Asian Journal of Conservation Biology, July 2026. Vol. 15 No. 1, pp. 182–191 AJCB: FP0292/88290
ISSN 2278-7666 ©TCRP Foundation 2026 https://doi.org/10.53562/ajcb.88290

Research Article

Climate Variability and Land-Use Change Effects on Earthworm Diversity and Soil Ecosystem Functions: A Review

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(Received: February 15, 2026; Revised: May 27, 2026; Accepted: June 30, 2026)

ABSTRACT

Earthworms play a crucial role as ecosystem engineers in soil formation, nutrient cycling, and overall ecosystem function. This report covers the effects of land-use change and climate variability on earthworm diversity and related soil ecosystem processes. With an emphasis on India, a comprehensive literature review of around 48 peer-reviewed papers at both regional and global levels was carried out using major scientific databases including Google Scholar, Scopus, and Web of Science. The overview demonstrates that soil physicochemical properties (such as soil organic carbon, nitrogen, pH, and texture) and climatic parameters (such as temperature and precipitation) have a significant impact on earthworm distribution, variety, and survival. Land-use changes including urbanization, deforestation, and increased agriculture have been shown to reduce native earthworm diversity and alter community composition, while invasive species like *Pontoscolex corethrurus* contribute to biotic homogenization and disruption of soil processes. The review highlights the detrimental consequences of climate variability and human disturbances on soil biodiversity and ecosystem functioning. The lack of long-term datasets and the insufficient mechanistic understanding of species-specific responses to environmental change are two examples of critical knowledge gaps. This study emphasizes the need for long-term monitoring and sustainable land management practices to maintain soil ecosystem services and preserve earthworm variety, particularly in climatically and physiographically diverse locations like India.

Key words: Biodiversity, Climate change, Earthworm invasions, Soil organisms, Anthropogenic disturbance

INTRODUCTION

Climate variability and land-use change are two of the major global sources of environmental change that have a substantial impact on soil biodiversity and ecosystem functioning. Variations in temperature and precipitation patterns, along with increasing anthropogenic pressures like urbanization, deforestation, and agricultural intensification, have led to significant changes in soil structure, nutrient dynamics, and biological populations. These changes pose a major danger to the sustainability of terrestrial ecosystems, particularly in regions where environmental changes are occurring rapidly. Soil organisms are essential for maintaining ecosystem services, and their responses to environmental change provide crucial information about the soil's resilience and health. Among these, Earthworms (Phylum Annelida, Class Clitellata) are known as "ecosystem engineers" due to their significant influence on the nitrogen cycle, microbial interactions, soil physical structure, and organic matter degradation. Earthworms enhance soil aeration, water infiltration, aggregate stability, and nutrient availability through their digging, ingesting, and casting activities, all of which are advantageous to plant productivity and the overall health of ecosystems. Earthworms are widely recognized as important "bioindicators" of soil fertility and health in both natural and managed ecosystems, reflecting changes in land use patterns, nutrient availability, and environmental factors (Saharan et al., 2025).

Earthworm variation extends beyond taxonomic to include functional differentiation, with species occupying a variety of ecological niches. Earthworms can roughly classified into three functional groups based on how they feed and burrow: epigeic (surface-dwelling), endogeic (soil- dwelling), and anecic (deep-burrowing). At different depths, each of these groups contributes differently to soil processes such nutrient cycling, organic matter breakdown, and soil mixing. Functional variation promotes ecosystem multifunctionality (Sutri et al., 2025). Earthworm diversity and distribution are influenced by a complex interplay of environmental and anthropogenic variables operating across spatial dimensions. Despite their ecological importance, earthworm diversity patterns are complicated globally. According to recent research, terrain and temperature have a greater overall geographical impact on earthworm ecosystems than local anthropogenic factors like urbanization level. For instance, environmental parameters such as elevation and temperature gradients were more predictive of earthworm biomass and abundance in urban environments than urban development levels (Phillips et al., 2025).

Additionally, it was found that earthworm species richness in semi-natural grasslands was significantly influenced by soil fertility and moisture, underscoring the earthworms' vulnerability to physicochemical and nutritional limitations (Torppa et al., 2023).The physicochemical properties of the soil and land use have an impact on the diversity and distribution of earthworms at the local and regional levels. Comparative studies in subtropical regions have shown that earthworm richness and density are higher in less disturbed settings, such as wastelands, than in highly maintained agroecosystems. Community structure was found to be significantlypredicted by soil organic matter, total nitrogen,

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potassium, and phosphorus levels (Liu et al., 2024).

In agroecosystems employing organic management strategies that reduce chemical inputs and tillage, earthworm populations have been observed to increase, highlighting the significance of sustainable practices in preserving below-ground biodiversity. Furthermore, species-specific ecological preferences that influence community composition across land-use gradients are indicated by the reactions of several earthworm species to soil moisture and temperature (Adhikari et al., 2024).

Anthropogenic disturbances that are increasingly acknowledged as major stressors that can change community composition and reduce earthworm variety include intensive agriculture, urbanization, soil pollution, and habitat fragmentation. Studies in Mediterranean agroecosystems have shown that earthworm diversity is often lower in regions with high agricultural activity than in regions with less extensive land use. These findings highlight the susceptibility of soil macrofauna to human-induced environmental changes (Bengrid et al., 2024).

Importantly, rather than acting independently, land-use change and climate variability interact in complex ways to impact ecosystem processes and earthworm diversity. Although a great deal of study has been done on earthworm ecology, it is typically fragmented and focuses on specific drivers or spatial scales. A thorough synthesis integrating global and regional patterns of earthworm diversity with the interactive impacts of climatic variability, edaphic variables, vegetation, and human disturbances is still lacking, especially in tropical and subtropical regions where biodiversity is high but long-term data is limited.

In this context, the current review aims to: (i) identify significant knowledge gaps and future research priorities; (ii) evaluate the combined impacts of land-use change and climate variability on the functioning of soil ecosystems; and (iii) examine the primary environmental factors influencing earthworm diversity across spatial scales. This review offers a comprehensive basis for understanding earthworm variation in the context of continuing environmental change.

METHODOLOGY

A systematic literature search was conducted across major scientific databases, including ScienceDirect, Web of Science, PubMed, and Google Scholar, covering the period from 2015 to 2025. This time frame was selected to represent current patterns in land-use change, climate variability, and their consequences on earthworm diversity and soil ecosystem functioning to include the most recent and relevant studies. The integration of new methodological advancements and improved data availability in research published during this period ensures a more up-to-date and reliable synthesis of findings.

Keywords like "earthworm diversity," "soil fauna," "climate change," "land-use change," and "edaphic factors" were combined using boolean operators (AND, OR) to create search strings like ("earthworm diversity" OR "soil fauna") AND ("climate change" OR "climate variability") AND ("land-use change") AND ("edaphic factors").

Peer-reviewed publications that investigated earthworm diversity, distribution, or soil ecosystem services in relation to environmental parameters like anthropogenic disturbances, land-use change, soil physicochemical properties, and climate variability were included. A total of 140 records were initially identified. After screening titles and abstracts, 92 articles were selected for full-text assessment, of which 51 studies were retained for final analysis. To ensure comprehensive coverage, the reference lists of a few selected works were also reviewed. The studies were classified based on their geographical scale (global, regional, and India-specific), land-use categories (forest, agricultural, grassland, urban, and degraded ecosystems), and environmental drivers (climatic factors, soil physicochemical qualities, and anthropogenic disturbances). When available, native and invasive species were identified, and earthworm assemblages were divided into ecological groups (epigeic, endogeic, and anecic).

Earthworm diversity metrics, sampling strategies, environmental factors, research design, and ecosystem functions were all thoroughly gathered. The selected studies were qualitatively evaluated based on

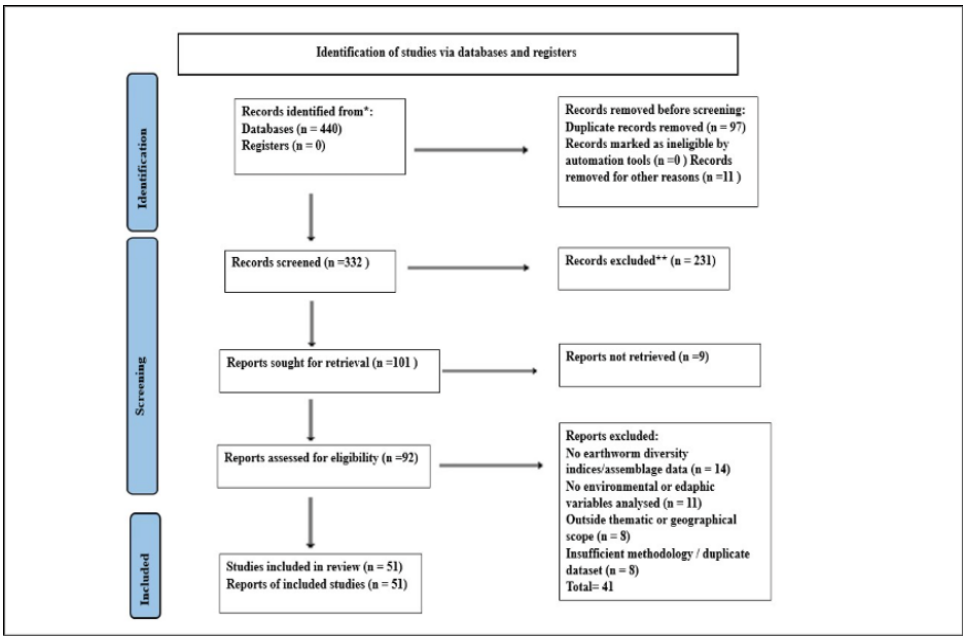

Figure 1. PRISMA flow diagram illustrating the literature search and study selection process for the systematic review on earthworm diversity and environmental drivers

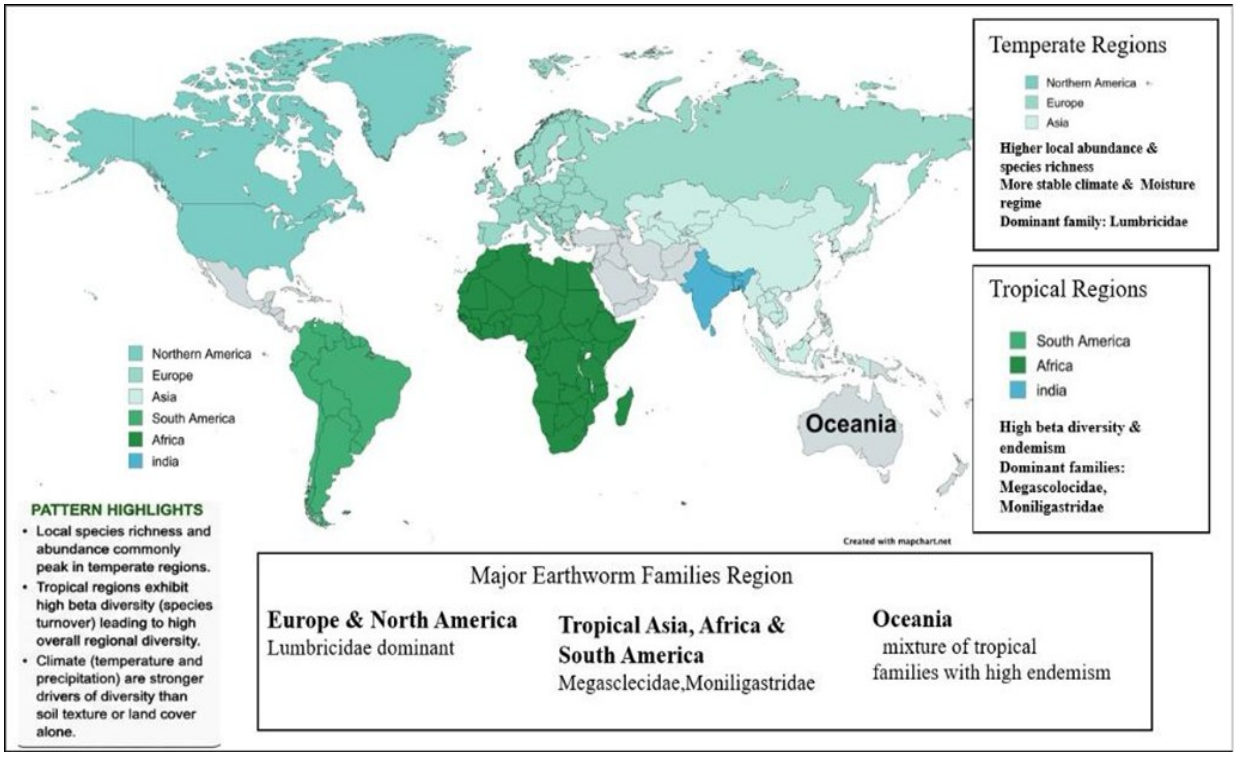

Figure 2. Global Patterns of Earthworm Diversity and Dominant Families Across Climatic Regions

their applicability, methodological soundness, and results consistency.To find patterns, trends, and significant research gaps across spatial scales, extracted data were organized into thematic categories and synthesized using a comparative analytical technique.

EARTHWORM DIVERSITY: GLOBAL AND REGIONAL (INDIA) PATTERNS

Global Patterns of Earthworm Diversity: Globally, earthworm diversity exhibits complex biogeographic patterns that do not follow the typical latitudinal gradients observed in many aboveground taxa. There have been around 5,738 species and subspecies described globally, indicating a high level of taxonomic diversity (Ghosh, 2022). Unlike many organisms, which exhibit peak diversity in tropical regions, earthworm species richness and abundance tend to be higher in temperate regions such as Europe, North America, and parts of local (alpha) diversity, exhibit high beta diversity, indicating extensive species turnover across landscapes. This emphasizes the importance of scale-dependent interpretations of biodiversity patterns, implying that tropical soils host a variety of unique and frequently endemic species (Phillips et al., 2019). Climate variables, notably temperature and precipitation, usually emerge as major drivers of earthworm diversity and community composition in study, often outweighing soil texture or land-use parameters (Bharti et al., 2024). These data suggest that macroclimatic variations play a significant role in shaping global distribution patterns. Furthermore, biogeographic history and evolutionary processes have an impact on continental-scale variability, with lumbricids dominating temperate regions and megascolecids and related families more diverse in tropical Asia, Africa, and South America (Phillips et al., 2021).

Regional Patterns of Earthworm Diversity (India):

India is the largest reservoir of earthworm variation throughout the world, with over 489 identified species and subspecies dispersed across 72 genera. The Indian earthworm fauna is notable for its extremely high level of endemism, with around 71% of genera and 89% of species being endemic. This high endemism reflects long-term evolutionary diversification across a variety of ecological and environmental conditions (Narayanan et al., 2023).When compared to global patterns, India's diversity highlights the importance of tropical and subtropical regions as reservoirs of regional (beta) diversity, despite the relatively low local species richness observed on a global scale. This supports the notion that tropical regions contribute disproportionately to global biodiversity through species turnover and endemism (Thakur & Yadav, 2018).

India's diversity originates mostly from enormous geographical and climatic variance, which includes the Himalayas, plains, plateaus, and coastal ecosystems, as well as strong seasonal variability associated with monsoon cycles. These qualities create a wide range of biological niches, from humid forest soils to semi-arid agroecosystems, where various and functionally distinct earthworm populations thrive (Tiwari et al., 2020; Tiwari et al., 2024).Megascolecidae, Acanthodrilidae, and Moniligastridae are taxonomically dominant in Indian fauna, with genera such as *Drawida, Perionyx,* and Eutyphoeus contributing significantly to species diversity. These patterns demonstrate both ecological adaptation and historical biogeographic dynamics (Ahmed et al., 2022a).

Environmental variables have an even greater influence on these patterns of diversity. Soil organic matter, moisture availability, and nutrient content are regularly identified as important determinants in earthworm abundance and dispersal, whereas land-use regimes range from forests to intensively controlled agroecosystems, impacting community composition (Jaouhari et al., 2024). Organically managed agricultural systems frequently support greater diversity than intensively managed systems, highlighting the relevance

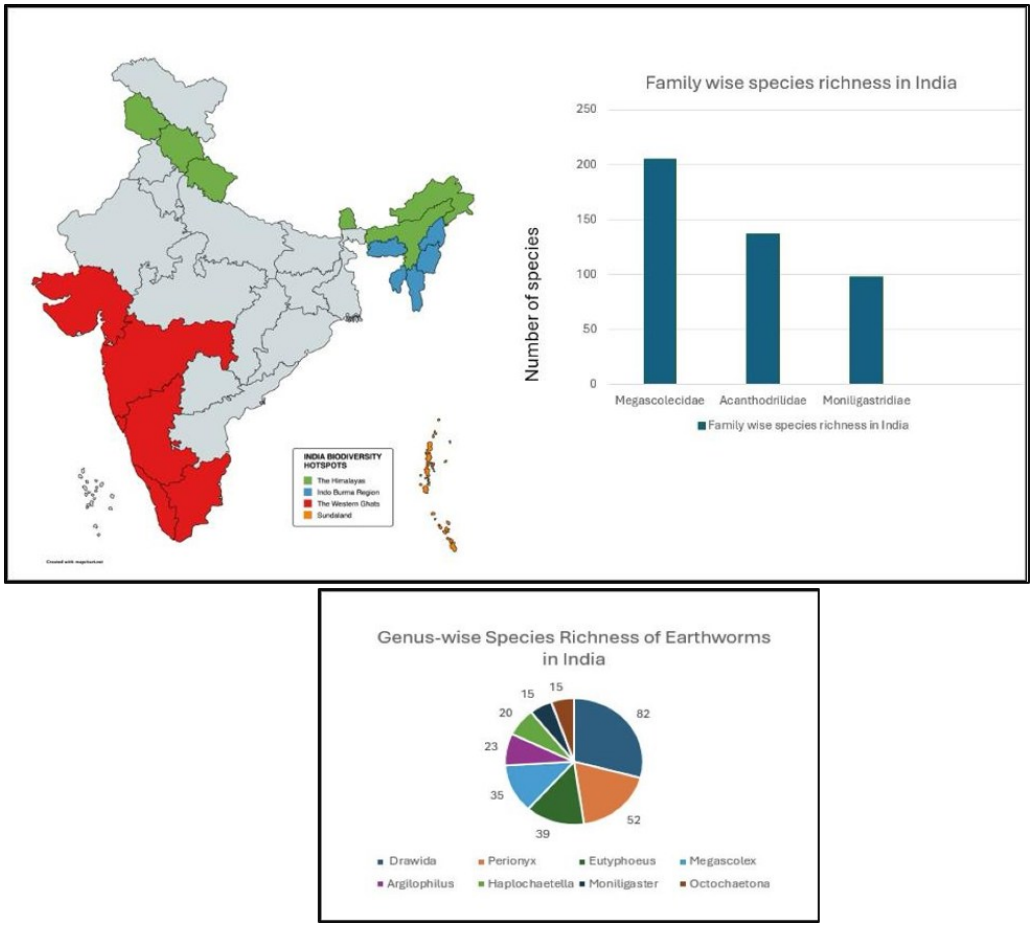

Figure 3: Earthworm Diversity and Biodiversity Hotspots in India: Family- and Genus-wise Species Richness

of sustainable practices. At the same time, anthropogenic influences are changing natural diversity patterns, particularly with the introduction of invasive species such as *Pontoscolex corethrurus* (Bhadauria et al., 2011). These species are highly adaptable to disturbed environments and may coexist with native taxa, although they may alter community structure and ecosystem function over time (Lavelle et al., 2006).

Synthesis of Global and Regional Patterns: Overall, earthworm diversity is determined by a hierarchical interaction of climatic, edaphic, and anthropogenic factors at distinct spatial scales. While climatic variables primarily influence large-scale global distribution patterns, habitat variability, soil qualities, and land-use dynamics all have a substantial impact on regional diversity, especially in countries like India.Importantly, the contrast between temperate dominance in local diversity and tropical dominance in regional diversity demonstrates the scale-dependence of earthworm biodiversity patterns. Anthropogenic factors, such as land-use change and biological invasions, are modifying these patterns, resulting in differences in community composition and functional diversity. These findings emphasize the need to go beyond descriptive assessments and toward a more mechanistic understanding of the processes that promote earthworm diversity. As a result, the following section investigates the major natural and human variables influencing earthworm communities.

Influence of Environmental and Anthropogenic Factors on Earthworm Diversity: Earthworm diversity and community structure are influenced by a complex interplay of natural and anthropogenic factors at various spatial scales. Climate, soil properties, landscape characteristics, and human disturbances have all been shown to influence variations in species richness, functional composition, and distribution patterns. These drivers work independently and collectively to control habitat suitability, resource availability, and physiological performance in earthworm groups. As a result, the following sections summarize the key factors influencing earthworm biodiversity (Singh et al., 2020).

Climate Drivers: Temperature, precipitation, and soil moisture are important large-scale predictors of earthworm distribution and activity.Temperature is an important physiological regulator since earthworms are poikilothermic organisms whose metabolic activities are directly impacted by environmental factors (Chen et al., 2011). Studies reveal that intermediate temperature regimes optimize earthworm activity, growth, and reproduction. Extreme conditions (below ~10°C or above ~40°C) severely limit eating, cocoon building, and juvenile development. Rising temperatures have also been related to reduced earthworm abundance, owing to increased metabolic stress and indirect effects on soil moisture and the carbon cycle (J. Singh et al., 2019).

Cold tolerance varies by species and is a critical adaptation in high latitude and high altitude environments. Some species use physiological mechanisms such as glycogen conversion to glucose or glycerol accumulation to survive in freezing temperatures (De Boer et al., 2018). However, temperature extremes continue to

impose significant biogeographic restrictions, limiting the spread of many species in colder climates (Shekhovtsov et al., 2015).

Precipitation and Soil Moisture:

Precipitation and soil moisture are two important climate variables that are closely associated and have a significant impact on where earthworms reside, how many exist, and how they reproduce (Goury et al., 2025). In all studies, more rain is associated with more earthworms and activity because it moistens the soil and stimulates litter buildup, improving the habitat and providing more food. Seasonal trends reinforce this link even further, as higher numbers and increased reproductive activity are frequently observed during wetter periods (Morón-Ríos et al., 2010). However, less rain and longer dry seasons are significant limiting factors that can cause earthworm populations to decline or perhaps disappear in extremely arid locations. Earthworm populations decrease significantly in areas with annual rainfall below ~800- 1000 mm, whereas they are absent in regions with extremely low precipitation (<330 mm per year) (Torppa et al., 2023).

These findings highlight the sensitivity of earthworm communities to changes in precipitation regimes, particularly in dry and semi-arid environments. Soil moisture directly affects physiological activities, including respiration, movement, growth, and reproduction. Moderate moisture levels enable optimal metabolic activity, but drought and waterlogging can be fatal to survival. Importantly, temperature-moisture interactions are critical because rising temperatures frequently reduce soil moisture through increased evaporation, limiting earthworm populations (Kumar et al., 2025).

Earthworms respond to moisture stress in different ways based on their species and functional groups. Anecic species (e.g., *Lumbricus terrestris*) are more resistant to drought due to their ability to burrow deeply and enter hibernation, whereas epigeic species are more vulnerable to desiccation due to their surface-dwelling behavior. Endogeic organisms have intermediate adaptability, traveling over soil profiles and forming temporary protective structures. Overall, precipitation and soil moisture act as major biological filters, regulating the regional distribution and temporal dynamics of earthworm populations, which has crucial implications for changing climate regimes (Garssen et al., 2014).

Topography and Altitude:

Topography and altitude influence regional climate, vegetation structure, and resource availability, all of which contribute to earthworm diversity. Across studies, elevational gradients are consistently connected to predictable changes in earthworm diversity and community composition, which are primarily mediated by temperature and moisture oscillations. Mid-elevation diversity peak is a common trend observed in many locales, with species richness highest at middle altitudes and decreasing at higher elevations due to harsher climatic conditions, fewer organic matter input, and limited habitat suitability (Ahmed et al., 2022b). This pattern represents the combined effects of climate gradients and resource availability across elevation zones. In addition to elevation, microtopographic variables such as slope and aspect affect fine-scale variability in earthworm distribution. These variables influence soil depth, moisture retention, and organic matter accumulation, resulting in diverse microhabitats that support different assemblages (Li et al., 2024).

Overall, landscape complexity promotes spatial variation in environmental circumstances, leading to distinct earthworm community architectures across ecosystems. These results highlight the importance of topographic and altitudinal gradients in understanding both large-scale and local patterns of below-ground biodiversity.

Soil Physicochemical Properties:

Soil physicochemical characteristics have a large impact on earthworm diversity and community composition because they influence habitat suitability, resource availability, and physiological performance. Rather than functioning separately, soil pH, texture, organic carbon, and nutrient availability interact collectively to control earthworm dispersal throughout ecosystems (Hallam et al., 2020). The research findings show a continuous pattern: soils with a good chemical balance, enough organic content, and an optimum physical structure support more earthworms and functional diversity. Soil pH acts as a primary ecological filter, influencing species distribution and survival. Most earthworm species prefer neutral to slightly acidic environments, although high acidity inhibits growth, reproduction, and long-term survival (Edwards and Arancon, 2022).

However, species-specific tolerance ranges increase the diversity of investigations. *Lumbricus rubellus,* for example, can survive in moderately acidic soils, whereas deep-burrowing species such as *Aporrectodea longa* are extremely sensitive to low pH and are rarely found in highly acidic soils. These distinctions highlight the role of pH in influencing community composition through selective pressure on species with varying physiological tolerances (Baker & Whitby, 2003). Soil texture influences earthworm distribution by regulating moisture retention, aeration, and nutrient dynamics. Because of their balanced physical properties, loamy and organic-rich soils often support expanded earthworm populations across habitats, but sandy or gravelly soils tend to limit abundance due to their limited water retention capacity (Huerta et al. 2007). However, patterns vary across the globe; for example, in tropical systems, earthworm population is typically positively associated with clay concentration, whereas in other ecosystems, excessive compaction may impede mobility and reduce habitat suitability. This implies that the effect of soil texture is context-dependent and closely tied to local climate conditions (Parthasarathi et al., 2015). Soil organic carbon is commonly highlighted as a main driver of earthworm abundance since it serves as the primary energy source for these detritivores. Most of the research suggests a positive relationship between organic matter availability and earthworm density, particularly in forest environments with high litter input (Chaudhuri et al., 2008). However, various anomalies have been observed, demonstrating that earthworm populations are influenced not only by the quantity, but also by the quality of organic matter and land use history. For example, whereas high organic content typically promotes greater abundance, disturbed systems such as shifting agriculture may exhibit lower populations despite increased organic inputs, indicating the existence of additional stressors (Garnier et al., 2022).

Earthworm development, reproduction, and population dynamics are all influenced by the availability of nutrients, particularly nitrogen. Earthworms prefer substrates that have a low carbon-to-nitrogen (C/N) ratio, which improves nutritional quality and efficiency. Increased nitrogen availability is frequently associated with increased earthworm biomass and abundance, indicating a link between nutrient dynamics and biological activity (Kumari & Kumari, 2025). In addition to responding to nutrient availability, earthworms actively influence soil fertility through ecological activities. Their burrowing and casting boost nitrogen mineralization, phosphorus and potassium availability, and microbial activity, resulting in increased soil structure and nutrient cycling. Species such as *Pontoscolex corethrurus* illustrate this function by producing nutrient- rich casts with high enzyme activity, which have a significant impact on soil biochemical processes in agroecosystems (Zhu et al., 2013).

Overall, present evidence indicates that soil physicochemical characteristics promote earthworm diversity via interconnected pathways that include chemical balance, physical structure, and resource availability. While overall trends indicate that earthworm populations benefit from neutral pH, balanced texture, high organic matter, and nutrient-rich settings, regional variations highlight the importance of species-specific responses and environmental context. These findings emphasize the significance of soil parameters as crucial local-scale variables that interact with larger climatic and land-use factors to influence earthworm dispersal and ecosystem function.

Anthropogenic Influences: Land-Use Change and Disturbances:

Land-use patterns and human disturbances are key drivers of earthworm diversity, influencing community structure, functional composition, and ecosystem processes on a variety of geographical scales. Studies repeatedly reveal that natural environments, such as forests and grasslands, support more earthworm biomass, diversity, and functional complexity than intensively controlled agricultural systems. The decline in agricultural landscapes is primarily due to habitat loss, soil disturbance, and reduced organic inputs induced by farming methods (Betancur-Corredor et al., 2024). Earthworm communities undergo tremendous changes as land usage escalates. Undisturbed ecosystems typically maintain diverse assemblages, including sensitive and unusual species, whereas simplified agricultural systems are frequently dominated by resilient, disturbance-tolerant taxa. This transition from functionally diverse groupings to ecologically simplified systems suggests that land-use intensity acts as a significant ecological filter for below-ground biodiversity (Phillips et al., 2025a). Agricultural management strategies alter these patterns by modifying soil microclimate, resource availability, and habitat structure. Organic agricultural practices, such as manure and compost application, have been related to increased earthworm density and diversity due to improved organic matter availability and soil conditions. Heavy tillage, on the other hand, disrupts burrow systems, depletes soil moisture, and reduces earthworm survival. Conservation practices such as reduced or no-tillage help to preserve soil structure and habitat stability, resulting in increased earthworm populations (Moos et al., 2016).

However, the effects of agrochemicals vary; excessive pesticide and herbicide use can have a significant impact on survival and reproduction, depending on the type, concentration, and mode of application. Beyond agricultural activities, anthropogenic disturbances such as urbanization, mining, habitat fragmentation, and soil pollution place additional burden on earthworm ecosystems. These disruptions frequently reduce species richness and functional variety by introducing physical and chemical stressors, such as heavy metals and toxic compounds, that impede survival and reproduction. Simple communities dominated by a few tolerant or invading species are especially favored in urban areas (Karimifard et al., 2023).

Anthropogenic disturbance has led to the introduction and spread of invasive earthworm species. Human-mediated activities such as agricultural soil transport, horticultural trade, and plant material movement have aided exotic species' spread beyond their natural environments. Because of their broad ecological tolerance and rapid reproductive capacity, these species commonly flourish in disturbed environments. *Pontoscolex corethrurus* is a widely distributed tropical species that may flourish in a variety of settings (Thounaojam et al., 2025). Invasive species, such as *Pontoscolex corethrurus*, can outcompete native taxa, alter community composition, and reduce native biodiversity (Ferlian et al., 2017). Although their presence may initially increase local species richness, the long-term consequences often include reduced functional diversity and environmental stability (Zhao et al., 2022).

These species can have a significant impact on soil processes by hastening decomposition, affecting soil structure, and influencing the nitrogen cycle. Furthermore, invasive earthworms can destabilize soil food webs by reducing microfaunal diversity and altering nutrient availability, resulting in cascading effects on ecosystem function (Adhikari et al., 2024). Overall, present evidence indicates that anthropogenic influences such as land-use intensification, management practices, and biological invasions are the principal causes of earthworm community rearrangement. These reasons not only reduce biodiversity, but also disturb ecological functions and biogeochemical cycles, jeopardizing soil ecosystem resilience and sustainability (Phillips et al., 2025b).

DISCUSSION

Earthworm diversity and community structure are influenced by anthropogenic, edaphic, and climatic factors at numerous spatial scales. These factors do not act alone; rather, their interactions affect habitat suitability, resource availability, and physiological performance across ecological groups. Global patterns differ from traditional latitudinal gradients; tropical ecosystems have high beta diversity and endemism, although temperate regions may have more local richness and biomass. This contrasting pattern can be attributed to stable moisture- temperature regimes in temperate regions, which support high local abundance, whereas environmental variety in the tropics promotes species turnover and niche specialization. Temperature, precipitation, and soil moisture all have a significant impact on earthworm physiology, reproduction, and survival primarily by controlling metabolic activity, cocoon development,

Table1. Key Environmental variables and Anthropogenic disturbances affecting Earthworm Diversity across spatial scales

Factors	Influence on Earthworms	Key Observations	References
Temperature	Influences activity, metabolism, and reproduction.	Activity decreases <10°C; cocoon formation stops >40°C	(Kabir & Ju, 2023)
Cold tolerance	Survival in Extreme Cold	Dendrobaena utilises glycogen; E. nordenskioeldii accumulates glycerol.	(Overgaard et al., 2009)
Precipitation	Affects density & reproduction	Density reduces when the annual precipitation is less than 330-800 mm, whereas reproduction increases during the rainy season.	(L. Chen et al., 2014)
Soil moisture	Essential for growth, reproduction	Anecic worms tolerate drought via deep burrows, while surface species decline.	(N. Ahmed & Al- Mutairi, 2022)
Soil pH	Determines species tolerance	Aporrectodea longa tolerates slightly acidic soils with a pH of less than 4.5.	(S. Singh et al., 2020b)
Soil Texture	Affects distribution and species concentration	Light/medium loams provide higher abundance; peaty soils are favourable.	(Fischer et al., 2014)
Soil Organic Carbon (SOC)	Food availability and habitat suitability	Forest litter promotes increased density; seasonal fluctuation was noted.	(Chaudhuri et al., 2008)
Soil NPK	Nutrient availability, food quality	Higher N increases abundance, nitrification, and nutrient cycling.	(Cai et al., 2019)
Land-use & Agriculture	Alters habitat & diversity	Organic farming improves density, while extensive tillage diminishes richness.	(Karimifard et al., 2023)
Anthropogenic disturbance	Habitat fragmentation, pollution, exotic species	Invasive P. corethrurus outcompetes native species, whereas urbanisation reduces functional diversity.	(Zhao et al., 2022)

and vertical migration within soil profiles, resulting in species- and functional group- specific responses to environmental stress.

Soil organic carbon, nitrogen availability, pH, and texture all influence habitat compatibility and food quality at the regional and local levels by controlling microbial activity, nutrient mineralization, and soil structural properties that influence burrowing behavior and resource access, and land-use intensity alters these relationships. India's great climatic and physiographic variety supports outstanding earthworm diversity, but the interaction of land-use intensification and shifting climatic conditions changes community composition toward disturbance-tolerant functional groups. Increased agricultural intensification and habitat destruction favor invading and dominant taxa over native species. Despite the increased availability of distinct species, peregrine earthworms such as *Pontoscolex corethrurus* have the potential to homogenize communities and alter soil processes.Sustainable approaches, such as reduced tillage and organic amendments, can help to mitigate some of these negative effects by improving soil structure, increasing organic inputs, and creating ideal microhabitats for various earthworm populations. Variations in earthworm diversity are highly related to ecosystem functioning, as distinct functional groups contribute to soil aggregation, nutrient mineralization, and carbon cycling, influencing overall ecosystem productivity and resilience. Overall, integrated, multi-scale frameworks that consider interactions among climate, soil properties, and land-use practices are essential for forecasting earthworm responses to environmental change, especially in understudied tropical regions where long-term data on functional diversity and ecosystem processes remain limited.

CONCLUSION

Earthworms are significant in ecosystem engineering because of their diversity and functional properties, which influence soil structure, nutrient cycling, and overall ecosystem efficiency. This review stresses that earthworm diversity is determined by the interaction of climate, soil quality, and land-use practices, rather than by specific environmental factors. This review demonstrates how a complex combination of climatic conditions, soil physicochemical qualities, topography, land-use practices, and anthropogenic disturbances at various spatial scales affect earthworm diversity patterns. Climate variables, particularly temperature and moisture regimes, have a significant impact on earthworm physiology, survival, and reproductive success, whereas soil organic carbon, nitrogen availability, pH, and texture affect habitat appropriateness and food availability. These factors determine the distribution of functional groups, which regulate important ecological processes such as soil aggregation, nutrient mineralization, and carbon cycling. Invasive species frequently homogenize populations and disrupt soil biogeochemical processes over time, despite increasing local abundance. Invasive taxa, in particular, can alter soil food webs and reduce functional diversity, resulting in long-term ecological instability. Organic supplements and reduced

tillage, on the other hand, are sustainable land management alternatives that can boost earthworm diversity while mitigating disturbance impacts by improving soil structure, boosting organic inputs, and supporting multiple ecological niches. Overall, the findings underline the importance of incorporating below-ground biodiversity into sustainable land management and climate adaptation strategies. These factors determine the distribution of functional groups, which regulate important ecological processes such as soil aggregation, nutrient mineralization, and carbon cycling. Invasive species frequently homogenize populations and disrupt soil biogeochemical processes over time, despite increasing local abundance. Invasive taxa can alter soil food webs and reduce functional diversity, resulting in long-term ecological instability.

STATEMENT AND DECLARATION

Both the authors, Bandna Kumari and Neelam Kumari, jointly carried out the work presented in the manuscript. Both authors read and approved the final manuscript. Both authors hold no financial, personal, or professional conflicts of interest that could influence the review's content, interpretation, or presentation. We declare that each perspective we have articulated is solely derived from our independent scholarly assessment, devoid of any conflicting interests with any individual, group, or institution. Both authors provide consent for publication of this manuscript.

REFERENCES

Adhikari, A., Bajgai, Y., Rabgyal, J., Lal, R., Tshering, N., Gurung, S., & Wangdi, T. (2024). Altitude, Land Use and Soil Depth Effects on Earthworm Density and its Relationship to Soil Properties in an On-Farm Study. *Journal of Soil Science and Plant Nutrition*, *24*(4), 6569–6583. https://doi.org/10.1007/s42729-024-01990-9

Ahmed, N., & Al-Mutairi, K. A. (2022). Earthworms Effect on Microbial Population and Soil Fertility as Well as Their Interaction with Agriculture Practices. *Sustainability*, *14*(13), 7803. https://doi.org/10.3390/su14137803

Ahmed, S., Marimuthu, N., Tripathy, B., Julka, J. M., & Chandra, K. (2022). Earthworm community structure and diversity in different land-use systems along an elevation gradient in the Western Himalaya, India. *Applied Soil Ecology*, *176*, 104468. https://doi.org/10.1016/j.apsoil.2022.104468

Baker, G. H., & Whitby, W. A. (2003). Soil pH preferences and the influences of soil type and temperature on the survival and growth of Aporrectodea longa (Lumbricidae). *Pedobiologia*, *47*(5–6), 745–753. https://doi.org/10.1078/0031-4056-00254

Bengrid, A., Bouzahouane, H., Trea, F., Amira, O., Becheker, A., & Ouali, K. (2024). Influence of anthropogenic factors and soil properties on earthworm diversity in southern Mediterranean agroecosystems. *Geoderma Regional*, *39*, e00877. https://doi.org/10.1016/j.geodrs.2024.e00877

Betancur-Corredor, B., Zaitsev, A., & Russell, D. J. (2024). The impact of multiple agricultural land uses in sustaining earthworm communities in agroecosystems - A global meta-analysis. *Scientific Reports*, *14*(1), 30160. https://doi.org/10.1038/s41598-024-81676-5

Bhadauria, T., Kumar, P., Kumar, R., Maikhuri, R., Rao, K., & Saxena, K. (2011). Earthworm populations in a traditional village landscape in Central Himalaya, India. *Applied Soil Ecology*, *53*, 83–93. https://doi.org/10.1016/j.apsoil.2011.11.011

Bharti, V., Harshlata, & Sharma, N. (2024). Diversity of earthworm (Lumbricidae) in India: A review. *Journal of Entomology and Zoology Studies*, *12*(2), 132–136. https://doi.org/10.22271/j.ento.2024.v12.i2b.9304

Cai, S., Wang, J., Lv, W., Xu, S., & Zhu, H. (2019). Nitrogen fertilization alters the effects of earthworms on soil physicochemical properties and bacterial community structure. *Applied Soil Ecology*, *150*, 103478. https://doi.org/10.1016/j.apsoil.2019.103478

Chen, I., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid Range Shifts of Species Associated with High Levels of Climate Warming. *Science*, *333*(6045), 1024– 1026. https://doi.org/10.1126/science.1206432

Chen, L., Wang, G., Wan, X., & Liu, W. (2014). Complex and nonlinear effects of weather and density on the demography of small herbivorous mammals. *Basic and Applied Ecology*, *16*(2), 172–179. https://doi.org/10.1016/j.baae.2014.12.002

De Boer, T. E., Roelofs, D., Vooijs, R., Holmstrup, M., & Amorim, M. J. B. (2018). Population- specific transcriptional differences associated with freeze tolerance in a terrestrial worm. *Ecology and Evolution*, *8*(7), 3774–3786. https://doi.org/10.1002/ece3.3602

Edwards, C. A., & Arancon, N. Q. (2022). The Influence of Environmental Factors on Earthworms. In *The Influence of Environmental Factors on Earthworms. In: Biology and Ecology of Earthworms* (pp. 191–232). Springer, New York, NY. https://doi.org/10.1007/978-0-387- 74943-3_7

Ferlian, O., Eisenhauer, N., Aguirrebengoa, M., Camara, M., Ramirez-Rojas, I., Santos, F., Tanalgo, K., & Thakur, M. P. (2017). Invasive earthworms erode soil biodiversity: A meta- analysis. *Journal of Animal Ecology*, *87*(1), 162–172. https://doi.org/10.1111/1365- 2656.12746

Fischer, C., Roscher, C., Jensen, B., Eisenhauer, N., Baade, J., Attinger, S., Scheu, S., Weisser, W. W., Schumacher, J., & Hildebrandt, A. (2014). How Do Earthworms, Soil Texture and Plant Composition Affect Infiltration along an Experimental Plant Diversity Gradient in Grassland? *PLoS ONE*, *9*(6), e98987. https://doi.org/10.1371/journal.pone.0098987

Garnier, P., Makowski, D., Hedde, M., & Bertrand, M. (2022). Changes in soil carbon mineralization related to earthworm activity depend on the time since inoculation and their density in soil. *Scientific Reports*, *12*(1), 13616. https://doi.org/10.1038/s41598-022- 17855-z

Garssen, A. G., Verhoeven, J. T. A., & Soons, M. B. (2014). Effects of climate-induced increases in summer drought on riparian plant species: a meta-analysis. *Freshwater Biology*, *59*(5), 1052–1063. https://doi.org/10.1111/fwb.12328

Ghosh, S. (2022). An annotated checklist of Earthworms from India. *Asian Journal of Conservation Biology*, *11*(2), 189–206. https://doi.org/10.53562/ajcb.74028

Goury, R., Münkemüller, T., Bonfanti, N., Calderón-Sanou, I., Poulenard, J., & Thuiller, W. (2025). The role of earthworms in mediating environmental impacts on mountain ecosystem functioning. *Global Ecology and Biogeography*, *34*(8). https://doi.org/10.1111/geb.70093

Hallam, J., Berdeni, D., Grayson, R., Guest, E. J., Holden, J., Lappage, M. G., Prendergast-Miller,

M. T., Robinson, D. A., Turner, A., Leake, J. R., & Hodson, M. E. (2020). Effect of earthworms on soil physico-hydraulic and chemical properties, herbage production, and wheat growth on arable land converted to ley. *The Science of the Total Environment*, *713*, 136491. https://doi.org/10.1016/j.scitotenv.2019.136491

Jaouhari, M. E., Damour, G., & Coulis, M. (2024). Relationship between farming practices, soil macrofauna and litter decomposition in organic versus conventional banana agroecosystems.*AppliedSoilEcology*, *204*, 105697. https://doi.org/10.1016/j.apsoil.2024.105697

Kabir, M. F., & Ju, L. (2023). On optimization of enzymatic processes: Temperature effects on activity and long-term deactivation kinetics. *Process Biochemistry*, *130*, 734–746. https://doi.org/10.1016/j.procbio.2023.05.031

Karimifard, S., Saberi-Pirooz, R., Ahmadzadeh, F., & Aghamir, F. (2023). Investigating the impacts of agricultural land use on soil earthworm communities: A case study of northern ZagrosMountains of Iran. *Heliyon*, *10*(1), e23523. https://doi.org/10.1016/j.heliyon.2023.e23523

Kumar, A., D, V., & Singh, J. (2025). The impact of climate change on agricultural ecosystem. In *Elsevier eBooks* (pp. 1–20). https://doi.org/10.1016/b978-0-443-26520-4.00002-0

Kumari, B., & Kumari, N. (2025). Ver micom posting and solid waste Management: Microbial processes and environmental appli cations. *UTTAR PRADESH JOURNAL OF ZOOLOGY*, *46*(24), 23–52. https://doi.org/10.56557/upjoz/2025/v46i245406

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P., & Rossi, J. (2006). Soil invertebrates and ecosystem services. *European Journal of Soil Biology*, *42*, S3–S15. https://doi.org/10.1016/j.ejsobi.2006.10.002

Li, X., Jiang, J., Zhang, Z., Liu, X., Wang, Y., Wu, Y., Li, Y., Qiu, J., & Zhao, Q. (2024). Earthworm biodiversity and its influencing factors in Baotianman National Nature Reserve. *Biodiversity Science*, *32*(4), 23352. https://doi.org/10.17520/biods.2023352

Liu, C., Luo, Q., Xiao, Y., Li, H., Dong, H., & Duan, C. (2024). Influence of land-use type on earthworm diversity and distribution in Yunnan: Insights from soil properties. *Applied Soil Ecology*, *205*, 105791. https://doi.org/10.1016/j.apsoil.2024.105791

Moos, J. H., Schrader, S., Paulsen, H. M., & Rahmann, G. (2016). Occasional reduced tillage in organic farming can promote earthworm performance and resource efficiency. *Applied Soil Ecology*, *103*, 22–30. https://doi.org/10.1016/j.apsoil.2016.01.017

Morón-Ríos, A., Rodríguez, M. Á., Pérez-Camacho, L., & Rebollo, S. (2010). Effects of seasonal grazing and precipitation regime on the soil macroinvertebrates of a Mediterranean old- field. *European Journal of Soil Biology*, *46*(2), 91–96. https://doi.org/10.1016/j.ejsobi.2009.12.008

Narayanan, S. P., Paliwal, R., Kurien, V. T., Thomas, A., & Julka, J. (2023). *Earthworms (Clitellata: moniligastrida, Crassiclitellata) of India: Distribution and Status*.

Overgaard, J., Tollarova, M., Hedlund, K., Petersen, S. O., & Holmstrup, M. (2009). Seasonal changes in lipid composition and glycogen storage associated with freeze-tolerance of the earthworm, Dendrobaena octaedra. *Journal of Comparative Physiology B*, *179*(5), 569–

577. https://doi.org/10.1007/s00360-009-0341-9

Phillips, H. R. P., Bach, E. M., Bartz, M. L. C., Bennett, J. M., Beugnon, R., Briones, M. J. I., Brown, G. G., Ferlian, O., Gongalsky, K. B., Guerra, C. A., König-Ries, B., Krebs, J. J., Orgiazzi, A., Ramirez, K. S., Russell, D. J., Schwarz, B., Wall, D. H., Brose, U., Decaëns, T., . . . Lincoln, N. K. (2021). Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. *Scientific Data*, *8*(1), 136. https://doi.org/10.1038/s41597-021-00912-z

Phillips, H. R. P., Guerra, C. A., Bartz, M. L. C., Briones, M. J. I., Brown, G., Crowther, T. W., Ferlian, O., Gongalsky, K. B., Van Den Hoogen, J., Krebs, J., Orgiazzi, A., Routh, D., Schwarz, B., Bach, E. M., Bennett, J. M., Brose, U., Decaëns, T., König-Ries, B., Loreau,M., . . . Nuutinen, V. (2019). Global distribution of earthworm diversity. *Science*, *366*(6464), 480–485. https://doi.org/10.1126/science.aax4851

Phillips, H. R. P., Hoeffner, K., Muys, B., Bayon, R. L., Cluzeau, D., Butt, K. R., Maréchal, J., Briones, M. J. I., Decaëns, T., Hedde, M., Gérard, S., Pérès, G., Petit-Dit-Grézériat, L., & Pelosi, C. (2025a). Urban earthworm communities driven more by climate and elevation than urbanisation intensity. *Urban Ecosystems*, *28*(6). https://doi.org/10.1007/s11252-025- 01826-z

Phillips, H. R. P., Hoeffner, K., Muys, B., Bayon, R. L., Cluzeau, D., Butt, K. R., Maréchal, J., Briones, M. J. I., Decaëns, T., Hedde, M., Gérard, S., Pérès, G., Petit-Dit-Grézériat, L., & Pelosi, C. (2025b). Urban earthworm communities driven more by climate and elevation than urbanisation intensity. *Urban Ecosystems*, *28*(6). https://doi.org/10.1007/s11252-025- 01826-z

Purwar, C. (2023). A BIOACTIVE COMPONENT MARMESIN FROM FERONIA LIMONIA FRUIT PERICARP: A REVIEW. *International Journal of Biological Innovations*, *05*(01), 155–160. https://doi.org/10.46505/ijbi.2023.5114

Saharan, B. S., Lata, P., Deshwal, R., Kumar, D., Tyagi, S., Sharma, D., Santal, A., Mandal, N. K., Kumar, R., Singh, G., Tokas, J., & Duhan, J. S. (2025). Insights of agricultural sustainability by the use of earthworms. *Discover Agriculture*, *3*(1). https://doi.org/10.1007/s44279-025-00322-4

Shekhovtsov, S. V., Berman, D. I., & Peltek, S. E. (2015). Phylogeography of the earthworm Eisenia nordenskioldi nordenskioldi (Lumbricidae, Oligochaeta) in northeastern Eurasia. *Doklady Biological Sciences*, *461*(1), 85–88. https://doi.org/10.1134/s0012496615020039

Singh, J., Schädler, M., Demetrio, W., Brown, G. G., & Eisenhauer, N. (2019). Climate change effects on earthworms - a review. *PubMed*, *91*(3), 114–138. https://doi.org/10.25674/so91iss3pp114

Singh, S., Sharma, A., Khajuria, K., Singh, J., & Vig, A. P. (2020). Soil properties changes earthworm diversity indices in different agro-ecosystem. *BMC Ecology*, *20*(1), 27. https://doi.org/10.1186/s12898-020-00296-5

Spurgeon, D. J., Liebeke, M., Anderson, C., Kille, P., Lawlor, A., Bundy, J. G., & Lahive, E. (2016). Ecological drivers influence the distributions of two cryptic lineages in an earthworm morphospecies. *Applied Soil Ecology*, *108*, 8–15. https://doi.org/10.1016/j.apsoil.2016.07.013

Sutri, M., Kuu, A., Escuer-Gatius, J., Konsap, K., Shanskiy, M., Reintam, E., & Ivask, M. (2025). Earthworm community structure under different land-use systems across various soil conditions. *Applied Soil Ecology*, *211*, 106151. https://doi.org/10.1016/j.apsoil.2025.106151

Thakur, S. S., & Yadav, S. (2018). Exploration of Earthworms of India through Online Digital Library. In *InTech eBooks*. https://doi.org/10.5772/intechopen.75666

Thounaojam, R. S., Singh, K. B., Singh, T. B., Keisham, S., & Singh, T. B. (2025). Assessment of Pontoscolex corethrurus, an exotic earthworm, in contrasting protected subtropical forest habitats in North-East India. *Discover Ecology*, *1*(1). https://doi.org/10.1007/s44396-025- 00010-z

Tiwari, N., Paliwal, R., Rashid, A., & Yadav, S. (2020). Checklist of earthworm species (Oligochaeta) of the North Eastern Region of India. *Zootaxa*, *4772*(2), zootaxa.4772.2.3. https://doi.org/10.11646/zootaxa.4772.2.3

Tiwari, N., Tiwari, P., Gupta, N., & Yadav, S. (2024). An annotated checklist of earthworms (Annelida: Clitellata: oligochaeta) of Indo-Gangetic plains of India. *Zootaxa*, *5477*(3), 251–294. https://doi.org/10.11646/zootaxa.5477.3.1

Torppa, K. A., Castaño, C., Glimskär, A., Skånes, H., Klinth, M., Roslin, T., Taylor, A. R., Viketoft, M., Clemmensen, K. E., & Maaroufi, N. I. (2023). Soil moisture and fertility drive earthworm diversity in north temperate semi-natural grasslands. *Agriculture Ecosystems & Environment*, *362*, 108836. https://doi.org/10.1016/j.agee.2023.108836

Zhao, Z., Wang, X., Zhang, W., Lu, X., & Liu, T. (2022). Effects of exotic and native earthworms on soil Micro-Decomposers in a subtropical forest: A Field mesocosm experiment. *Forests*, *13*(11), 1924. https://doi.org/10.3390/f13111924

Zhu, X., Lian, B., Yang, X., Liu, C., & Zhu, L. (2013). Biotransformation of earthworm activity on potassium-bearing mineral powder. *Journal of Earth Science*, *24*(1), 65–74. https://doi.org/10.1007/s12583-013-0313-6