical climate with an annual mean maximum and minimum temperature of 35.8 °C and 7.6 °C, respectively. The average annual rainfall is 1452.2 mm received by the South-West monsoon (Adhikary et al. 2019). The soil of the study area is well-drained and low water-holding capacity of red laterite, black and alluvial soil with sandy to loamy soil texture (Taradatt 2016). Tropical Moist Deciduous Forests and Tropical Dry Deciduous Forests cover 24.51% of the total study area (FSI 2021). Cropland is the major land cover in the study area (34.2%) based on a rainfed cropping system (Adhikary et al. 2019). The majority of the region's agriculture is rain-fed and mono-cropped. Shifting cultivation,

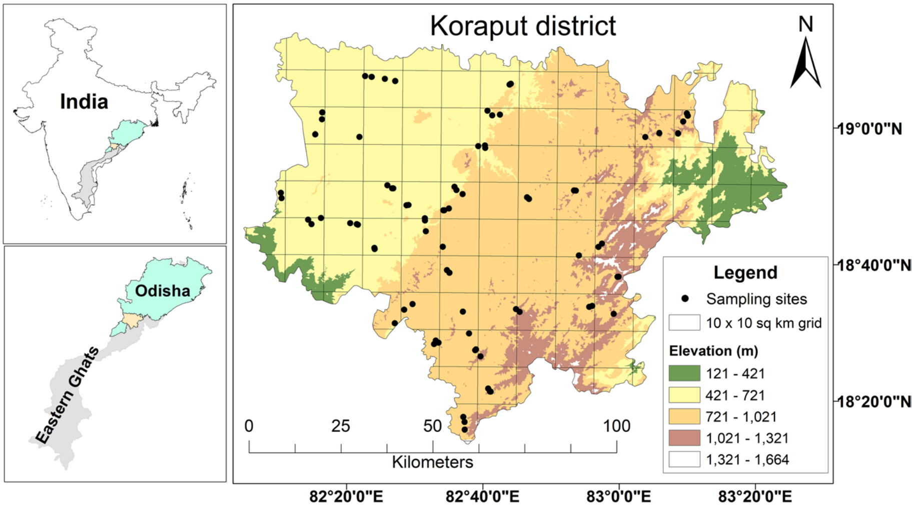

Fig. 1 Location of selected sampling sites in Koraput region of the Eastern Ghats, India

often known as “Podu chasa” or “slash and burn agriculture,” is still one of the key agricultural practices in this area. The brief shifting cultivation cycle of the land is repeatedly used, resulting in shifting farmed follows that eventually degrade into fallow land (Dash et al. 2018). An elevational gradient-based agriculture system is practised in this region where agricultural land declines and forested land increases at higher elevations (Dash et al. 2018).

Sampling sites and earthworm sampling

The study area has been divided into 10 × 10 km^2 grids and 25% grids i.e., 30 grids (covering 90 sampling plots) are randomly selected for sampling (Debata et al. 2019) at six land use systems (number of sampling plots at each land use system given in the parenthesis): moist deciduous forests (13), dry deciduous forests (37), fallow lands (10), croplands (12), sewage soils (18). Moist deciduous forests were characterised by dense vegetation with a heterogeneous canopy layer dominated by *Dillenia pentagyna*, *Xylia xylocarpa*, *Dalbergia latifolia*, *Mangifera indica*, *Michelia champaca*, *Litsea macrophylla*, *Syzygium cumini* and *Madhuca indica* etc. Dry deciduous forest is relatively degraded and open vegetation dominated by *Tectona grandis*, *Shorea robusta*, *Madhuca indica*, *Diospyros melanoxylon*, *Bombax ceiba* etc. (Mahata 2021). Fallow lands are arable lands which left unseeded during subsequent growing seasons for nutrient recovery i.e., shifting cultivated land. Croplands are intensively cultivated lands dominated by paddy cultivation (40%), millets, maize, oil seeds, ragi, gramme and vegetables in irrigated areas. Sewage soil is the soil irrigated with sewage water in the residential area having high organic content. Three sampling sites have been chosen in each grid based on the land use system. In each sampling site, three sampling plots with a minimum distance of 10 m were been placed for earthworms’ collection. Earthworms were collected in each sampling plot by manually digging the soil up to 15 cm of a 50 × 50 cm^2 quadrat, followed by hand sorting (Rajwar et al. 2022). Sampling plots numbering 30 under 10 grids were sampled in each successive season i.e., pre-monsoon, monsoon, and post-monsoon from April to December 2022. The collected adult earthworms were counted, cleaned, and stored in 70% ethyl alcohol for further study (Julka 1988).

Measurement of edaphic factors

Edaphic factors were characterized for understanding the physical, chemical, and biological properties of soil that affect the organisms living in a certain area (Ulery 2005). During earthworm collections, soil samples were collected at a depth of 0–15 cm from each sampling quadrat and analysed using standard physicochemical procedures (Maiti 2013). The physical factors i.e., temperature, moisture and texture (percentage of sand, silt and clay) and chemical factors i.e., pH, Electrical conductivity (EC), Available Nitrogen (Avl. N), Available Phosphorous (Avl. P), Available Potassium (Avl. K) and Soil Organic Carbon (SOC) of soil were analysed in this study. Soil temperature was measured with a digital soil thermometer (MEXTECH, India) in each quadrat during sapling. The soil moisture was carried out by the hot air oven method (ASTM International 2017). Soil samples taken from the field were air-dried and sieved through a 0.2 mm size sieve and were kept in a plastic bag for further analysis. Sand was defined as soil particles less than 2 mm but greater than 0.05 whereas silt particles with a diameter of more than 0.002 mm but less than 0.05 mm and clay particles were less than 0.002 mm in size (Weil and Brady 2017). Soil pH was determined by Potentiometric Methods by a pH-sensitive glass electrode inserted into a soil: water suspension (1:2.5) in laboratory condition (Weil and Brady 2017). Electrical Conductivity (EC) was recorded by measuring the conductivity of a 1:2 soil: water mixture using glass conductivity electrode (Weil and Brady 2017). Avl. N was analysed using micro-Kjeldahl apparatus by KELPLUS, Pelican Classic-DX Model (Bremner 1960). Avl. P was carried out by Brays Method (Bray and Kurtz 1945). Avl. K was estimated with Ammonium acetate (NH_4OAc) as an extractant (Stanford and English 1949) using a Flame Photometer (Model-128, Systronics India Limited, India). SOC was analysed by Walkley and Black Method (Walkley and Black 1934).

Statistical analysis

Habitat-based relative abundance along with hill numbers have been calculated for six different habitats respectively to find the community structure (Magurran 1988). Relative abundance (RA) can be defined as the percent composition of each species of a particular kind concerning the total number of species present in a particular area.

Hill numbers are a kind of diversity indices that give a consistent framework for quantifying species diversity by combining both species richness and evenness within ecological communities (Hill 1973; Hsieh et al. 2016; Budka et al. 2018). Hill numbers (q = 0, q = 1, q = 2) are the diversity measures defined as

$$^{q}D = \left(\sum_{i=1}^{s} p_i^q \right)^{\frac{1}{1-q}}, q \geq 0, q \neq 1$$

where q determines the sensitivity of the measure to the relative frequencies. D is the diversity measure, and p_i is the proportion of individuals in the ith species (Hill 1973; Hsieh et al. 2016; Budka et al. 2018).

When q = 0, ^{0}D is simply species richness.

When q = 1, then

$$^{1}D = \lim_{q \to 1} {}^{q}D = \exp\left(\sum_{i=1}^{s} pi\log pi\right)$$

It is the exponential of the familiar Shannon index, referred to here as Shannon diversity. q = 2, then

$$^{2}D = 1/\sum_{i=1}^{s} pi^{2}$$

It is the inverse of the Simpson concentration, referred to here as Simpson diversity (Hsieh et al. 2016).

The value of species richness changes with sample size (number of sampling sites from which to draw data) and we can estimate species richness asymptotically for all land use types when sample sites are infinite. The sampling coverage and estimated species richness can be predicted as a function of species coverage i.e., the pool of species occurring in different land use types. The Hill numbers can be represented by analogous curves, which are graphs of functions that increase with sample completeness. The actual sample size (obtained from field sampling) acts as a reference sample to construct a sample size-based rarefaction and extrapolation curve (Budka et al. 2019). In this study, Sample-based rarefaction approaches (three times the lowest reference samples with 1000 times randomization) have been considered for biodiversity estimation (rarefaction and extrapolation with Hill numbers) (Chao et al. 2014; Mahata and Palita 2023). The analysis was carried out using package 'iNEXT' in R 3.4.3 (Hsieh et al. 2016).

To understand the effects of edaphic factors on earthworm abundance, Pearson Correlation Coefficients (r) have been carried out. One-way ANOVA (F) along with Tukey HSD to compare the mean difference of variables among land use systems. Analyses were performed using IBM SPSS software (ver. 23) and tested with a 5% level of significance. In addition, Hierarchical Cluster Analysis (HCA) was employed to assess similarity measures (based on RA of earthworms) among land use systems, utilizing the Bray–Curtis similarity index and the Unweighted Pair-Group Average method of agglomeration. The analysis was conducted using PAleontological Statistics software, version 4.13 (Hammer et al. 2001; Hammer and Harper 2007).

Results

A total of 16 species of earthworm species under 14 genera and 8 families were recorded in this study. The most taxonomically rich was the family Megascolecidae having 5 species (*Amynthas alexandri*, *Megascolex* sp., *Metaphire houlleti*, *Perionyx excavatus*, *Polypheretima elongata*) followed by Acanthodrilidae with 3 species (*Dichogaster bolaui*, *Lennogaster pusilus*, *Pellogaster bengalensis*) followed by 2 species each in Octochaetidae (*Octochaetona beatrix, Octonochaeta rosea)* and Moniligastridae family (*Drawida calebi, Drwilda willsi)*. The rest four families are represented by single species each, i.e., family Almidae (*Glyphidrilus tuberosus*), Eudrilidae (*Eudrilus eugeniae*), Glossoscolecidae (*Pontoscolex corethrurus*) and Ocnerodrilidae (*Ocnerodrilus occidentalis*) included single species in each. Among these 16 species recorded in the present study, 15 species are new records from Koraput district except *Eudrilus eugeniae*. Further, among the recorded species, seven species are exotic i.e., *Amynthas alexandri, Dichogaster bolaui, Eudrilus eugeniae, Metaphire houlleti, Ocnerodrilus occidentalis, Pontoscolex corethrurus and Polypheretima elongata* (Table 1). *Eudrilus eugeniae, Pontoscolex corethrurus, Polypheretima elongata* and *Perionyx excavatus are* utilized for vermicomposting. *Drawida calebi, Metaphire houlleti* and *Pontoscolex corethrurus* were widely distributed and found in all land use systems. Most abundant species are endogeic (10 species), followed by epigeic (3 species) and anecic (3 species) (Table 1). The most dominant exotic species is *Pontoscolex corethrurus* (38.22%), followed by *Metaphire houlleti* (12.08%) contributes 50% of the total abundance. Relative abundance of earthworms based on land use systems is given in Table 1. *Pontoscolex corethrurus* showed the highest relative abundance in CP (78.68), DDF (36.69), MDF (20.66), and SS (50.43). *Metaphire houlleti* and *Lennogaster pusillus* both were dominant in CL (17.76) whereas *Lennogaster pusillus was* in FL (31.71) (Table 1).

The highest values of the Shannon index ($^1D = 9.89$) and Simpson diversity ($^2D = 9.14$) in the reference sample were found for the FL with 11 taxa which is lower than the highest taxa of 14 species detected in CL (13) (Table 2). These results were also verified by the rarefaction/extrapolation biodiversity curves (Fig. 2). The same pattern on the rarefaction/extrapolation curve has been obtained for all land use systems (Fig. 2). Furthermore, the same curve order was observed for each land use system: the highest values were obtained for species richness, followed by the Shannon index (which strongly reflects the number of frequent species), and finally for the inverse Simpson index (which strongly reflects the number of very frequent species). The species richness curve (^0D) for each land use type

Table 1 Relative abundance of earthworm species under six land use systems in the Koraput region of the Eastern Ghats, India

Species	E-cat	CL	CP	DDF	FL	MDF	SS
*Amynthas alexandri**	Anecic	5.41	0.00	4.14	8.94	9.92	2.36
*Dichogaster bolaui**	Epigeic	0.39	0.74	1.18	0.00	0.83	0.00
Drawida calebi	Endogeic	8.49	2.94	1.78	2.44	4.13	0.86
Drawida willsi	Anecic	0.00	1.47	0.00	4.88	0.00	0.00
*Eudrilus eugeniae**[a]	Epigeic	0.39	0.00	0.00	0.00	0.83	22.96
Glyphidrilus tuberosus	Endogeic	12.36	0.00	0.00	11.38	0.83	0.00
Lennogaster pusillus	Endogeic	17.76	0.74	14.20	31.71	0.00	4.29
*Metaphire houlleti**[a]	Endogeic	17.76	9.56	5.92	15.45	12.40	10.94
Megascolex sp.	Endogeic	0.00	0.00	0.00	0.00	9.92	0.00
Octochaetona beatrix	Endogeic	0.39	0.00	11.83	3.25	9.09	0.86
*Ocnerodrilus occidentalis**[a]	Endogeic	8.11	0.00	2.37	0.00	19.83	0.00
Octonochaeta rosea	Endogeic	5.02	2.94	15.38	0.00	11.57	2.58
Pellogaster bengalensis	Endogeic	4.25	2.94	4.73	2.44	0.00	2.15
*Pontoscolex corethrurus**[a]	Endogeic	16.22	78.68	36.69	13.01	20.66	50.43
*Polypheretima elongata**[a]	Anecic	0.00	0.00	1.18	4.88	0.00	2.58
Perionyx excavatus[a]	Epigeic	3.47	0.00	0.59	1.63	0.00	0.00

CL cropland, *CP* compost pit, *DDF* dry deciduous forest, *FL* fallow land, *MDF* moist deciduous forest, *SS* sewage soil, *E-cat* ecological category

*Represents exotic species

[a]Represents earthworm species used for vermicomposting

Table 2 Observed and expected Hill's numbers for six land-use systems in Koraput region of the Eastern Ghats India

Land use systems	Sampling sites (n)	Sobs	Q1	Q2	Sest	Missing species ($S_{est} - S_{obs}$)	$^1D_{obs}$	$^1D_{est}$	$^2D_{obs}$	$^2D_{est}$	Sample coverage (%)
CL	20	13	4	3	16	3	9.73	11.48	7.95	9.14	91.94
CP	12	8	5	1	20	12	5.26	8.12	3.77	4.26	75.88
DDF	17	12	4	1	20	8	9.74	12.52	8.31	10.16	89.23
FL	10	11	3	3	13	2	9.89	12.3	9.14	12.68	90.56
MDF	13	11	4	2	15	4	9.67	12.96	8.8	12.54	85.23
SS	18	10	4	1	18	8	6.97	8.66	5.54	6.15	89.5

Sobs: Observed species richness, Q1: The number of species encountered by a single sample, Q2: The number of species encountered by a two samples, Sest: Estimated species richness, $^1D_{obs}$: Observed Hill number (q = 1), $^1D_{est}$: Estimated Hill number (q = 1), $^2D_{obs}$:Observed Hill number (q = 2), $^2D_{est}$: Estimated Hill number (q = 2)

CL cropland, *CP* compost pit, *DDF* dry deciduous forest, *FL* fallow land, *MDF* moist deciduous forest, *SS* sewage soil

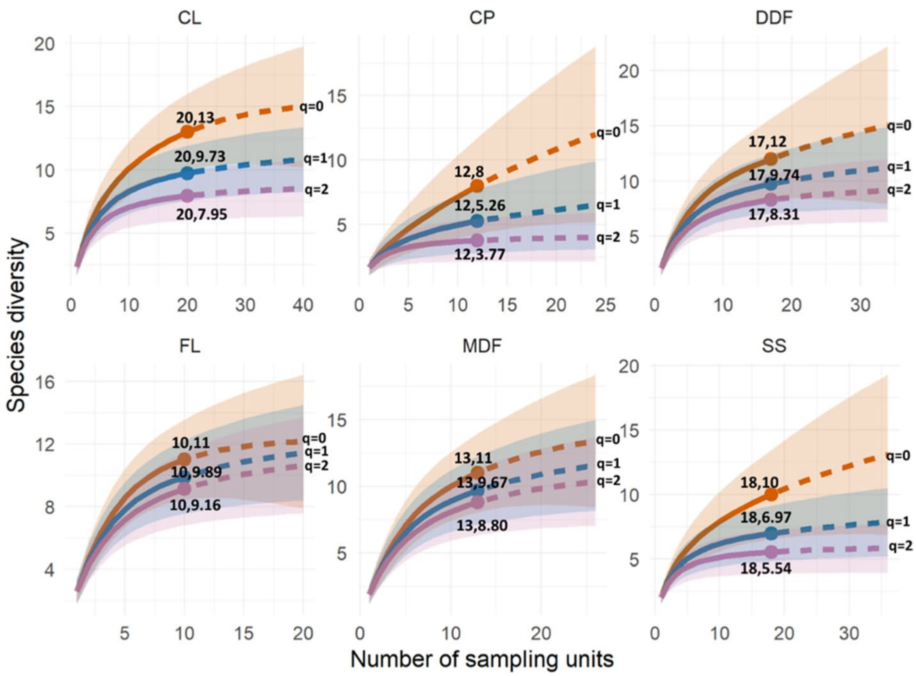

Fig. 2 Rarefaction/extrapolation biodiversity curves based on Hill's numbers (^{q}D), where q = 0 (species richness), q = 1 (Shannon index), and q = 2 (Simpson index) concerning land-use system) in Koraput region of the Eastern Ghats, India. The rarefaction curve is represented by the solid line, and the extrapolation curve, which extends up to twice the size of the reference sample, is represented by the dotted line. The sample size and the observed Hill's number in the reference sample are listed in brackets, while points denoting biodiversity coordinates for the reference data are denoted with dots. *CL* cropland, *CP* compost pit, *DDF* dry deciduous forest, *FL* fallow land, *MDF* moist deciduous forest, *SS* sewage soil

was continuously increasing with an increase in the sample size and cannot reach asymptote except FL. Regarding the two remaining indicators, each land use type showed rather slow development with increasing sampling effort, and the sample's completeness was already determined at the beginning of the extrapolation phase except FL and MDF (Fig. 2). The highest sample coverage was achieved by CL (91.94%) followed by FL (90.56%), SS (89.50%), DDF (89.23%), MDF (85.23%) and least by CP (75.88%) (Table 2). Comparing land use systems based on Hierarchical Cluster Analysis (Similarity measures based on RA data) showed that six land use systems (CL, CP, DDF, FL, MDF, and SS) clustered into two major groups i.e., forests and associates (MDF- DDF group closely linked with nearby CL) and anthropized lands (FL and SS). However, CP acted as an 'out-group' in this study (Fig. 3). MDF and DDF showed maximum similarity (42.701%) and grouped in CL with 41.468% similarity of relative abundance of earthworms. Furthermore, FL and SS clustered into a group with 39.51% similarity of relative abundance of earthworms (Fig. 3).

Edaphic variables (mean ± SD) and earthworm density based on land use systems are given in Table 3. Among the six land use systems, SS showed the highest moisture (47.29 ± 10.26%), EC (0.27 ± 0.08 mS cm^{-1}), OC (1.33 ± 0.371%), Avl. N (615.66 ± 70.38 kg/ha) and clay content (29.62 ± 9.39%), whereas CP showed highest pH (5.847 ± 0.547), Avl. P (2.60 ± 0.944 kg/ha) and Avl. K (385.61 ± 108.79 kg/ha). FL showed high soil

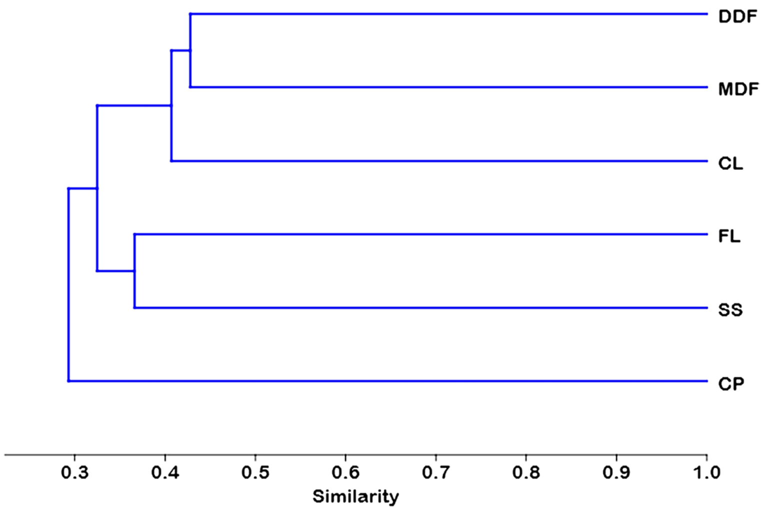

Fig. 3 Hierarchical Cluster Analysis (HCA) was employed to assess similarity (based on RA of earthworms) among land use systems in Koraput region of the Eastern Ghats, India, utilizing the Bray–Curtis similarity index and the Unweighted Pair-Group Average method of agglomeration. *CL* cropland, *CP* compost pit, *DDF* dry deciduous forest, *FL* fallow land, *MDF* moist deciduous forest, *SS* sewage soil

temperature (29.05 ± 1.71 °C) and silt content (16. 91 ± 4.72%). In contrast, the lowest amount of soil temperature 26.31 ± 1.65 °C), moisture (36.41 ± 7.85%), OC (0.91 ± 0.36%), and Avl. N (475.41 ± 123.23 kg/ha) found in CP. Furthermore, DDF located in the lowest elevation zones (722.29 ± 145.77 m) has lower EC (0.22 ± 0.17 mS cm^{-1}). MDF located in the highest elevation zone (888.07 ± 194.90 m) contained the highest amount of sand (65.85 ± 7.14%), whereas the lowest amount of silt (14.69 ± 3.06%) and clay (19.44 ± 5.99%). CL contained the lowest amount of sand 57.07 ± 7.75%) (Table 3).

One-way ANOVA among different edaphic variables showed significant differences among six land use systems in temperature [F (5,84) = 7.432, $p < 0.01$], moisture [F (5,84) = 3.734, $p < 0.05$], Avl. N [F (5,84) = 2.817, $p < 0.05$], Avl. P [F (5,84) = 20.653, $p < 0.01$], Avl. K [F (5,84) = 21.862, $p < 0.01$], sand content [F (5,84) = 3.595, $p < 0.05$], and clay content [F (5,84) = 3.346, $p < 0.05$]. The temperature showed significant mean difference between CL and MDF (2.36, < 0.05). FL showed a significant mean difference in temperature with CP (2.74, $p < 0.05$), DDF (2.51, $p < 0.05$), MDF (3.69, $p < 0.05$) and SS (2.18, $p < 0.05$). SS showed a significant mean difference in moisture with MDF (14.48, $p < 0.05$). SS showed a significant mean difference with CP (140.24, $p < 0.05$) and MDF (133.602, $p < 0.05$) in Nitrogen estimation. CP showed a significant mean difference in Avl. P with CL (1.68, $p < 0.05$), DDF (1.83, $p < 0.05$), FL (1.51, $p < 0.05$) and MDF (1.22, $p < 0.05$). Also, SS showed a significant mean difference with CL (1.55, $P < 0.05$) and DF (1.69, $p < 0.05$) in Avl P. CP showed a significant mean difference in Avl. K with CL (635.133, $p < 0.05$), DDF (412.004, $p < 0.05$), FL (544.250, $p < 0.05$), MDF (415.316, $p < 0.05$) and SS (283.565, $p < 0.05$). DDF showed a significant mean difference in Avl. K with CL (223.18, $p < 0.05$) and CP (− 412.004, $p < 0.05$). MDF showed a significant mean difference with CL (219.817, $p < 0.05$). Furthermore, SS showed a significant mean difference with CL (351.56, $p < 0.05$) and FL (260.685, $p < 0.05$). MDF showed a significant mean difference in sand content with CL (8.781, $p < 0.05$) and SS (10.791, $p < 0.05$). Clay content was significantly different in the mean

Table 3 Edaphic factors and earthworm abundance (Mean ± SD) in six land use in Koraput region of the Eastern Ghats, India

Variables	CL	CP	DDF	FL	MDF	SS
Sample size	20	12	17	10	13	18
Elevation (m asl)	735.950 ± 154.644	781.833 ± 154.962	722.294 ± 145.771	783.500 ± 143.469	888.077 ± 194.900	731.556 ± 156.433
Temperature (°C)	27.724 ± 2.150	26.310 ± 1.652	26.537 ± 0.988	29.050 ± 1.717	25.359 ± 1.500	26.862 ± 1.372
Moisture (%)	40.714 ± 9.335	36.418 ± 7.857	39.090 ± 11.716	43.377 ± 11.015	32.806 ± 9.991	47.295 ± 10.267
pH	5.755 ± 0.701	5.847 ± 0.547	5.689 ± 0.659	5.460 ± 0.633	5.980 ± 0.633	5.812 ± 0.762
EC (mS cm^{-1})	0.233 ± 0.044	0.268 ± 0.046	0.224 ± 0.170	0.252 ± 0.065	0.229 ± 0.063	0.270 ± 0.089
OC (%)	1.286 ± 0.423	0.911 ± 0.367	1.104 ± 0.415	0.947 ± 0.277	1.210 ± 0.671	1.330 ± 0.371
Avl. N (kg/ha)	511.966 ± 101.079	475.416 ± 123.236	543.705 ± 141.667	497.900 ± 139.571	482.064 ± 171.842	615.666 ± 70.380
Avl. P (kg/ha)	0.917 ± 0.337	2.604 ± 0.944	0.773 ± 0.277	1.087 ± 0.360	1.375 ± 0.641	2.471 ± 1.105
Avl. K (kg/ha)	385.616 ± 108.792	1020.750 ± 132.542	608.745 ± 176.047	476.500 ± 170.393	605.433 ± 175.154	737.185 ± 258.078
Sand (%)	57.076 ± 7.753	58.859 ± 7.109	58.916 ± 5.845	57.721 ± 7.015	65.858 ± 7.149	55.066 ± 8.451
Silt (%)	16.658 ± 3.574	15.631 ± 4.218	16.115 ± 2.150	16. 912 ± 4.725	14.695 ± 3.061	15.307 ± 4.092
Clay (%)	25.015 ± 6.325	25.509 ± 6.993	24.320 ± 6.044	25.365 ± 4.608	19.446 ± 5.990	29.626 ± 9.392
Individuals m^{-2}	51.800 ± 48.860	45.333 ± 48.101	39.765 ± 36.673	49.200 ± 28.098	37.231 ± 38.171	103.556 ± 94.218
Number of native species	7	5	6	7	5	5

CL cropland, *CP* compost pit, *DDF* dry deciduous forest, *FL* fallow land, *MDF* moist deciduous forest, *SS* sewage soil with SS and MDF (10.179, $p < 0.05$). In addition to edaphic factors, earthworm abundance significantly differs among six land use systems [$F_{(5,84)} = 3.256$, $p < 0.05$]. SS showed a significant mean difference with DDF (15.947, $p < 0.05$) and MDF (16.581, $p < 0.05$).

Pearson correlation coefficient (r) among edaphic variables as well as earthworm abundance is given in Table 4. Temperature showed a significant negative correlation with elevation ($r = -0.314$, $p < 0.01$), pH ($r = -0.276$, $p < 0.01$), Avl. N ($r = -0.232$, $p < 0.05$), while positive with Avl. K ($r = 0.222$ $p < 0.05$). Moisture has a significant positive correlation with OC ($r = 0.604$, $p < 0.01$), Avl. N ($r = 0.654$, $p < 0.01$), and clay ($r = 0.511$, $p < 0.01$), while negative with sand content ($r = -0.488$, $p < 0.01$). pH showed a significant positive correlation with Avl. K ($r = 0.235$, $p < 0.05$). EC showed a significant positive correlation with elevation ($r = 0.463$, $p < 0.01$), OC ($r = 0.259$, $p < 0.05$), Avl. N ($r = 0.230$, $p < 0.05$), and Avl. K ($r = 0.214$, $p < 0.05$). OC showed a significant positive correlation with Avl. N ($r = 0.701$, $p < 0.01$) and clay ($r = 0.393$, $p < 0.01$), while negative with sand content ($r = -0.382$, $p < 0.01$). Avl. N showed a significant positive correlation with clay ($r = 0.481$, $p < 0.01$), while negative with sand content ($r = -0.456$, $p < 0.01$). Avl. P showed a significant positive correlation in Avl. K ($r = 0.491$, $p < 0.01$), and clay ($r = 0.265$, $p < 0.05$). In addition to edaphic factors, earthworm abundance showed a significant positive relationship with moisture ($r = 0.538$, $p < 0.01$), OC ($r = 0.560$, $p < 0.01$), Avl. N ($r = 0.525$, $p < 0.01$) and clay content ($r = 0.535$, $p < 0.01$), whereas negatively correlate with sand content ($r = -0.513$, $p < 0.01$) of soil (Table 4).

Seasonal variation (pre-monsoon, monsoon, post-monsoon) was found in edaphic factors as well as earthworm abundance in this study (Table 5). One-way ANOVA among seasons showed a significant difference in EC [$F_{(2,87)} = 4.000$, $p < 0.05$], OC [$F_{(2,87)} = 35.201$, $p < 0.01$], Avl. N [$F_{(2,87)} = 38.260$, $p < 0.01$], Avl. K [$F_{(2,87)} = 4.841$, $p < 0.05$], Moisture [$F_{(2,87)} = 29.895$, $p < 0.01$], sand content [$F_{(2,87)} = 11.768$, $p < 0.01$], and clay content [$F_{(2,87)} = 16.112$, $p < 0.01$]. Tukey HSD test showed, EC has a significant mean difference between pre-monsoon and monsoon (− 0.0491, $p < 0.05$). OC in monsoon has a significant mean difference with pre-monsoon (0.799, $p < 0.05$) and post-monsoon (0.343, $p < 0.05$). Furthermore, OC in post-monsoon has a significant mean difference from pre-monsoon (0.455, $p < 0.05$). Avl. N in monsoon has a significant mean difference with pre-monsoon (219.638, $p < 0.05$) and post-monsoon (62.255, $p < 0.05$). Furthermore, Avl. N in post-monsoon has a significant mean difference from pre-monsoon (157.383, $p < 0.05$). Avl. K in monsoon has a significant mean difference with post-monsoon (223.244, $p < 0.05$). Moisture in monsoon has a significant mean difference with pre-monsoon (16.592, $p < 0.05$) and post-monsoon (4.881, $p < 0.05$). Furthermore, moisture in post-monsoon has a significant mean difference with pre-monsoon (11.710, $p < 0.05$). Sand content in pre-monsoon has a significant mean difference with monsoon (8.448, $p < 0.05$) and post-monsoon (6.637, $p < 0.05$). Furthermore, sand content in post-monsoon has a significant mean difference with monsoon (1.810, $p < 0.05$). Clay content in monsoon has a significant mean difference with pre-monsoon (8.956, $p < 0.05$) and post-monsoon (1.845, $p < 0.05$). Furthermore, clay content in post-monsoon has a significant mean difference from pre-monsoon (7.111, $p < 0.05$). In addition to edaphic factors, earthworm abundance showed seasonal variation [$F_{(2,87)} = 46.463$, $p < 0.01$]. The abundance of earthworms in monsoon has a significant mean difference with pre-monsoon (25.367, $p < 0.05$) and post-monsoon (18.467, $p < 0.05$). Furthermore, clay content in post-monsoon has a significant mean difference with pre-monsoon (6.900, $p < 0.05$).

Table 4 Pearson Correlation (r) among edaphic factors and earthworm abundance in the study (n = 90) in Koraput region of the Eastern Ghats, India

Variables	Elevation	Temperature	Moisture	PH	EC	OC	Avl. N	Avl. P	Avl. K	Sand	Silt	Clay
Temperature (°C)	− 0.314**											
Moisture (%)	− 0.110	− 0.013										
pH	0.043	− 0.276**	− 0.035									
EC (mS cm^{-1})	0.463**	− 0.187	0.173	− 0.072								
OC (%)	0.124	− 0.173	0.604**	0.095	0.259*							
Avl. N (kg/ha)	0.096	− 0.232*	0.654**	0.088	0.230*	0.701**						
Avl. P (kg/ha)	− 0.104	− 0.061	0.089	0.123	0.143	− 0.041	0.052					
Avl. K (kg/ha)	0.074	− 0.222*	0.000	0.235*	0.218*	0.033	0.110	0.491**				
Sand (%)	0.156	− 0.039	− 0.488**	0.087	0.051	− 0.382**	− 0.456**	− 0.172	0.128			
Silt (%)	0.009	− 0.033	− 0.019	0.031	− 0.101	0.001	− 0.021	− 0.129	− 0.086	− 0.339**		
Clay (%)	− 0.140	0.044	0.511**	− 0.067	0.033	0.393**	0.481**	0.265*	− 0.046	− 0.868**	− 0.088	
Abundance (m^{-2})	− 0.073	− 0.186	0.538**	0.151	0.111	0.560**	0.525**	0.124	− 0.016	− 0.513**	0.061	0.535**

* and **Represent statistical significance at 0.05 and 0.01 level respectively

Table 5 Edaphic factors and earthworm abundance (Mean ± SD) based on seasons (i.e., pre-monsoon, monsoon and post-monsoon) in Koraput region of the Eastern Ghats, India

Variables	Pre-monsoon	Monsoon	Post-monsoon
Sample size	30	30	30
Temperature (°C)	27.361 ± 1.960	26.35 ± 1.950	27.11 ± 1.610
Moisture (%)	30.759 ± 8.585	47.351 ± 9.52	42.469 ± 7.445
pH	5.840 ± 0.133	5.883 ± 0.543	5.572 ± 0.693
EC (mS cm^{-1})	0.226 ± 0.041	0.275 ± 0.085	0.264 ± 0.077
OC (%)	0.686 ± 0.062	1.486 ± 0.072	1.142 ± 0.067
Avl. N (kg/ha)	406.583 ± 124.470	626.222 ± 66.283	563.966 ± 107.279
Avl. P (kg/ha)	1.718 ± 0.17	1.905 ± 0.47	1.960 ± 0.71
Avl. K (kg/ha)	653.165 ± 62.713	707.522 ± 48.007	484.277 ± 46.489
Sand (%)	63.595 ± 6.906	55.146 ± 7.874	56.957 ± 6.450
Silt (%)	15.898 ± 3.44	15.690 ± 3.68	15.924 ± 3.545
Clay (%)	19.839 ± 5.99	28.796 ± 7.336	26.951 ± 5.943
Abundance (no per plot)	3.400 ± 1.429	28.77 ± 8.020	10.300 ± 2.535

Discussion

The study area Koraput district of Odisha is the global biodiversity hotspot under the Eastern Ghats of India with a rich assembly of unique floral and faunal diversity (Julka and Senapati 1987; Misra et al. 2009; Dash et al. 2017; Mahata 2021). A total of 30 earthworm species have been reported from the state of Odisha, but no systematic work has been carried out in southern Odisha, particularly in the Koraput region. Sankar (2019) reported 10 earthworm species from southern Odisha out of which five species were from the Eastern Ghats Highlands region. Our study reported 16 species of earthworms contributing new records of 15 species from the Koraput district. Seven recorded species in the present study are widely distributed peregrine species that have been accidentally introduced into the soil around the roots of exotic plants (Julka 1988; Tripathi and Bhardwaj 2004). In addition, peregrine vermicompost species *Eudrilus eugeniae, Pontoscolex corethrurus* and *Polypheretima elongata* are widely distributed throughout the study area through vermicomposting (Julka 1988, 1993). The study recorded 63% endogeic earthworm species which increased the priming effect of the soil ecosystem by ingesting large amounts of soil and assimilating a part of the organic matter it contains (Bernard et al. 2012). The most dominant exotic species is *Pontoscolex corethrurus* a very active compacting endogeic invasive earthworm and it tolerates conditions that many native species cannot, and it alters the ecosystem in ways that make the recovery of other species more challenging (Lavelle et al. 2007). Moreover, a compacting species increases the bulk density and the proportion of large aggregates in soil, whereas eudrilid worms (*Eudrilus eugeniae*) feed on it and decrease the bulk density of soil (Blanchart et al. 1999; Bernard et al. 2012). *Pontoscolex corethrurus* showed the highest relative abundance in CP, DDF, MDF and SS which were higher in OC-containing soil, providing favourable macroaggregate structure in the soil, decreasing the infiltration rate and increasing water retention capacity (Blanchart et al. 1999). *Lennogaster pusillus* showed the highest relative abundance in CL and FL due to its good adaptation to different agroecosystem conditions (Sinha et al. 2003).

In addition, the study recorded endogeic species of earthworm to be more abundant (62.5%), whereas a comparatively lesser abundance was recorded in the case of epigeic (18.75%) and anecic (18.75%) earthworm species during the study period. Similar patterns were also recorded in different studies in Mexico, Cuba, Peru and India (Fragoso et al. 1997; Kale and Karmegam 2010). Endogeic earthworms ingest soil and assimilate a small fraction of the organic matter it contains, whereas anecic and epigeic earthworms directly ingest poorly degraded litter at the soil surface (Bertrand et al. 2015). Endogeic species typically flourish in no-tillage systems because they dig horizontally and are concentrated in the rhizosphere soil (i.e., in the plough layer) which may reflect the higher proportion of SOC and low-disturbance sites (Cameron et al. 2021). Endogeic species predominate in both natural and disturbed environments in our study, showing that epigeic species are not a significant part of natural earthworm communities and that perturbation has a less significant impact on functional diversity (Fragoso et al. 1999).

Different land uses support a variety of vegetation species and covering, resulting in noticeable disparities in material and energy inputs above and below ground, which may alter the physical and chemical conditions of the soil (Cardinael et al. 2019; Li et al. 2020). Changes in soil physicochemical parameters can have an impact on soil fauna (Feijoo et al. 2011; Cassani et al. 2021; Ahmed et al. 2022). Hill numbers in this study varied greatly based on the land use system due to species-specific habitat requirements (Kale and Karmegam 2010; Bacha and Sahoo 2018). Higher species richness (^{0}D) was observed in CL, due to high clay and moisture content, whereas high diversity (^{1}D and ^{2}D) was recorded in FL. Bacha and Sahoo (2018) evaluated the density and species richness of earthworms and physicochemical properties of soil in different land use systems in Sambalpur district of western Odisha, India and reported that the highest density (Ind m^{-2}) and species richness observed in cropland soil followed by fallow land due to high moisture content, pH, SOC, K and P content of the soil. Furthermore, encouraging decomposition and mineralization of SOC in surface soil during past cropping years, as well as accumulation of soil nutrients with fallow period age to make the soil favourable for earthworm species (Bacha and Sahoo 2018). CL also supported a wide range of exotic species of which some are vermicomposting species. The general topography of the Northern Eastern Ghats High Land Region having a slopy gradient consisting of forest land at high altitude, followed by fallow land (mostly shifting cultivated) and followed by cropland at low elevation and they are closely associated (Dash et al. 2018). Thus, FL acts as an ecotone between pristine forest and anthropized land and harbours both native and exotic kind of species (Senapati and Sahu 1993; Smith et al. 2008; Zeithaml et al. 2009). Native species were recorded in natural forests as well as croplands due to wide geographical distribution of the majority of native species in this region (Fragoso et al. 1999).

Soil physico-hydraulic and chemical properties regulate not only the taxonomic diversity but also functional diversity (Fragoso et al. 1997; Hallam et al. 2020). The earthworm populations were found to have a substantial positive association with physical parameters such as temperature, moisture, and organic matter (Bhadauria et al. 2000; Bacha and Sahoo 2018). Although earthworms can survive in soils with a pH of 4.5 to 8.7, neutral soils have higher earthworm numbers than alkaline or acidic soils (Julka 1993). Soil texture can have an impact on earthworm populations due to its effects on other soil variables such as soil moisture relationships, nutritional status, and cation exchange capacity, all of which can have a significant impact on earthworm populations (Edwards and Arancon 2022). Our study showed significant positive relationships with moisture, SOC and Avl. N which are the crucial parameters for earthworm assemblages supported by various studies (Edwards and Arancon 2022). Soil texture increases the infiltration process which is the key determinant for the water-holding capacity of the soil, subsequently regulating the earthworm abundance (Fischer et al. 2014). Earthworm assemblages are influenced by higher clay content in the soil and negatively influenced by sand content (Hendrix et al. 1992; Singh et al. 2020; Cameron et al. 2021). The present study showed earthworm abundance was positively correlated with higher clay content and negatively correlated with sand content as clayey soil is more nutrient-rich and high water water-holding capacity than sandy soil (Hendrix et al. 1992; Birkhofer et al. 2012). Similarly, high amount of moisture, OC, Avl. N and clay content in the soil increased the earthworm density in SS in this study (Table 3). However dominance of exotic invasive species i.e., *Pontoscolex corethrurus* and *Eudrilus eugeniae* decrease the species diversity in SS. Hendrix et al. (1992) reported that slightly eroded soil contained coarsely textured soil to hold water and organic matter may present an unfavourable habitat to earthworms whereas moderately to severely eroded soils contained more fine particles (due to mixing of the A horizon with clayey subsoil by previous years of ploughing). The FL and CL in this study at Koraput are situated in foothills of the hill and are regularly recharged with moderate to severe eroded soils of the upland forested area through the stream. This may be the reason for higher earthworm assemblages in these two land use systems.

Seasonal variation of earthworms indicates that the monsoon is the most preferred seasons for their activity i.e., breeding, cocoon production, hatching, and mass migration (Gates 1961; Senapati et al. 1979; Kale and Karmegam 2010; Najar and Khan 2011; Suthar 2012). According to Kale and Karmegam (2010), the fluctuation in earthworm abundance throughout the seasons is influenced by climatic parameters such as soil temperature, soil moisture, humidity, and rainfall. In our investigation, we observed that the seasonal variations in edaphic factors, namely EC, OC, Avl. N, Avl. K, moisture, sand, and clay content, were linked to the seasonal fluctuations of earthworms. While most species were present in three seasons, their abundances varied significantly in our study due to reduced soil moisture, OC, and Avl. N during dry periods (Kale and Karmegam 2010).

Koraput region of Eastern Ghats involves a traditional farming system of ploughing 6–7 times, 25–30 cm deep in a criss-cross fashion, manual weeding and minimal use of chemical pesticides and fertiliser (Adhikary et al. 2015). This also enhances the earthworm assemblages in the CL (Fragoso et al. 1999) and overall diversity in FL in this region. Besides FL and CL, a high amount of organic matter present in the DDF and MDF harbour higher species richness as well as diversity. HCA showed MDF and DDF created a cluster with maximum similarity (42.701%) due to the dominance of *Octonochaeta rosea* (next to invasive *Pontoscolex corethrurus*) particularly found in undisturbed natural forest (Vikram Reddy et al. 1995). In contrast, anthropized lands group i.e., FL and SS showed 39.51% similarity due to the dominance of exotic eurytopic species such as *Pontoscolex corethrurus, Metaphire houlleti, Amynthas alexandri,* and *Polypheretima elongata* (Julka 1993; Fragoso et al. 1999). Since many native species exhibit strong adaptations to agroecosystems, thriving even in arable lands due to their widespread nature, a heterogeneous landscape comprising both pristine forests and minimally impacted anthropized lands is essential for promoting species diversity (Fragoso et al. 1999). The record of 16 species of earthworms from six different land use systems in the present study including around 50% of indigenous species i.e., *Drawida calebi, Drawida willsi, Glyphidrilus tuberosus, Lennogaster pusillus, Octochaetona beatrix, Octonochaeta rosea, Pellogaster bengalensis, Perionyx excavatus* from Koraput district in Eastern Ghats very much exemplify this. However, this highly biodiverse region of Eastern Ghats experiences a high level of habitat destruction due to urbanization, agricultural expansion, road expansion, increased mining activity, and dam construction which leads to rapid biodiversity loss (Rawat 1997; Adhikary et al. 2019; Mahata and Palita 2023; Mahata et al. 2023). A wide distribution of peregrine species especially dominant *Pontoscolex corethrurus* is a cause of concern and may be responsible for perturbation of habitat in this region (Julka 1988, 1993; Lavelle et al. 2007). The prevalence of *Pontoscolex corethrurus* led to a substantial decline in indigenous earthworms and other invertebrates, causing soil decompaction and resulting in a notable degradation of the physical structure of the soil (Fragoso et al. 1999). Fragoso et al. (1999) reported *Pontoscolex corethrurus* are uncommon in India. However, our investigation revealed that the invasive *Pontoscolex corethrurus* exhibited the highest relative abundance in CP (78.68%), DDF (36.69%), MDF (20.66%), and SS (50.43%). This observation underscores the pressing need for prompt measures to preserve the composition of native species from a conservation standpoint. This suggests an urgent requirement for conservation management initiatives to protect the distinctive natural biodiversity of this area using sustainable approaches.

Conclusion

Our extensive study carried out in the biodiverse Eastern Ghats in India has deepened our understanding of the complex dynamics influencing earthworm diversity and population fluctuations in relation to edaphic factors in various land use zones. Despite ongoing disturbances, the presence of a diverse array of indigenous species (50%) underscores the urgent need for conservation management efforts to preserve the unique natural history of this region sustainably. Traditional agricultural practices characterized by minimal chemical inputs, limited disturbances, and proximity to pristine natural forests create favourable conditions for earthworm assemblages. The study underscores the significance of soil moisture, organic carbon, available nitrogen, and soil texture in shaping earthworm communities. However, the high biodiversity of the Eastern Ghats is threatened by extensive habitat destruction caused by urbanization, agricultural expansion, road development, mining activities, and dam construction, leading to rapid biodiversity loss. Moreover, the invasion of *Pontoscolex corethrurus* has further exacerbated the decline in indigenous earthworms, resulting in soil decompaction and significant degradation of soil structure. The study emphasizes the importance of maintaining heterogeneous land use systems that incorporate pristine natural forests to safeguard species diversity in this region through effective land management practices.

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Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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