



Distance Gradient Effects of Coal Mining on Tree Composition and Forest Structure of Pasan Range of Katghora Forest Division, Chhattisgarh, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study investigates the impact of mining-related disturbances on forest structure and biodiversity in tropical dry deciduous forests within the Katghora Forest Division of Chhattisgarh, India. Vegetation sampling was carried out across four zones situated at increasing distances from a coal mining site to assess variations in species composition, diversity, and structural attributes. Sixty species and 3,007 individual trees were recorded and analyzed using ecological indices, including the Shannon-Wiener Index, Simpson's Dominance and Diversity Indices, Pielou's Evenness, and Margalef's Richness Index. Results revealed a gradient in forest conditions. Zone I

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(nearest to the mining site) showed the highest species richness but the lowest basal area, suggesting early successional stages with high disturbance. In contrast, Zone IV (farthest from the mine) exhibited higher basal area, evenness, and diversity, indicative of a more mature and stable forest. One-way ANOVA confirmed significant differences in ecological parameters across zones. The findings highlight the adverse effects of mining on forest ecosystems and underscore the need for restoration and conservation efforts to maintain ecological resilience in disturbed landscapes.

Keywords: *Diversity; indices; ecological; anthropogenic; mining; biodiversity.*

1. INTRODUCTION

Mining plays a vital role in the economic development strategies of countries rich in mineral resources (Unanaonwi & Amonum, 2017). In particular, surface mining involves the removal of rocks, soil, and vegetation to access underlying mineral deposits (Nayak, 2010). This process often contributes significantly to global carbon dioxide (CO₂) emissions due to the deforestation and degradation of forest ecosystems that accompany mineral extraction. Forests are essential for maintaining biodiversity, controlling hydrological cycles, and storing carbon in the atmosphere (FAO 2020). Tropical forests contain the highest levels of species richness and are home to almost two-thirds of Earth's terrestrial biodiversity (Barlow et al. 2021, Sagar et al., 2003). Tropical dry deciduous forests predominate in most of central India, including Chhattisgarh state, where forests occupy over 44% of the land area (Negi et al., 2015). These forests are especially significant because they provide livelihoods for communities that depend on them, operate as carbon sinks, support a diverse range of plants and animals, and control the hydrological cycle. In regions like Katghora Forest Division in Korba district, increasing anthropogenic pressures such as coal mining have significantly altered natural forest structures. The transformation of land for mining and industrial use leads to habitat loss, fragmentation, and a decline in tree species diversity and regeneration potential (Neeraja et al., 2021). Comparative assessments of forest ecosystems along disturbance gradients have consistently shown shifts in species composition, structure, and reduced floristic diversity with increasing disturbance intensity (Sagar et al., 2003). For example, studies conducted in dry tropical forests have demonstrated a marked decline in species richness and uneven distribution of trees in areas exposed to frequent anthropogenic activities such as logging, fire, grazing, and mining (Negi et al., 2015; Neeraja et al., 2021). These pressures not only reduce biodiversity but also

affect ecological resilience and the ability of forests to recover from degradation.

Understanding how mining and other disturbances affect forest dynamics is essential for developing effective conservation strategies and rehabilitation frameworks in tropical regions. Monitoring tree population structure, composition, and diversity can provide critical insights into the ecological health of the forest and guide restoration efforts in degraded landscapes such as Katghora.

Sarma et al. (2010) conducted a comprehensive study to assess the impact of coal mining on plant diversity and tree population structure in the Jaintia Hills district of Meghalaya, India. The study compared mined and unmined areas across a 400 km² coal belt using distance-gradient sampling and vegetation analysis. He found a sharp decline in tree species richness (27 to 3–11 species) and density (1040 to 515–646 stems/ha), while herbaceous species increased (23 to 31–41 species) due to habitat disturbance. The study highlights the need for regulated mining and ecological rehabilitation to restore vegetation structure. By comparing the vegetation characteristics of disturbed and undisturbed forest areas, Mondal et al. (2020) examined the effects of coal mining on tree diversity in the Raniganj coalfield region of West Bengal, India. They discovered that there were fewer tree species in the disturbed areas—13 species (8 families) compared to 19 (12 families) in the undisturbed areas—and that the species richness (2.623) and evenness (1.985) were lower in the disturbed zones. Sorenson's similarity index was only 31.25%, and the Shannon-Weaver diversity index decreased, suggesting that mining had significantly changed the composition of the forest. Dubey & Dubey (2011) explored the ecological impacts of coal mining on forest fragmentation and species diversity in the dry tropical forests of Central India, using a gradient-

based study design across three zones: near mining zone (NMZ), intermediate zone (IMZ), and far zone (FZ). Their results highlighted a significant loss of biodiversity and structural degradation in forests closest to mining activities.

Given the ecological importance of tropical dry deciduous forests and the increasing anthropogenic pressures—particularly mining-related disturbances—in the Katghora Forest Division, it becomes crucial to assess how these activities influence forest composition and diversity. The present study is therefore designed to assess and compare tree species distribution patterns across a distant gradient of mining-induced disturbance.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in the Pasan range of the Katghora Forest Division, located in the Korba District of Chhattisgarh, central India. This region is characterized by tropical dry deciduous forests dominated by species such as *Tectona grandis*, *Terminalia tomentosa*, *Diospyros melanoxylon*, and *Lagerstroemia parviflora*. The study area is situated at approximately 22.84° N latitude and 82.31° E longitude, with an average elevation of around 325 meters above sea level. The terrain mixes undulating hills, plateaus, and plains interspersed with dense, degraded forest patches. The study region experiences a tropical monsoon climate characterized by three distinct seasons. During the summer months (March to June), temperatures typically range from 30°C to 46°C, accompanied by relatively low humidity. The monsoon season (July to September) brings the majority of the annual precipitation, with rainfall averaging between 1200 mm and 1600 mm, predominantly influenced by the southwest monsoon. Winter (November to February) is marked by cool and dry conditions, with temperatures generally fluctuating between 10°C and 25°C. The forest has seen increasing fragmentation due to coal mining, road expansion, and other land-use changes. The focus area includes the regions surrounding the Vijay West Coal Mine and nearby forested villages, which experience varying degrees of anthropogenic disturbances due to mining activities.

Four sites were selected based on the distance from the mining site: Zone I, II, III and IV located at 1, 2, 5 and 10 km from coal mining zone respectively. Each site type included four replicates in each direction, leading to sixteen sampling locations. Each sampling location has nested quadrat. Vegetation sampling was conducted using 31.62 m × 31.62 m quadrats (0.1 ha) with ≥20 cm GBH. Regional floras and standard literature were used to identify the representative taxa gathered during the field study (Krishen, 2013). Data on height, abundance, and girth at breast height (GBH) were documented of each individual.

2.2 Data Analysis

The collected data were analyzed using the following ecological indices and statistical tools:

Species Richness (S) and Shannon-Wiener Diversity Index (H'): To assess species diversity across disturbance gradients.

$$\text{Shannon - Wiener (H')} = - \sum p_i \times \ln p_i \quad \text{Eq. (1)}$$

Simpson's Index of Dominance (D): To determine species dominance in each site.

$$\text{Simpson's Diversity Index (D)} = \sum_{i=1}^S p_i^2 \quad \text{Eq. (2)}$$

$$\text{Simpson's Diversity Index (1-D)} = 1 - \sum_{i=1}^S p_i^2 \quad \text{Eq. (3)}$$

Pielou's Evenness Index (E) (Pielou, 1975) takes rare species into account.

$$\text{Pielou's Evenness Index (E)} = \frac{H'}{\ln(S)} \quad \text{Eq. (4)}$$

Margalef's Richness Index (d) to quantify species richness, accounting for the number of species and individuals:

$$\text{Margalef's Richness Index (d)} = \frac{S-1}{\ln(N)} \quad \text{Eq. (5)}$$

Basal Area (m²/ha): Calculated from GBH data to assess forest structure.

$$\text{BA} = 0.00007854 \times \text{DBH}^2 \quad \text{Eq. (6)}$$

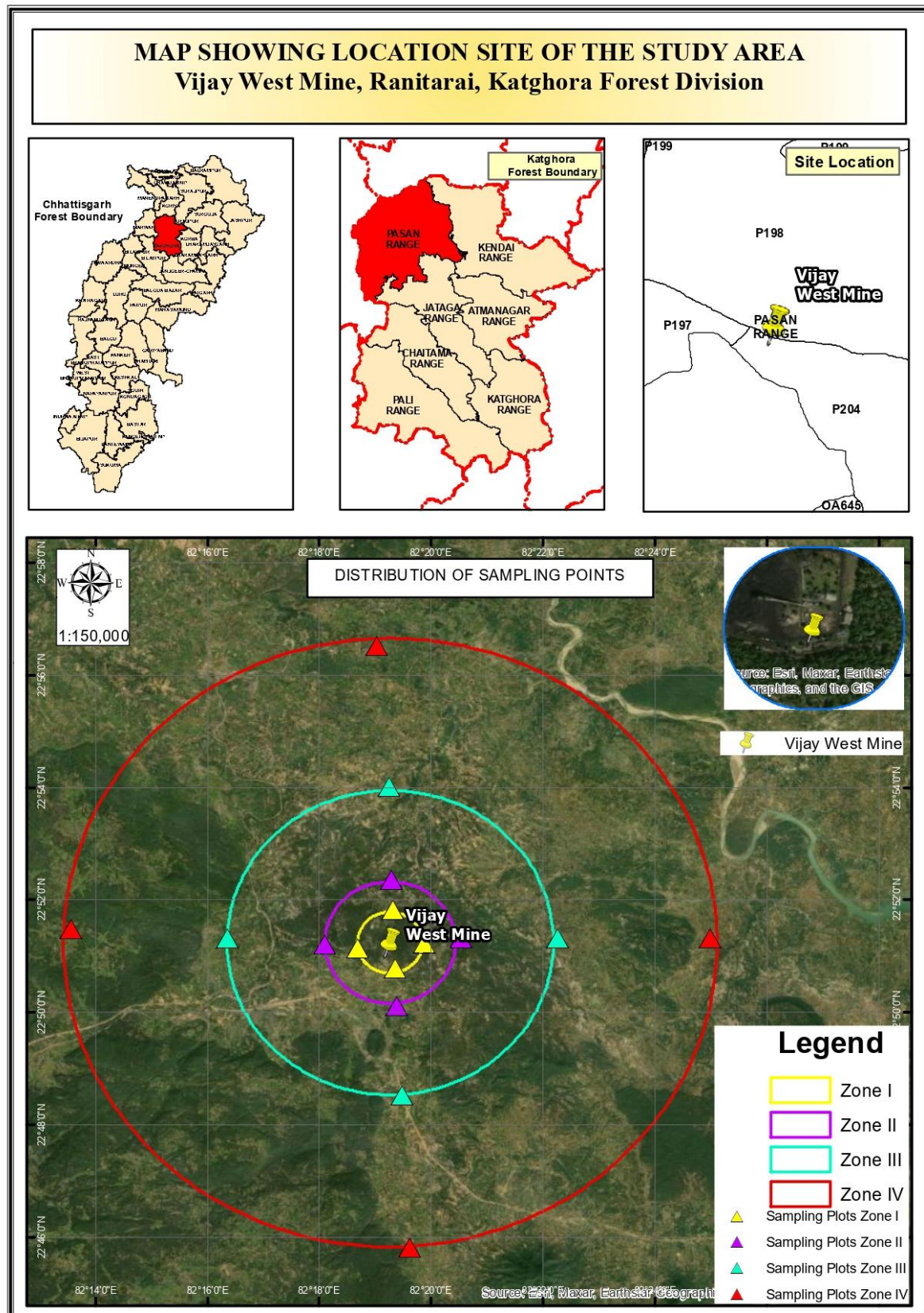


Fig. 1. Study Area

3. RESULTS AND DISCUSSION

A comparative analysis of floristic diversity and structural parameters was conducted across four zones at increasing distances from the mining site. Zone I was the nearest and Zone IV the farthest. A gradient in species richness, diversity, and stand structure was observed, suggesting varying degrees of anthropogenic disturbance. The variations in species composition could be primarily linked to the mining operations because the mined nearby areas were situated at similar climatic, edaphic, and physiographic parameters (Jha and Singh 1990).

The observed variation in species richness, diversity, and forest structural attributes across the four zones provides strong evidence for a clear ecological gradient driven by proximity to mining activities. This gradient reflects not only the spatial influence of disturbance but also the successional trajectory of the forest ecosystem in response to anthropogenic stressors.

Margalef's Richness Index (5.52) and species richness ($S = 37$) were highest in Zone I, which was closest to the mining activity. A more thorough ecological analysis reveals a different reality, despite the initial suggestion of a very bio

diverse environment. Zone I has the lowest basal area ($13.42 \text{ m}^2 \text{ ha}^{-1}$) despite this richness, suggesting that the forest is primarily made up of smaller and probably younger individuals. The classification of this area as a regenerating or early successional forest is further supported by the preponderance of trees in the lower DBH classes (20–40 cm). In disturbed ecosystems, where fast-growing, opportunistic, or pioneer species quickly occupy open niches generated by habitat disruption, this paradox of high richness but low structural complexity is common (Chazdon et al. 2003; Meyer et al 2021). The establishment of climax species and the development of complex forest structures are hampered by mining activities, which frequently result in extensive deforestation, soil compaction, and microclimatic changes (Bian & Lu, 2013; Jafari et al., 2022; Jentsch et al. 2022). Similar trends have been observed in the Amazon region of Peru. Pioneer species predominated at mining-affected areas, according to Kaushal & Baishya (2021); Bury & Dyderski (2025), which resulted in exaggerated species counts but poor biomass and basal area. These results are consistent with the trends seen in Zone I and imply that diminished ecosystem maturity and halted forest development are related to mining proximity.

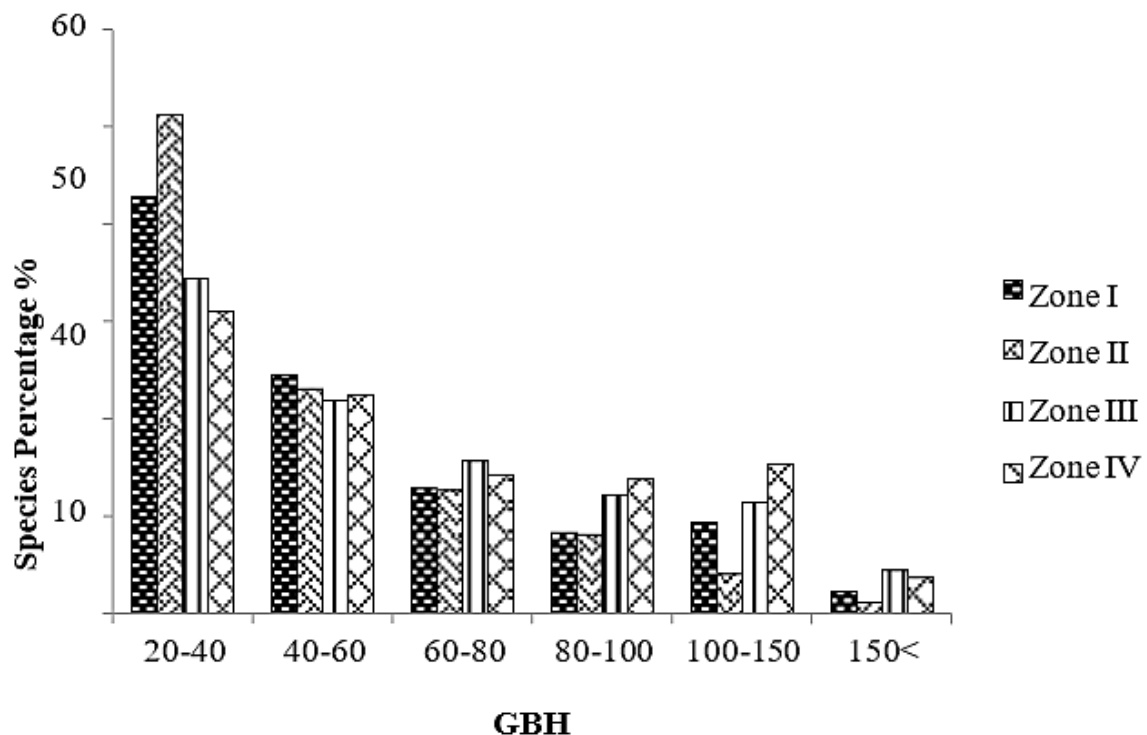


Fig. 2. Percentage of species composition of different girth

Table 1. Diversity indices of different zones of the study area

Index	Zone I	Zone II	Zone III	Zone IV
Total Species (S)	37	32	25	28
Total Individuals (N)	677	706	831	793
Basal area (m ² ha ⁻¹)	13.42	16.94	22.35	22.88
Shannon-Wiener Index (H')	2.6319	2.4156	2.3115	2.5580
Simpson's Dominance Index (D)	0.1095	0.1317	0.1335	0.0979
Simpson's Diversity Index (1 - D)	0.8905	0.8683	0.8665	0.9021
Pielou's Evenness (E)	0.7289	0.697	0.7181	0.8690
Margalef's Richness Index	5.5234	4.7260	3.5700	4.0444

Zone IV, the location most far from the mining influence, displayed notably distinct biological features at the other end of the gradient. This zone has the highest basal area (22.88 m² ha⁻¹), Simpson's Diversity Index (1 - D = 0.9021), and evenness (E = 0.8690), despite having a lower total species richness (S = 28). These measurements point to a better developed and ecologically balanced forest structure where no species dominates the community. This change in structural and compositional characteristics is in line with trends seen in late-successional or undisturbed forests, where resource partitioning permits greater functional diversity and slower-growing, shade-tolerant species predominate (Laurance et al., 1998; Dislich 2011; Wilfahrt, 2016). Greater basal area and bigger trees in Zone IV suggest a longer duration of ecological stability and less human influence. According to Rosa et al. (2021), these intact regions in Brazil's Atlantic Forests have higher ecological resilience and structural integrity despite occasionally having fewer species. To sustain ecosystem services like nutrient cycling, carbon storage, and habitat provision, these systems depend more on functional diversity and balanced species composition than on the sheer number of species.

Between the severely disturbed Zone I and the less disturbed Zone IV, Zones II and III showed intermediate values for the majority of ecological parameters (tree density, basal area, species richness etc.). These zones, which show disturbed and recovering ecosystem traits, are probably in an ecological, structural, and compositional transition. Interestingly, Zone III exhibited the lowest species richness and diversity indices despite recording the greatest number of individuals (N = 831). This points to the phenomena known as density compensation, in which the abundance of a small number of tolerant species increases to compensate for the loss of species diversity. Degraded secondary forests frequently exhibit this pattern, with a

small number of generalist or disturbance-adapted species monopolising ecological niches (Pardini et al. 2017). This situation is similar to findings from tropical forests in Southeast Asia, where Hughes (2017) reported high stem densities in forests that had been somewhat disturbed. They also found that the dominance of a few number of fast-growing and competitive species had reduced species diversity. The consequences are substantial: biodiversity and ecological functionality may continue to be in danger even though forest cover may appear to recover.

A fundamental ecological concept is shown by the general pattern observed in all zones: the severity of mining impacts decreases as one gets farther away from the source of the disturbance. A successional process influenced by human pressure is suggested by the gradient from high richness but low structure (Zone I) to reduced richness but higher structural maturity (Zone IV). Forest resilience is undermined by mining, which has long been identified as a primary cause of habitat fragmentation, soil degradation, hydrological modification, and microclimatic disruption (Timms 2023; Tannor., 2024). Similar spatial gradients were documented by Brandt et al. (2013) in Canadian boreal forests, where zones close to mineral extraction demonstrated sharp declines in biodiversity as a result of extensive canopy and soil disturbances. These impacts on forest systems next to extractive industries are not unique; rather, they are part of a global trend. According to McDowell & Potter (2022), the kind of forest, the severity of the disturbance, and the biological history of the site all affect how quickly a site recovers from such disturbances. Restoration must therefore be customised to the biophysical characteristics and degradation routes of each impacted site.

The study's conclusions directly affect conservation planning and forest management in

areas affected by mining. Zones nearer the mining front in the early successional stages need to be treated right away to stop biodiversity loss and long-term degradation. Planting trees and restoring native species composition, functional diversity, and structural complexity should be the top priorities of restoration projects. Reforested transition zones and conserved remnant patches are examples of ecological buffers that can be essential for soil regeneration, microclimate stabilization, and species dispersal. These tactics have worked well in post-mining settings in South America; Griscom and Ashton (2011) showed that restoration projects that used pre-existing forest pieces and soil amendment techniques boosted regeneration. In addition, Bernard- Jannin et al. (2017) make the case for comprehensive ecological restoration frameworks that guarantee the complete reassembly of ecosystem processes, going beyond biomass recovery. To address continuous ecological changes, this entails combining long-term monitoring, adaptive management, and local ecological expertise.

The geographical distribution of species diversity, richness, and structural characteristics throughout the zones under study provides a convincing illustration of ecological gradients brought about by mining. The fragility of such biodiversity is highlighted by the damaged zones' low ecological stability and structural immaturity, even if species richness may first seem high there. On the other hand, ecologically balanced and structurally complex communities that are indicative of greater forest health and resilience are supported by more remote and less disturbed zones. A workable solution to lessen the long-term ecological effects of mining and encourage sustainable forest recovery is targeted restoration, which is informed by ecological principles and actual data. To track developments and improve restoration tactics suited to the particular circumstances of post-mining landscapes, further investigation and observation will be necessary.

4. CONCLUSION

This study reveals the notable biological differences in biodiversity and forest structure along a disturbance gradient brought on by mining operations. The findings show that Zone I, the areas nearest to the mining site, has lower structural maturity but higher species richness, indicating an environment dominated by early successional species and impacted by frequent

disruptions. On the other hand, Zone IV, which is the area furthest away from the mining site, has larger basal area, more balanced species distribution, and more structural complexity—all of which are signs of more established and stable forest ecosystems. With modest species richness and diversity values, the intermediate zones (Zones II and III) had transitional features and highlighted a gradient of ecological recovery or degradation affected by the level of anthropogenic impact. The impact of the mining ecological footprint is spatially extensive, as evidenced by its decreasing influence with distance from the mining site. These results highlight the critical need for ecological restoration and conservation measures close to mining areas. Reforestation initiatives employing native species, habitat establishment, and efficient land-use planning may all aid in reducing the negative effects of mining and promoting forest regeneration. To fully evaluate ecosystem health and recovery paths, future studies should concentrate on long-term monitoring and incorporate soil quality, faunal diversity, and regeneration dynamics.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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