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Industrialization and heavy metals: Impacts on earthworm biodiversity and soil health

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Abstract
Soils are dynamic ecosystems that sustain terrestrial life through nutrient cycling, organic matter decomposition, and fertility regulation. Earthworms, recognized as ecosystem engineers, play a pivotal role in restructuring soil, enhancing microbial activity, and maintaining ecological balance. India's diverse agro climatic zones harbor rich earthworm diversity, yet rapid industrialization and land use change have disrupted their populations. Comparative studies consistently reveal higher abundance, biomass, and diversity indices in non industrial soils compared to industrial soils, underscoring their sensitivity to anthropogenic stressors. Heavy metals such as cadmium, lead, chromium, and mercury accumulate in industrial soils and bioaccumulation in earthworm tissues, impairing growth, reproduction, and DNA integrity, thereby compromising ecological functions. Functional classifications epigeic, endogeic, and anecic illustrate their unique contributions to decomposition, aeration, and nutrient cycling, while emerging research highlights microbiome interactions as next generation bioindicators of soil health. Climate change further compounds stress by altering rainfall and temperature regimes, reshaping distribution patterns. The Rewari district of Haryana exemplifies the ecological costs of industrialization, where non industrial soils sustain biodiversity and fertility, while industrial soils exhibit contamination and decline. This review emphasizes the need for integrated comparative assessments, remediation strategies, and sustainable land use planning to safeguard soil biodiversity and ecosystem resilience in rapidly industrializing regions.

Keywords: Earthworm diversity, agro climatic zones, industrialization, heavy metal contamination, bioindicators of soil health

1. Introduction

Soils are dynamic ecosystems that sustain terrestrial life by regulating nutrient cycling, organic matter decomposition, and fertility. Among soil macro fauna, earthworms are widely recognized as ecosystem engineers due to their ability to restructure soil, enhance microbial activity, and regulate nutrient dynamics (Phillips *et al.,* 2021) [10]. India, with its diverse agro climatic zones, harbors significant earthworm diversity, yet industrialization and land use change have increasingly disrupted their populations (Bharti *et al.,* 2024; Chakraborty *et al.,* 2023) [1, 2]. Industrial expansion alters soil physicochemical properties through contamination, compaction, and reduced organic matter, leading to biodiversity decline. Comparative studies consistently show that earthworm abundance, biomass, and diversity indices are higher in non-industrial soils than in industrial soils, underscoring their sensitivity to anthropogenic stressors (Verma *et al*., 2021) [19]. Heavy metals such as cadmium, lead, and mercury accumulate in soils through industrial discharge and bioaccumulation in earthworm tissues, impairing growth, reproduction, and survival (Vaidya, 2022; Latifi *et al.,* 2020) [17, 9]. These toxic effects compromise their ecological functions, including litter decomposition, nutrient mineralization, and soil fertility enhancement (Raj *et al.,* 2025) [11].

Ecologically, earthworms are classified into epigeic, endogeic, and anecic groups, each contributing uniquely to soil processes. Their burrowing and feeding activities improve aeration, water infiltration, and nutrient translocation, while their interactions with microbial communities accelerate carbon and nitrogen cycling (Gupta and Kumar, 2024; Goswami, 2025) [5, 4]. Recent advances highlight earthworm microbiome interactions as next generation bioindicators of soil health, offering insights into pollutant detoxification and ecosystem resilience (Goswami, 2025) [4]. The climate change and industrial pollution act synergistically, reshaping earthworm community composition and ecological roles.

Studies reveal that altered temperature and moisture regimes combined with contamination, significantly affect diversity indices and distribution patterns (Singh *et al.,* 2020; Kooch, 2024) [13, 8]. These findings emphasize the need for comparative assessments of industrial and non-industrial soils, particularly in regions like Rewari, Haryana, where rapid industrialization coexists with traditional agriculture.

2. Review of Literature

Earthworms are widely recognized as ecosystem engineers, playing a vital role in soil fertility, nutrient cycling, and plant productivity. Studies across India's diverse agro climatic zones reveal over 400 species, with richness highest in humid regions and lowest in arid/semi arid zones, highlighting their sensitivity to ecological conditions. Functional classifications epigeic, endogeic, and anecic demonstrate their contributions to decomposition, aeration, and microbial interactions. However, industrialization has led to soil compaction, reduced organic matter, and biodiversity decline, with heavy metals such as cadmium, lead, chromium, and mercury bioaccumulation in earthworm tissues, impairing growth, reproduction, and DNA integrity. Their physiological and reproductive responses make earthworm's reliable bioindicators of soil health, while emerging research on gut microbiome interactions offers new monitoring tools. Climate change further compounds stress by altering rainfall and temperature regimes, reshaping distribution patterns. Comparative studies in Rewari district confirm that non industrial soils support higher diversity and fertility, whereas industrial soils show contamination and ecological decline, underscoring the urgent need for remediation and sustainable land use planning.

2.1 Soil Biodiversity and Role of Earthworms

Soil represents one of the most biologically diverse ecosystems, supporting a vast array of microorganisms and macrofauna that collectively regulate nutrient cycling, organic matter decomposition, and fertility. Among these organisms, earthworms are widely recognized as ecosystem engineers, owing to their capacity to restructure soil, enhance microbial activity, and improve nutrient availability (Phillips *et al.,* 2021) [10]. Their burrowing and casting activities increase aeration, water infiltration, and soil aggregation, thereby creating favorable conditions for plant growth and sustaining agricultural productivity (Torppa *et al.,* 2024) [16]. India, with its varied agro climatic zones, harbors rich earthworm diversity, much of which is native and adapted to specific soil and climatic conditions (Bharti *et al.,* 2024) [1]. However, rapid industrialization and land use changes have significantly altered soil properties, leading to biodiversity decline and reduced earthworm abundance (Verma *et al*., 2021) [19]. Heavy metals and pollutants introduced through industrial discharge accumulate in soils, bioaccumulation in earthworm tissues, and impair their growth, reproduction, and ecological functions (Yadav *et al.,* 2023) [20]. Beyond their ecological roles, earthworms serve as bioindicators of soil health, reflecting changes in physicochemical parameters such as pH, moisture, and organic matter content (Gupta and Kumar, 2024) [5]. Their sensitivity to environmental stressors makes them valuable for monitoring ecosystem sustainability and assessing the impacts of industrialization on soil biodiversity. Recent advances highlight earthworm microbiome interactions and climate change studies as emerging areas of research, further underscoring their importance in ecological monitoring and sustainable soil management (Goswami, 2025) [4].

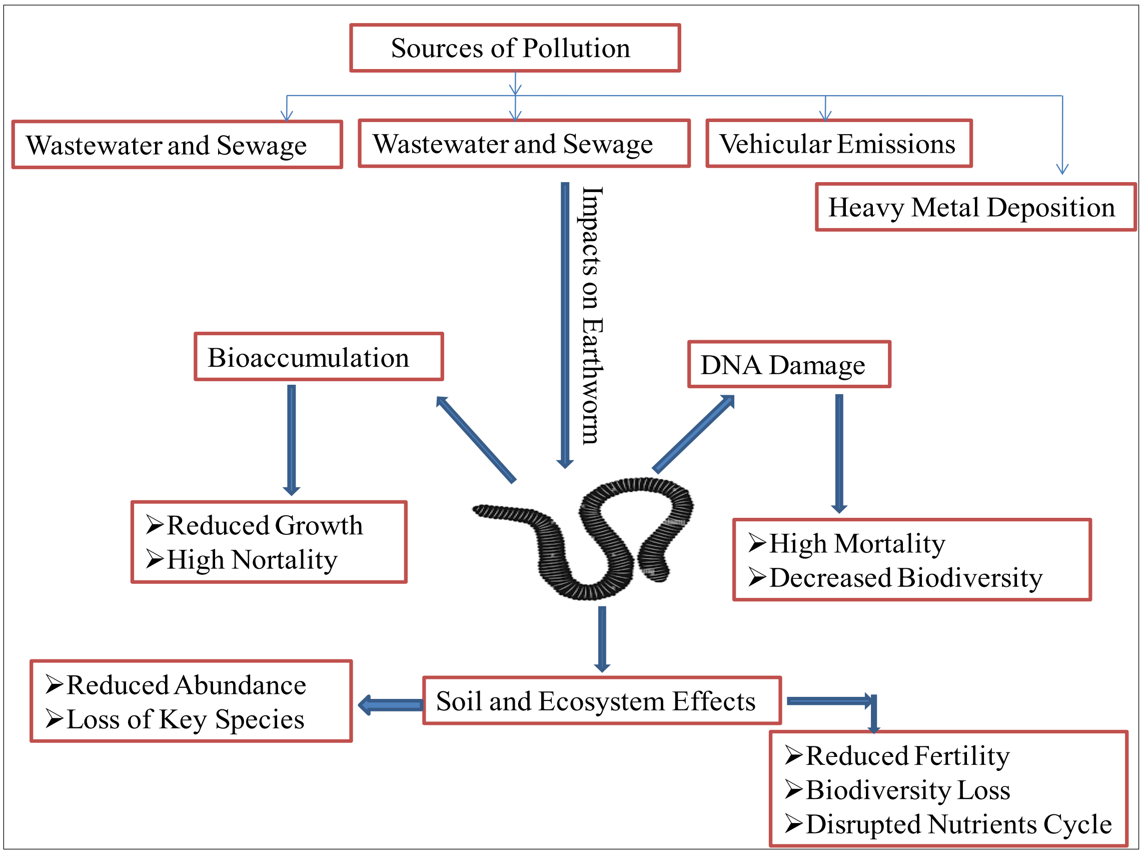

Fig 1: Pollution Sources, Heavy Metal Deposition, and Ecological Impacts on Earthworm Communities and Soil Health

2.2 Earthworm Diversity in Agro Climatic Zones of India

India's vast geographical expanse and heterogeneous agro climatic conditions have resulted in remarkable earthworm diversity. With 15 major agro climatic zones ranging from arid deserts to humid tropics, the distribution of earthworm species is strongly influenced by soil type, vegetation, rainfall, and land use practices (Sharma and Poonam, 2014; Julka and Paliwal, 2005) [12, 7]. Recent surveys highlight that India harbors more than 400 species, of which nearly 89% are native, underscoring the country's role as a biodiversity hotspot (Bharti *et al.,* 2024) [1]. Comparative studies reveal that regions such as the Western Ghats and Eastern Himalayas exhibit high species richness, while semi-arid zones like Gujarat Plains and the Trans Gangetic region show relatively poor diversity due to climatic constraints and anthropogenic pressures (Suthar, 2011; Singh *et al.,* 2020) [15, 13]. In Haryana, patchy distribution of endemic species such as *Aporrectodea robustus* and *Octochaetus beatrix* has been documented, reflecting the sensitivity of earthworm communities to soil physicochemical variations and industrial activity (Sharma and Poonam, 2014) [12].

Table 1: Integrated Research Insights on Earthworm Diversity, Ecology, and Industrial Impacts

Keyword	Industrial Effects	Ecosystem Parameters	Approaches	Implications for Ecology and Management	References
Soil biodiversity	Earthworms act as ecosystem engineers, enhancing fertility, nutrient cycling, and plant productivity.	Soil structure, organic matter, microbial activity	Field surveys, soil physicochemical analysis	Central to sustainable agriculture and soil health.	Phillips *et al.,* 2021; Torppa *et al.,* 2024 [10, 16]
Diversity in India	>400 species; 89% native; high richness in Western Ghats and Himalayas; poor diversity in arid zones.	Species richness, evenness, abundance indices	Diversity indices (Shannon, Simpson, Margalef)	Reflects ecological heterogeneity; conservation needed in industrializing regions.	Bharti *et al.,* 2024; Singh *et al.,* 2020 [1, 13]
Agro-climatic zones	Soil moisture, fertility, and organic carbon drive diversity indices; patchy distribution in Trans Genetic plains.	Moisture, organic carbon, pH, temperature	Agro ecosystem surveys, GIS mapping	Agro ecosystem management directly influences earthworm communities.	Torppa *et al.,* 2024; Verma *et al.,* 2021 [16, 19]
Functional roles	Epigeic, endogeic, anecic groups regulate decomposition, aeration, nutrient cycling, and microbial interactions.	Nutrient cycling (C, N, P), soil aeration, microbial diversity	Functional classification, nutrient assays	Enhance soil fertility, crop yields, and resilience against degradation.	Gupta and Kumar, 2024; Goswami, 2025 [5, 4]
Industrialization	Industrial soils show reduced abundance, biomass, and diversity; contamination alters soil properties.	Soil compaction, reduced organic matter, pollution load	Comparative soil sampling (industrial vs. non-industrial)	Industrial expansion poses ecological risks; biodiversity loss linked to soil degradation.	Verma *et al.,* 2021 [19]
Heavy metals	Cadmium, lead, chromium bioaccumulate in tissues; impair growth, reproduction, and DNA integrity.	Bioaccumulation factor (BAF), histological changes, reproductive success	Atomic Absorption Spectrophotometry (AAS), histological studies	Toxicity reduces ecological functions; remediation strategies essential.	Yadav *et al.,* 2023; Latifi *et al.,* 2020; Vaidya, 2022 [20, 9, 17]
Bioindicators	Diversity indices correlate with soil pH, moisture, organic matter; physiological responses reveal contamination.	Shannon, Simpson indices; cocoon production; enzyme activity	Ecological monitoring, laboratory bioassays	Reliable indicators of soil quality; useful for monitoring impacts.	Fan *et al.,* 2023; Goswami, 2025 [3, 4]
Microbiome interactions	Gut microbial communities respond dynamically to pollutants and soil conditions.	Microbial diversity, pollutant detoxification	Microbial sequencing, gut content analysis	Emerging bioindicator approach; enhances ecological monitoring.	Goswami, 2025 [4]
Climate change	Altered rainfall and temperature regimes reshape distribution patterns and diversity indices.	Temperature, rainfall, soil moisture	Long-term ecological monitoring	Climate stress interacts with industrial pollution, compounding biodiversity loss.	Singh *et al.,* 2020; Kooch, 2024 [13, 8]
Rewari district case	Non-industrial soils support higher diversity and fertility; industrial soils show contamination and decline.	Soil pH, organic matter, heavy metal content	Comparative field surveys, diversity indices, AAS	Highlights ecological costs of industrialization; informs sustainable land use planning.	Singh *et al.,* 2020; Raj *et al.,* 2025 [13, 11]

Earthworm diversity is also regulated by land use intensity. Agricultural soils with moderate organic matter support higher abundance compared to heavily industrialized soils, where contamination and compaction reduce species richness (Verma *et al*., 2021) [19]. Recent findings emphasize that soil moisture, fertility, and organic carbon are the strongest drivers of diversity indices across agro ecosystems (Torppa *et al.,* 2024) [16]. Moreover, climate change is reshaping distribution patterns, with altered rainfall and temperature regimes influencing population dynamics and community composition (Singh *et al.,* 2020) [13]. The diversity of earthworms across India's agro climatic zones reflects a complex interplay of ecological, climatic, and anthropogenic factors. Understanding these patterns is essential for biodiversity conservation, sustainable agriculture, and ecological monitoring in rapidly industrializing regions such as Haryana.

2.3 Functional Roles of Earthworms in Soil Ecosystems

Earthworms are integral components of terrestrial ecosystems, often referred to as ecosystem engineers due to their ability to modify soil structure, enhance nutrient cycling, and regulate microbial activity (Phillips *et al.,* 2021) [10]. Their burrowing and casting activities improve soil aeration, water infiltration, and aggregation, thereby creating favorable conditions for plant root growth and sustaining agricultural productivity (Torppa *et al.,* 2024) [16]. Functionally, earthworms are classified into three ecological groups: epigeic species, which inhabit surface litter and accelerate organic matter decomposition; anecic species, which construct vertical burrows and incorporate surface residues into deeper layers; and endogeic species, which burrow horizontally and feed within the mineral soil, contributing to rhizosphere nutrient dynamics (Hendrix and Bohlen, 2002) [6]. Together, these groups maintain soil fertility and resilience across diverse agro ecosystems.

Earthworms also play a pivotal role in nutrient mineralization and cycling. By ingesting organic debris with varying carbon to nitrogen ratios, they convert it into nutrient rich casts that enhance nitrogen and phosphorus availability for plants (Gupta and Kumar, 2024) [5]. Their interactions with soil microbes further accelerate decomposition processes, supporting carbon sequestration and improving soil health (Goswami, 2025) [4]. Meta analyses confirm that earthworm activity significantly increases crop yields, highlighting their agronomic importance (Van Groenigen *et al.,* 2014) [18]. Beyond soil fertility, earthworms act as bioindicators of environmental quality. Their sensitivity to pollutants such as heavy metals and micro plastics makes them valuable for monitoring soil contamination and ecosystem sustainability (Yadav *et al.,* 2023; Fan *et al.,* 2023) [20, 3]. Recent studies emphasize that earthworm microbiome interactions provide novel insights into pollutant detoxification and resilience mechanisms, positioning them as next generation indicators of soil health (Goswami, 2025) [4]. The functional roles of earthworms extend beyond decomposition and nutrient cycling to encompass ecological monitoring, sustainable agriculture, and climate resilience. Their contributions underscore the need to conserve earthworm diversity, particularly in regions undergoing rapid industrialization and land use change.

2.4 Industrialization, Heavy Metal Contamination, and Earthworm Communities: Industrialization has profoundly altered soil ecosystems by introducing pollutants, modifying land cover, and disrupting natural biodiversity. Among soil fauna, earthworms are particularly sensitive to industrial stressors, making them reliable indicators of soil health (Verma *et al*., 2021) [19]. Industrial soils often exhibit reduced abundance, biomass, and diversity compared to non-industrial soils, reflecting the negative impacts of contamination, compaction, and reduced organic matter (Singh *et al.,* 2020) [13]. One of the most critical consequences of industrial activity is the accumulation of heavy metals such as cadmium, lead, chromium, and mercury in soils. These metals enter earthworm tissues through ingestion of contaminated organic matter or dermal absorption, leading to physiological stress, reduced growth, impaired reproduction, and histological damage (Yadav *et al.,* 2023) [20]. Recent studies confirm that heavy metal bioaccumulation can disrupt DNA integrity, enzyme activity, and metabolic pathways, thereby compromising earthworm survival and ecological functions (Latifi *et al.,* 2020; Vaidya, 2022) [9, 17]. The ecological implications extend beyond earthworm populations. By reducing their ability to decompose organic matter and recycle nutrients, heavy metal contamination diminishes soil fertility and plant productivity (Raj *et al.,* 2025) [11]. Furthermore, synergistic effects of industrial pollution and climate change exacerbate stress on earthworm communities, altering diversity indices and distribution patterns across agro ecosystems (Singh *et al.,* 2020; Kooch, 2024) [13, 8]. Despite these challenges, earthworms continue to play a role in bioremediation. Their interactions with soil microbes can enhance pollutant degradation and nutrient cycling, offering potential strategies for restoring contaminated soils (Gupta and Kumar, 2024) [5]. Thus, comparative assessments of industrial and non-industrial soils are essential for understanding the extent of biodiversity loss, guiding remediation efforts, and ensuring sustainable soil management in rapidly industrializing regions such as Haryana.

Table 2: Impact of Industrialization and Heavy Metal Contamination on Earthworm Communities

Factor	Source	Methods of Study	Physiological / Biological Impacts on Earthworms	Soil / Ecosystem Outcomes	Management / Remediation Strategies	References
Industrialization	Factories, land-use change, soil compaction, reduced organic matter	Comparative soil sampling (industrial vs. non-industrial), diversity indices	Decline in abundance, biomass, and species richness	Loss of biodiversity, reduced fertility, altered soil structure	Pollution control, organic amendments, ecological monitoring	(Verma *et al.*, 2021) [19]
Cadmium (Cd)	Industrial discharge, fertilizers, sewage sludge	Atomic Absorption Spectrophotometry (AAS), tissue analysis	Bioaccumulation, impaired growth, reduced reproduction	Soil fertility decline, toxicity transfer to food chain	Bioremediation, vermicomposting with tolerant species	(Yadav *et al.,* 2023) [20]
Lead (Pb)	Vehicular emissions, battery industries, smelting	Histological studies, enzyme assays	Neurological stress, reduced cocoon production, enzyme inhibition	Soil contamination, impaired nutrient cycling	Phytoremediation, stricter emission controls	(Latifi *et al.,* 2020) [9]
Chromium (Cr)	Tannery effluents, electroplating industries	DNA integrity assays, reproductive studies	DNA damage, histological changes, reduced survival	Soil toxicity, ecosystem imbalance	Wastewater treatment, soil amendments	(Vaidya, 2022) [17]
Mercury (Hg)	Industrial effluents, mining	Oxidative stress markers, metabolic assays	Disruption of metabolic pathways, oxidative stress	Long-term soil contamination, reduced microbial activity	Bioremediation using microbes and organic matter	(Yadav *et al.,* 2023) [20]

Combined pollution load	Synergistic effects of multiple heavy metals and industrial pollutants	Diversity indices (Shannon, Simpson), comparative field surveys	Altered diversity indices, reduced resilience, mortality	Soil degradation, biodiversity collapse, reduced productivity	Integrated soil management, remediation protocols	(Singh *et al.,* 2020; Raj *et al.,* 2025) [13, 11]
Bioindicator role	Sensitivity to pollutants and soil changes	Laboratory bioassays, ecological monitoring	Physiological and reproductive endpoints reveal contamination	Early detection of soil stress and contamination	Use earthworms in biomonitoring frameworks	(Gupta and Kumar, 2024) [5]

2.5 Earthworms as Bioindicators of Soil Health and Environmental Quality

Earthworms are increasingly recognized as bioindicators of soil health, owing to their sensitivity to changes in physicochemical properties and their ability to reflect ecosystem quality. Their abundance, diversity, and community structure provide valuable insights into soil fertility, contamination levels, and ecological resilience (Singh *et al.,* 2020) [13]. Because they interact directly with soil through feeding, burrowing, and casting, earthworms integrate multiple environmental signals, making them reliable indicators of both natural and anthropogenic disturbances (Verma *et al*., 2021) [19]. Industrial and agricultural activities often introduce pollutants such as heavy metals, pesticides, and micro plastics into soils. Earthworm's bioaccumulation these contaminants and their physiological, histological, and reproductive responses serve as measurable endpoints for environmental monitoring (Yadav *et al.,* 2023; Fan *et al.,* 2023) [20, 3]. For example, reduced cocoon production, altered enzyme activity, and tissue damage have been documented in contaminated soils, highlighting their role as early warning systems for ecological stress (Latifi *et al.,* 2020) [9]. Beyond contamination, earthworm diversity indices are strongly correlated with soil properties such as moisture, organic carbon, and pH. Studies demonstrate that soils with higher fertility and balanced moisture regimes support greater earthworm abundance and species richness, whereas degraded or polluted soils show reduced diversity (Torppa *et al.,* 2024) [16]. This relationship underscores their utility in assessing soil quality across different land use systems. Recent advances emphasize the importance of earthworm microbiome interactions as next generation bioindicators. The gut microbial communities of earthworms respond dynamically to pollutants and soil conditions, offering new avenues for monitoring ecosystem health (Goswami, 2025) [4]. Together, these findings establish earthworms not only as contributors to soil fertility but also as critical tools for evaluating environmental quality in the face of industrialization and climate change.

2.6 Comparative Assessment of Industrial and Non Industrial Soils in Rewari District

The district of Rewari in Haryana represents a unique landscape where rapid industrial expansion coexists with traditional agricultural practices. This juxtaposition provides an ideal setting for comparative studies of soil biodiversity, particularly earthworm communities. Industrial soils, often exposed to heavy metal contamination, reduced organic matter, and altered physicochemical properties, contrast sharply with non-industrial soils such as agricultural fields and horticultural gardens that maintain relatively stable ecological conditions (Verma *et al*., 2021) [19]. Recent studies demonstrate that earthworm abundance, biomass, and diversity indices are consistently higher in non industrial soils compared to industrial sites (Singh *et al.,* 2020) [13]. Industrial soils typically exhibit lower species richness and evenness due to contamination and compaction, while non-industrial soils support diverse communities that contribute to nutrient cycling and soil fertility (Torppa *et al.,* 2024) [16]. Heavy metals such as cadmium, lead, and chromium, prevalent in industrial soils, bioaccumulation in earthworm tissues, impairing their physiological functions and reducing reproductive success (Yadav *et al.,* 2023; Latifi *et al.,* 2020) [20, 9]. Comparative assessments in Rewari are particularly significant because they highlight the ecological costs of industrialization in a region undergoing rapid economic development. By analyzing soil parameters such as pH, organic matter, moisture, and nutrient availability alongside earthworm diversity indices, researchers can establish clear correlations between environmental stressors and biodiversity decline (Gupta and Kumar, 2024) [5]. These findings not only provide insights into the resilience of earthworm communities but also underscore their role as bioindicators of soil health. Ultimately, such comparative studies contribute to sustainable land use planning and environmental management. They emphasize the need for remediation strategies, including organic amendments and bioremediation approaches, to restore soil quality in industrial zones while safeguarding biodiversity in non industrial landscapes (Raj *et al.,* 2025) [11].

3. Conclusion

The review highlights the pivotal role of earthworms as ecosystem engineers and bioindicators of soil health, emphasizing their contributions to nutrient cycling, organic matter decomposition, and fertility across India's diverse agro climatic zones. Evidence consistently demonstrates that industrialization and heavy metal contamination reduce earthworm abundance, biomass, and diversity, thereby impairing ecological functions and diminishing soil quality. Comparative studies, particularly in Rewari district, reveal stark contrasts between industrial and non-industrial soils, underscoring the ecological costs of rapid industrial expansion. Functional classifications of earthworm's epigeic, endogeic, and anecic illustrate their unique contributions to soil processes, while emerging research on microbiome interactions and climate change impacts expands their relevance as next generation bioindicators. Collectively, these findings establish earthworms as critical tools for monitoring environmental quality, guiding remediation strategies, and ensuring sustainable soil management. The synthesis underscores the urgent need for integrated approaches that combine biodiversity conservation, pollution control, and adaptive land use planning to safeguard soil ecosystems in industrializing regions.

4. CRediT authorship contribution statement

- **Anoop:** Writing - original draft, Validation, Formal analysis, Data curation, Conceptualization.

- **Namrata Dangi and Amrita Kumari:** Editing, Visualization, Supervision.

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6. Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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8. Data availability: All the data is provided with in the manuscript.

References
1. Bharti V, Harshlata, Sharma N. Diversity of earthworm (Lumbricidae) in India: A review. Journal of Entomology and Zoology Studies. 2024;12(2):132-136.
2. Chakraborty S, Debbarma B, Chaudhuri P. Ecology and diversity of earthworms in different land use systems of northeast India: A review. Asian Journal of Conservation Biology. 2023;12(2):267-286. https://doi.org/10.53562/ajcb.82300.
3. Fan W, Qiu C, Qu Q, Hu X, Mu L, Gao Z, *et al*. Sources and identification technology of microplastics in soil. Soil and Environmental Health. 2023:100019.
4. Goswami D. Earthworm-microbiome interactions: Unlocking next-generation bioindicators and bioengineered solutions for soil health. Journal of Entomology and Zoology Studies. 2025;13(4):92-101.
5. Gupta S, Kumar S. Earthworms as biological tools for assessing soil pollutants. Environment and Ecology. 2024;42(4C):2004-2014.
6. Hendrix PF, Bohlen PJ. Exotic earthworm invasions in North America: Ecological and policy implications. BioScience. 2002;52(9):801-811.
7. Julka JM, Paliwal R. Distribution of earthworms in different agro-climatic regions of India. In: Soil Biodiversity, Ecological Processes and Landscape. Oxford and ABH Publications. 2005:3-13.
8. Kooch Y. Earthworms, ecological processes, and climate change. In: Earthworms and Ecological Processes. Springer. 2024:121-150.
9. Latifi F, Musa F, Musa A. Heavy metal content in soil and their bioaccumulation in earthworms (*Lumbricus terrestris* L.). Agriculture and Forestry. 2020;66(1).
10. Phillips HRP, Bach EM, Bartz MLC, *et al*. Global data on earthworm abundance, biomass, diversity and environmental properties. Scientific Data. 2021;8:136.
11. Raj L, Sharma A, Sankhla MS, *et al*. The effects of heavy metal on earthworm and nutrient status of vermicompost. In: The Green Revolution: Building Sustainable Solutions. Springer. 2025:71-83.
12. Sharma RK, Poonam B. Earthworm diversity in trans-gangetic habitats of Haryana, India. Research Journal of Agriculture and Forestry Sciences. 2014;2(6):1-6.
13. Singh J, Schädler M, Demetrio W, Brown GG, Eisenhauer N. Climate change effects on earthworms: A review. Soil Organisms. 2020;91(3):114-138.
14. Singh S, Sharma A, Khajuria K, Singh J, Vig AP. Soil properties change earthworm diversity indices in different agro-ecosystems. BMC Ecology. 2020;20(1):1-14.
15. Suthar S. Earthworm biodiversity in western arid and semiarid lands of India. The Environmentalist. 2011;31(1):74-86.
16. Torppa KA, Castaño C, Glimskär A, *et al*. Soil moisture and fertility drive earthworm diversity in north temperate semi-natural grasslands. Agriculture, Ecosystems and Environment. 2024;362:108836.
17. Vaidya VV. Investigating the accumulation patterns of heavy metals in earthworms and their implications for environmental health management. IJRAR Journal. 2022.
18. Van Groenigen JW, Lubbers IM, Vos HM, Brown GG, De Deyn GB, Van Groenigen KJ. Earthworms increase plant production: A meta-analysis. Scientific Reports. 2014;4(1):6365.
19. Verma F, Singh S, Singh J, Dhaliwal SS, Parkash C. Assessment of earthworm community structure in industrial and non-industrial soils. Asian Journal of Biological and Life Sciences. 2021;10(1):183-190.
20. Yadav R, Kumar R, Gupta RK, Kaur T, Yodha K, Kour A, *et al*. Heavy metal toxicity in earthworms and its environmental implications: A review. Environmental Advances. 2023:100374.