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Quantitative Assessment of Vegetation Dynamics through Species Composition and Diversity Indices in Restoring Nandini Limestone Mines, Chhattisgarh

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ABSTRACT

The study was conducted in the year 2023–24 for a duration of one year at Nandini Limestone Mines, District- Durg, Chhattisgarh, India with the objective to gather information about the floral diversity and to enable the presence or likely presence of components of flora before planning, conservation management, and development decisions for the specific area of land as mining activities have altered the land use patterns, leading to significant soil degradation and creating challenging conditions for plant growth. However, some plant species adapt well to these conditions and support ecological restoration. Studying such species is crucial for biodiversity conservation and effective land management in degraded areas. The baseline biodiversity survey with random quadrate sampling method was adopted in 25 different quadrats for vegetation analysis which resulted in the identification of a total of 136 species of terrestrial flora including 48 species of trees, 51 species of herbs and shrubs, 7 species of climbers, and 30 species of grasses. The Shannon-wiener index for tree species was 3.583, other diversity indices namely; Simpson's index, Simpson's index of diversity, Simpson's reciprocal index, Evenness, and Margalef richness index were calculated at 0.034, 0.966, 29.412, 0.926 and 7.2845 respectively. The highest Family Importance Value Index (FIVI) was observed as 54.82 for the Fabaceae family whereas the highest Importance Value Index (IVI) was observed for *Dalbergia sissoo* Roxb. (IVI 20.54). The biodiversity index for other vegetation structures is 3.234, 2.976, and 1.242 for herbs/ shrubs, grasses, and climbers respectively.

KEYWORDS: Flora diversity, mining, vegetation, degradation, biodiversity, limestone

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Despite the tremendous impact of limestone mining activities on the economic growth of Chhattisgarh and India, its negative impact on biodiversity is of great environmental concern. Mining activities not only disrupt natural landscapes but also influence vegetative communities (Maharana and Patel, 2013, Shah et al., 2021) altering various ecosystem functioning. The environmental impacts of mining activities are extensive (Lin et al., 2004), which leads to disturbed geomorphic system (Rajan et al., 2010, Patil et al., 2024) through alterations in microbial mineralization and decomposition of organic matter (Kardol et al., 2006) that causes problems for pedogenesis and revegetation (Pandey and Maiti, 2008) through generation of limestone mine overburden spoil. On these mine spoils process of natural succession is very slow due to adverse physicochemical properties of mine spoils (Maitry et al., 2024). Mine spoils soil is deficient in various macro and micro nutrient content especially organic carbon, available nitrogen, and available phosphorus which is essential for plant growth as well as metabolism (Murguía et al., 2016). In search of the solution, sustainability in limestone mining may be achieved by developing and integrating practices that lower the impacts of mining on the environment (Saini et al., 2016) which can be achieved through vegetation development studies in the area.

The study of biological diversity involves a participatory approach requiring intensive and extensive knowledge of flora and fauna (Jaiswal and Patil, 2020, Maitry et al., 2023). Floral diversity refers to the variety of plants found in a given region at a given time (Thakur et al., 2020, Haq et al., 2021, Mexudhan et al., 2024). It generally refers to the variety of indigenous or native plants that occur naturally and their studies are prior to the making of planning, conservation management and development decisions for the degraded land areas (Biswas et al., 2021, Daipan et al., 2023). In the context of limestone mining areas, the re-establishment of native flora can help accelerate soil recovery by enhancing microbial activity, organic carbon content, and nutrient cycling processes (Ali et al., 2022). Native species, adapted to the local climatic and soil conditions, are more likely to survive and thrive in nutrient-deficient soils, contributing to the stabilization of the ecosystem (Sonter et al., 2018). The incorporation of vegetative cover not only improves soil fertility but also mitigates adverse effects such as erosion, water loss, and habitat fragmentation (Sakhre et al., 2024). Ultimately, the findings from floral diversity assessments can inform the development of site-specific restoration plans aimed at enhancing ecosystem resilience and functionality (Baruah et al., 2013). Through adaptive management practices, limestone mining areas can be rehabilitated to support both ecological balance and sustainable livelihoods for local communities, aligning with broader environmental conservation goals (Kumar et al., 2014). Hence, the main objective of the study is to understand the vegetation dynamics of the area through random quadrate sampling method which helps in obtaining information about the floral species composition and diversity of the mining area and develop future restoration management plans. By integrating soil amelioration, native species planting, and adaptive management, limestone mining areas can be transformed into productive ecosystems, contributing to biodiversity conservation and the sustainable use of land resources (Kumar et al., 2014). Such efforts align with global commitments to restore degraded lands under initiatives like the Bonn Challenge and the United Nations Decade on Ecosystem Restoration (Maitry et al., 2023).

2. MATERIALS AND METHODS

2.1. Study site

The study was conducted during the year 2023–24 at Nandini Limestone Mines which is located in Dhamdha, District- Durg of Chhattisgarh State, India. The total area of mine is distributed in 970 hectares located between Latitude N 21° 22' 25.56" to N 21° 25' 04.1" and Longitude E 81° 22' 01.2" to E 81° 23' 01.88" in which about 350 hectares is covered by core mined zone, about 600 hectares is covered by outer buffer zone and rest with infrastructural developments (Figure 1). It comprises of various water bodies, large stratified woody clusters and small grassland areas. The maximum elevation of the site is about 284 meters from mean sea level. The general ground slope is towards N, with gradient about 5°. During the survey period of 60 days, the average temperature ranged from 39°C (maximum) to 28°C (minimum) and average rainfall about 240 mm with 21 rainy days. The mean relative humidity was found to be ranging from 35–65.5%. The pH of surface water was slightly alkaline due to the presence of limestone.

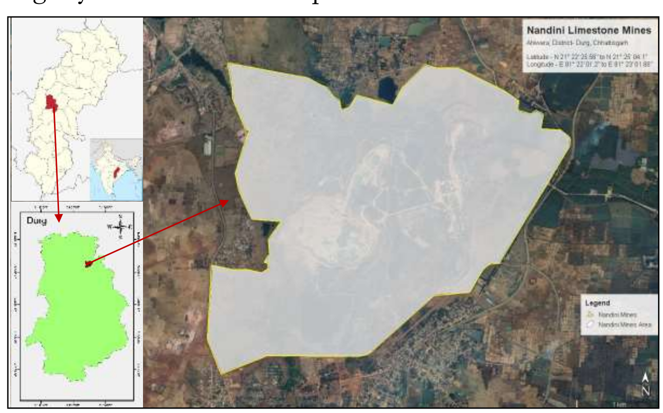

Figure 1: Geographical location of Nandini Limestone Mines (970 hectares) in Durg, Chhattisgarh

2.2. Methodology of data collection

The stratified random quadrate sampling approach was followed for quantitative assessment of floral species in the present study. Sampling was done in all the strata i.e., trees, herbs, shrubs and grasses. The size of the quadrat for sampling of trees, shrubs and grass was determined by species-area-curve method (Mueller- Dombois and Ellenberg, 1974; Misra, 1968). A 10×10 m quadrat for trees (>30 cm dbh), two 5×5 m quadrats for shrubs and climbers and four 1×1 m quadrats for herbs and grasses were laid at each sample site. As such, a total of 25 quadrats were randomly laid throughout the study site to quantify floral biodiversity and tree composition (Figure 2).

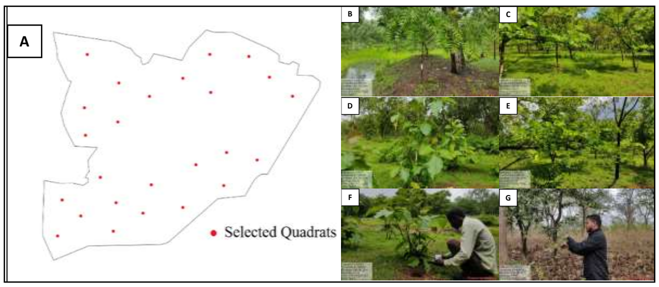

Figure 2: (A) Randomly selected 25 quadrats in the study site to quantify floral biodiversity and tree composition, (B-G) Assessment of Species Composition and Diversity in different quadrates installed at Nandini Limestone Mines, Chhattisgarh

The dominance of the plant species was determined using the Importance Value Index (IVI) of tree species which is the sum of relative density (RD), relative frequency (RF) and relative dominance (RDo) (Misra, 1968) and the Family Importance Value Index (FIVI) of an individual family was determined by summing up relative density (RD), relative dominance (RDo) and relative diversity (RDi), where relative diversity is number of species of family i/ total number of species (Mori et al. 1983). Vegetation composition was evaluated by analysing the frequency, density, abundance, and IVI, using the following formula given by Mishra (1968) and Curtis and McIntosh (1951):

Frequency=(Total no.of quadrats in which the species occured/Total no.of quadrats studied)×100 ....(1)

Relative Frequency%=(Frequency of a species/Frequency of all species)×100 ....(2)

Density= (Total no. of individuals of a species/Total no. of quadrats studied) ....(3)

Relative Density%=(Number of individuals of a species/ Number of individuals of all species)×100 ....(4)

Abundance=Total no.of individuals of a species/Total no.of quadrats in which the species occured ....(5)

Relative Dominance%=(Basal area of a species/Basal area of all species)×100 ....(6)

Basal cover is considered as the portion of ground surface occupied by a species (Greig-Smith, 1983). Basal area measurement was based on the following formula:

Total Basal Cover (TBC)=Mean basal area of a species× density of that species ....(7)

Mean Basal Area (MBA)=$C^2/(4\times\pi^2)$...........................(8)

where C is the average circumference of one individual of that species, and MBA is expressed as cm^{-2} $plant^{-1}$ (Mishra, 1968).

IVI (Importance Value Index)=RD+RF+RDo ....(9)

FIVI (Family importance value index)=RD+RDo+RDi ..(10)

In accordance to the recent study be Mexudhan et al. (2024), diversity indices for trees like species diversity (H') was calculated by using the Shannon-wiener index (Shannon and Weaver, 1949); Concentration of Dominance (D) was calculated through Simpson's index (Simpson 1949); Species Richness (R) by Margalef's index (Margalef, 1968) and Species Evenness (E) by (Pielou, 1966) respectively.

$H\hat{}'=-\sum^{S}_{i=1}$ (pi lnpi) ....(11)

$D=\sum^{S}_{i=1}(pi)^2$ ....(12)

R = S-1/ln (N) ....(13)

E = H'/H^{max} ....(14)

Where,

S=The number of species (species richness)

ln=Natural log

pi=The relative abundance of each species *(ni/N)*

ni =Total number of a particular *(ith)* species

N=The total number of individuals of all species

H^{max}=ln (S)

2.3. Statistical analysis

All the statistical calculations including standard diversity parameters and correlation analysis were performed using Microsoft Excel 2021 statistical program. The scatterplot matrix and Hierarchical Cluster Analysis (HCA) were performed using SPSS (Version 25).

3. RESULTS AND DISCUSSION

3.1. Species composition and diversity indices

The floristic survey conducted in the Nandini Limestone Mines revealed a diverse range of plant species distributed across various strata including trees, herbs, shrubs, and grasses. A total of 136 species were identified: 48 tree species of 20 families, 51 herb and shrub species, 7 climber species, and 30 grass species (Figure 3) in the study site. The vegetation analysis employed random quadrate sampling in 25 different quadrats, which provided comprehensive data on species composition and diversity. The key findings of the tree species from the study includes the Shannon-Wiener diversity index (H') which was calculated to be 3.583. Other diversity indices calculated were Simpson's index (0.034), Simpson's index of diversity (0.966), Simpson's reciprocal index (29.412), Evenness (0.926), and Margalef richness index (7.2845). Also, the biodiversity index for other vegetation structures was recorded as 3.234, 2.976 and 1.242 for herb/shrubs, grasses and climbers respectively (Figure 4). The findings of this study underscore the importance of biodiversity in the Nandini Limestone Mines area and highlight the resilience of certain plant species to the adverse conditions created by mining activities. The high species richness and diversity indices suggest that despite the environmental stressors (Mayfield, 2010), the area supports a robust and varied plant community justifying the restoration efforts.

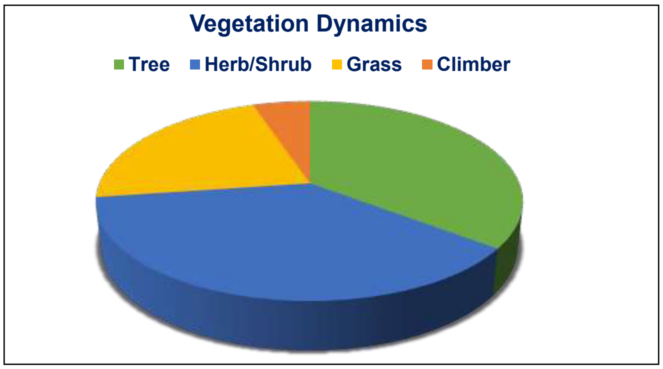

Figure 3: Vegetation dynamics of different flora categories studied in Nandini Limestone Mines

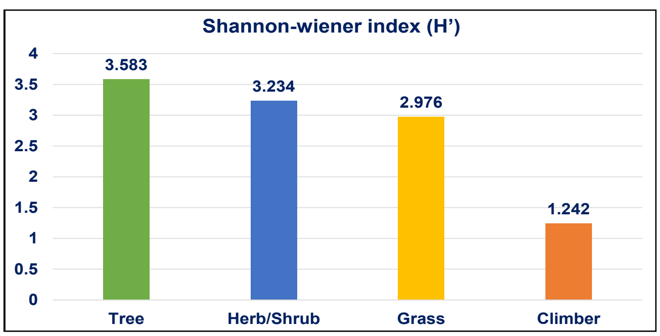

Figure 4: Diversity index (H') of different flora categories studied in Nandini Limestone Mines

3.2. *Diversity assessment of tree species*

Table 1 indicates the most dominant tree species, based on Importance Value Index (IVI), included *Dalbergia sissoo* Roxb. (IVI 20.54), *Azadirachta indica* A. Juss (IVI 18.04), *Tectona grandis* Linn. f. (IVI 16.86), and *Albizia procera* (Roxb.) Benth. (IVI 13.41). The presence of species with high Importance Value Indexes, such as *Azadirachta indica* A. Juss and *Albizia procera* (Roxb.) Benth., indicates their significant role in the ecosystem, potentially providing stability and supporting other plant and animal life (Parrotta, 1999). These species may offer critical ecosystem services, such as soil stabilization, microclimate regulation, and habitat for wildlife (Dhyani et al., 2009). The success of certain species in colonizing and thriving in mined areas suggests potential candidates for reforestation and land reclamation projects. For instance, species like *Dalbergia sissoo* Roxb. and *Tectona grandis* Linn. f., with their high IVI, could be prioritized in restoration efforts due to their proven adaptability and ecological importance in different ecosystems (Nand, 1999; Tewari, 1995). Similar to the research findings of Shah et al. (2022), the highest family importance value index (FIVI) was observed as 54.82 for Fabaceae family also having highest number of genus and species i.e. 15 and 16 respectively, followed by Combretaceae (17.52) and Lamiaceae (15.03) whereas the lowest FIVI was observed as 0.78 for Annonaceae and 1.16 for Myrtaceae family.

3.3. *Diversity assessment of herb and shrub species*

Also, the survey of herb and shrub species revealed a diverse array of plant life, contributing significantly to the overall biodiversity of the area. Notable species included *Justicia glauca* (Forssk.) Vahl, *Calotropis gigantea* (L.) Dryand., and *Asparagus racemosus* Willd. (Table 2). These species, despite harsh conditions, have adapted well and contribute to the ecological restoration by improving soil quality and providing cover for other plants and animals (Purohit and Vyas, 2004). Moreover, the diversity of herb and shrub species contributes to the structural complexity and functional diversity of the ecosystem (Ranjan et al., 2015; Kashyap et al., 2014). This layer of vegetation plays a crucial role in nutrient cycling, soil formation, and providing food and habitat for a variety of organisms (Myers et al., 2000; Sundarapandian and Swamy, 1999).

3.4. *Diversity assessment of grass and climber species*

Grasses play an essential role in the initial stages of land reclamation by stabilizing soil and reducing erosion. The dominant grass species identified includes *Cynodon dactylon* (L.) Pers., *Brachiaria mutica* (Forssk.) Stapf, *Cenchrus pedicellatus* (Trin.) Morrone and *Echinochloa colona* (L.) Link (Table 3). The presence of these grasses indicates successful soil stabilization efforts, which is a critical first step in ecological restoration (Njarui et al., 2016). The outcome indicates that the flora in the Nandini Limestone Mines area is diverse and includes several species including climbers (Table 4) capable of thriving in the challenging conditions posed by the mining activities. The diversity indices reflect a healthy ecosystem with a high level of species richness and evenness (Montagnini and Jordan, 2005).

Table 1: Quantitative data of tree species observed in Nandini Mines with their IVI and FIVI

Sl. No.	Family	Scientific name	RD	RF	RDo	IVI	FIVI
1.	Anacardiaceae	*Mangifera indica* Linn.	1.26	1.34	0.94	3.54	11.18
2.		*Semecarpus anacardium* Linn. f.	1.42	1.34	1.19	3.95	
3.	Annonaceae	*Annona reticulata* Linn.	0.47	0.45	0.29	1.21	0.78
4.	Arecaceae	*Borassus flabellifer* Linn.	0.16	0.45	0.20	0.80	3.08
5.		*Roystonea regia* (Kunth) O.F.Cook	0.32	0.89	0.47	1.67	
6.	Boraginaceae	*Cordia dichotoma* G.Forst.	0.95	0.89	0.45	2.29	1.42
7.	Combretaceae	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	3.79	2.68	6.20	12.67	17.52
8.		*Terminalia bellirica* (Gaertn.) Roxb.	2.84	2.68	2.93	8.45	
9.	Ebenaceae	*Diospyros melanoxylon* Roxb.	1.89	1.79	1.72	5.39	3.63
10.	Fabaceae	*Acacia auriculiformis* A.Cunn. ex Benth.	0.95	0.89	0.46	2.30	54.82*
11.		*Albizia procera* (Roxb.) Benth.	4.42	4.46	4.53	13.41	
12.		*Bauhinia variegata* Linn.	3.47	3.57	2.10	9.14	
13.		*Butea monosperma* (Lam.) Taub.	1.26	1.34	0.88	3.48	
14.		*Cassia fistula* Linn.	1.89	1.79	1.20	4.88	
15.		*Dalbergia sissoo* Roxb.	7.57	7.14	5.83	20.54*	
16.		*Delonix regia* (Bojer ex Hook.) Raf.	2.52	2.68	3.09	8.30	
17.		*Millettia pinnata* (Linn.) Panigrahi	1.89	2.23	1.43	5.55	
18.		*Peltophorum pterocarpum* (DC.) K.Heyne	2.05	2.23	2.11	6.39	
19.		*Pithecellobium dulce* (Roxb.) Benth.	1.10	1.34	1.11	3.55	
20.		*Pterocarpus marsupium* Roxb.	0.79	0.89	0.85	2.53	
21.		*Saraca asoca* (Roxb.) Willd.	0.63	1.34	0.77	2.74	
22.		*Senna siamea* (Lam.) H.S.Irwin & Barneby	0.47	0.45	0.43	1.35	
23.		*Senna spectabilis* (DC.) H.S.Irwin & Barneby	0.63	0.89	0.49	2.01	
24.		*Tamarindus indica* Linn.	2.84	2.68	3.87	9.39	
25.		*Vachellia nilotica* (Linn.) P.J.H.Hurter & Mabb.	4.26	4.46	4.39	13.12	
26.	Lamiaceae	*Gmelina arborea* Roxb. ex Sm.	3.31	4.02	2.63	9.96	15.03
27.		*Tectona grandis* Linn. f.	5.05	4.91	6.90	16.86	
28.	Leguminosae	*Acacia catechu* (Linn. f.) Willd.	4.10	3.57	5.24	12.91	9.36
29.	Malvaceae	*Bombax ceiba* Linn.	2.52	3.13	2.55	8.19	5.09
30.	Meliaceae	*Azadirachta indica* A.Juss.	5.99	5.36	6.69	18.04	12.71
31.	Moraceae	*Artocarpus heterophyllus* Lam.	0.47	0.89	0.55	1.92	4.54
32.		*Ficus benghalensis* Linn.	0.32	0.89	0.98	2.19	
33.		*Ficus nota* (Blanco) Merr.	0.16	0.45	0.28	0.88	
34.		*Ficus racemosa* Linn.	0.32	0.45	0.51	1.27	
35.		*Ficus religiosa* Linn.	0.79	1.34	1.68	3.81	
36.	Moringaceae	*Moringa oleifera* Lam.	0.63	0.89	0.67	2.19	1.32
37.	Myrtaceae	*Psidium guajava* Linn.	1.26	1.34	0.76	3.36	1.16
38.		*Syzygium cumini* (Linn.) Skeels	2.84	3.13	3.64	9.60	
39.		*Eucalyptus globulus* Labill.	2.21	1.34	2.29	5.84	

Table 1: Continue...

Sl. No.	Family	Scientific name	RD	RF	RDo	IVI	FIVI
40.	Oleaceae	*Nyctanthes arbor-tristis* Linn.	2.05	1.79	1.44	5.28	3.51
41.	Phyllanthaceae	*Phyllanthus emblica* Linn.	4.89	3.57	3.33	11.79	12.77
42.		*Cleistanthus collinus* (Roxb.) Benth. & Hook.f.	2.68	1.79	2.39	6.86	
43.	Rhamnaceae	*Ziziphus mauritiana* Lam.	2.37	2.23	1.47	6.07	3.85
44.	Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	1.89	1.79	1.60	5.27	7.60
45.		*Neolamarckia cadamba* (Roxb.) Bosser	2.21	1.79	2.34	6.34	
46.	Rutaceae	*Aegle marmelos* (Linn.) Corrêa	1.89	1.34	2.18	5.41	6.49
47.		*Limonia acidissima* Linn.	1.10	1.79	0.88	3.76	
48.	Sapindaceae	*Schleichera oleosa* (Lour.) Merr.	1.10	1.34	1.12	3.56	2.24

Biodiversity Index of tree species H' = 3.583; *Species with highest IVI and family with highest FIVI.

Table 2: Checklist of herb and shrub species observed in Nandini Mines

Sl. No.	Family	Scientific name	Sl. No.	Family	Scientific name
1.	Acanthaceae	*Justicia glauca* (Forssk.) Vahl	27.	Fabaceae	*Senna obtusifolia* (L.) H.S.Irwin & Barneby
2.	Aizoaceae	*Trianthema portulacastrum* L.	28.	Fabaceae	*Sesbania aculeata* (Willd.) Pers.
3.	Apocynaceae	*Calotropis gigantea* (L.) Dryand.	29.	Fabaceae	*Tephrosia purpurea* (L.) Pers.
4.	Apocynaceae	*Calotropis procera* (Aiton) W.T.Aiton	30.	Hypoxidaceae	*Curculigo orchioides* Gaertn.
5.	Asparagaceae	*Asparagus racemosus* Willd.	31.	Lamiaceae	*Hyptis suaveolens* (L.) Poit.
6.	Asteraceae	*Ageratum conyzoides* L.	32.	Lamiaceae	*Leucas aspera* (Willd.) Link
7.	Asteraceae	*Crassocephalum crepidioides* (Benth.) S.Moore	33.	Lamiaceae	*Mesosphaerum suaveolens* (L.) Kuntze
8.	Asteraceae	*Cyanthillium cinereum* (L.) H.Rob.	34.	Loganiaceae	*Spigelia anthelmia* L.
9.	Asteraceae	*Parthenium hysterophorus* L.	35.	Malvaceae	*Corchorus aestuans* L.
10.	Asteraceae	*Tridax procumbens* L.	36.	Malvaceae	*Melanthera corchorifolia* (Retz.) Sch.Bip. ex B.D.Jacks.
11.	Balsaminaceae	*Impatiens balsamina* L.	37.	Malvaceae	*Sida acuta* Burm.f.
12.	Boraginaceae	*Trichodesma indicum* (L.) Lehm.	38.	Malvaceae	*Sida rhombifolia* L.
13.	Caesalpiniaceae	*Cassia tora* L.	39.	Malvaceae	*Urena lobata* L.
14.	Cleomaceae	*Cleome viscosa* L.	40.	Martyniaceae	*Martynia annua* L.
15.	Convolvulaceae	*Evolvulus alsinoides* (L.) L.	41.	Phyllanthaceae	*Flueggea virosa* (Roxb. ex Willd.) Voigt
16.	Convolvulaceae	*Evolvulus nummularius* (L.) L.	42.	Phyllanthaceae	*Phyllanthus urinaria* L.
17.	Euphorbiaceae	*Croton bonplandianus* Baill.	43.	Rhamnaceae	*Ziziphus oenoplia* (L.) Mill.
18.	Euphorbiaceae	*Croton glandulosus* L.	44.	Rubiaceae	*Spermacoce articularis* L.f.
19.	Euphorbiaceae	*Euphorbia hirta* L.	45.	Rubiaceae	*Spermacoce remota* Lam.
20.	Euphorbiaceae	*Euphorbia prostrata* Aiton	46.	Solanaceae	*Datura inoxia* Mill.
21.	Euphorbiaceae	*Jatropha curcas* L.	47.	Solanaceae	*Datura stramonium* L.
22.	Euphorbiaceae	*Jatropha gossypiifolia* L.	48.	Solanaceae	*Solanum virginianum* L.
23.	Fabaceae	*Desmodium triflorum* (L.) DC.	49.	Verbenaceae	*Lantana camara* L.
24.	Fabaceae	*Indigofera hirsuta* L.	50.	Verbenaceae	*Phyla nodiflora* (L.) Greene

Table 2: Continue...

Sl. No.	Family	Scientific name	S l . No.	Family	Scientific Name
25.	Fabaceae	*Mimosa pudica* L.	51.	Violaceae	*Hybanthus enneaspermus* (L.) F.Muell.
26.	Fabaceae	*Senna alata* (L.) Roxb.			
Biodiversity Index of herb and shrub species H' = 3.234					

Table 3: Checklist of grass species observed in Nandini Mines

Sl. No.	Family	Scientific name	Sl. No.	Family	Scientific name
1.	Asteraceae	*Parthenium hysterophorus* L.	16.	Poeceae	*Dichanthium caricosum* (L.) A.Camus
2.	Asteraceae	*Soliva sessilis Ruiz* & Pav.	17.	Poaceae	*Digitaria ciliaris* (Retz.) Koeler
3.	Cyperaceae	*Bulbostylis barbata* (Rottb.) C.B.Clarke	18.	Poaceae	*Digitaria sanguinalis* (L.) Scop.
4.	Cyperaceae	*Cyperus rotundus* L.	19.	Poaceae	*Echinochloa colona* (L.) Link
5.	Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl	20.	Poaceae	*Eleusine indica* (L.) Gaertn.
6.	Poaceae	*Aristida adscensionis* L.	21.	Poaceae	*Eragrostis amabilis* (L.) Wight & Arn.
7.	Poaceae	*Bambusa vulgaris* Schrad. ex J.C.Wendl.	22.	Poaceae	*Eragrostis minor* Host
8.	Poaceae	*Bothriochloa pertusa* (L.) A.Camus	23.	Poaceae	*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.
9.	Poaceae	*Brachiaria mutica* (Forssk.) Stapf	24.	Poaceae	*Isachne globosa* (Thunb.) Kuntze
10.	Poaceae	*Celosia argentea* L.	25.	Poaceae	*Oplismenus compositus* (L.) P.Beauv.
11.	Poaceae	*Cenchrus pedicellatus* (Trin.) Morrone	26.	Poaceae	*Oplismenus undulatifolius* (L.) P.Beauv.
12.	Poaceae	*Cynodon dactylon* (L.) Pers.	27.	Poaceae	*Panicum repens* L.
13.	Poaceae	*Cyperus rotundus* L.	28.	Poaceae	*Setaria pumila* (Poir.) Roem. & Schult.
14.	Poaceae	*Dendrocalamus strictus* (Roxb.) Nees	29.	Poaceae	*Tragus racemosus* (L.) All.
15.	Poaceae	*Dichanthium annulatum* (Forssk.) Stapf	30.	Poaceae	*Urochloa mutica* (Forssk.) T.Q.Nguyen
Biodiversity Index of grass species H' = 2.976					

Table 4: Checklist of climber species observed in Nandini Mines

Sl. No.	Family	Scientific name	Sl. No.	Family	Scientific name
1.	Apocynacae	*Cryptolepis sinensis* (Lour.) Merr.	5.	Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.
2.	Apocynacae	*Cryptolepis sanguinolenta* (Lindl.) Schltr.	6.	Menispermaceae	*Cocculus hirsutus* (L.) Diels
3.	Convolvulaceae	*Convolvulus arvensis* L.	7.	Passifloraceae	*Passiflora foetida* L.
4.	Convolvulaceae	*Ipomoea hederifolia* L.			
Biodiversity index of climber species H' = 1.242					

3.5. Assessment of species composition in trees through SPM

Understanding the species composition through scatterplot matrix, on one side (Figure 5A), the histogram for density showed a distribution that is skewed to the left, indicating that most values are clustered toward the lower end of the scale with a long tail on the higher end. The histogram for Frequency had a similar shape to Density, also showing a left-skewed distribution. The histogram for Abundance appeared to have a different distribution, potentially more symmetric, but also showing some skewness. The scatterplot between Density and Frequency showed a positive correlation, where higher Density values tend to correspond with higher Frequency values. The points are relatively clustered, suggesting a strong relationship. Similar findings can be observed in the scatterplot between Density and Abundance, but the relationship appears to be more dispersed, indicating a weaker correlation compared to the above one. Scatterplot of Frequency and Abundance showed somewhat similar pattern to Density vs. Abundance, where there is a positive relationship, but the data points are

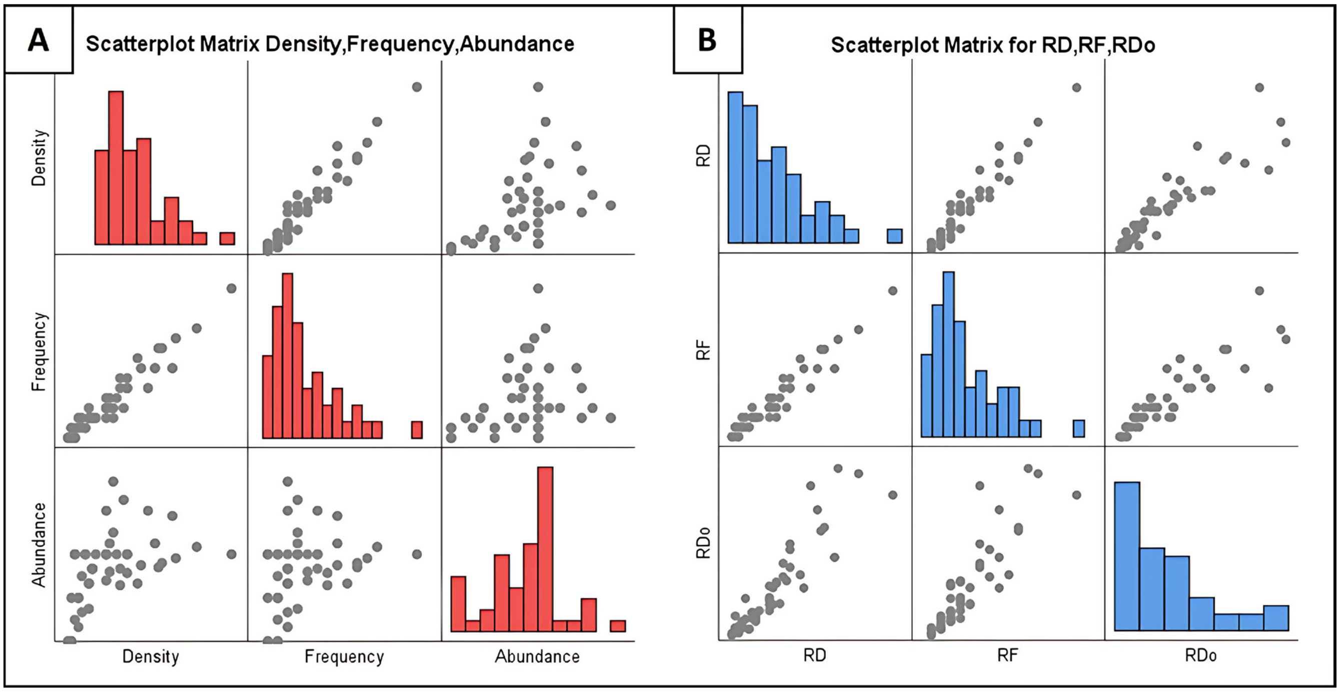

Figure 5: Scatterplot matrix of the studied 48 tree species in Nandini Limestone Mines; A: Based on density, frequency and abundance, B: Based on relative density, relative frequency and relative dominance

more spread out. All three variables show positive pairwise correlations with each other, but the strength of these correlations varies. Density and Frequency appear to have the strongest relationship, while the relationships involving Abundance are weaker. Both Density and Frequency are left-skewed, whereas Abundance has a different distribution, which may suggest different underlying factors influencing it.

On the other side (Figure 5B), the histogram for RD shows a left-skewed distribution, with most of the data concentrated towards the lower end. This suggests that the majority of the data points have lower values of Relative Density. The RF histogram also displays a left-skewed distribution, similar to RD. The distribution suggests that there are more occurrences of lower Relative Frequency values. The RDo histogram has a distribution that appears slightly less skewed but still shows a tendency towards lower values. This indicates that the majority of data points have lower Relative Dominance values. The scatterplot between RD and RF shows a strong positive correlation. The points form a tight cluster along an upward trend line, indicating that as Relative Density increases, Relative Frequency also tends to increase. The scatterplot between RD and RDo also shows a positive correlation, though the relationship is somewhat weaker compared to RD vs. RF (Figure 5B). The points are more dispersed, suggesting that while there is a general trend, the correlation is not as strong. The scatterplot between RF and RDo shows a similar positive correlation to RD vs. RDo, with the data points forming a dispersed cluster, indicating a positive but weaker relationship between Relative Frequency and Relative Dominance. All three variables (RD, RF, RDo) show positive correlations with each other, with the strongest relationship observed between RD and RF. The correlations involving RDo are slightly weaker, with more dispersion in the data points. The histograms indicate that the variables are generally left-skewed, with most data points having lower values of RD, RF, and RDo.

3.6. Assessment of species dominance in trees through HCA

In the Hierarchical Cluster Analysis (HCA) based on IVI using Average Linkage (Figure 6), the dendrogram formed represents all the 48 studied tree species in vertical axis and the tree species that are more similar to each other are grouped together and connected by branches at shorter distances on the horizontal axis. The height at which two branches are joined together represents the similarity level between the groups of species, smaller values indicate higher similarity in IVI. At the far right of the dendrogram, large clusters are formed where multiple species are connected at higher rescaled distances, indicating that these species are more distantly related in terms of the measured characteristics i.e. IVI. Within these major clusters, sub-clusters are formed, showing more closely related species (Figure 6). The tree species connected at very low rescaled distances (e.g., values like 2.167 or 3.667), indicates very high similarity between these species (namely *Dalbergia*

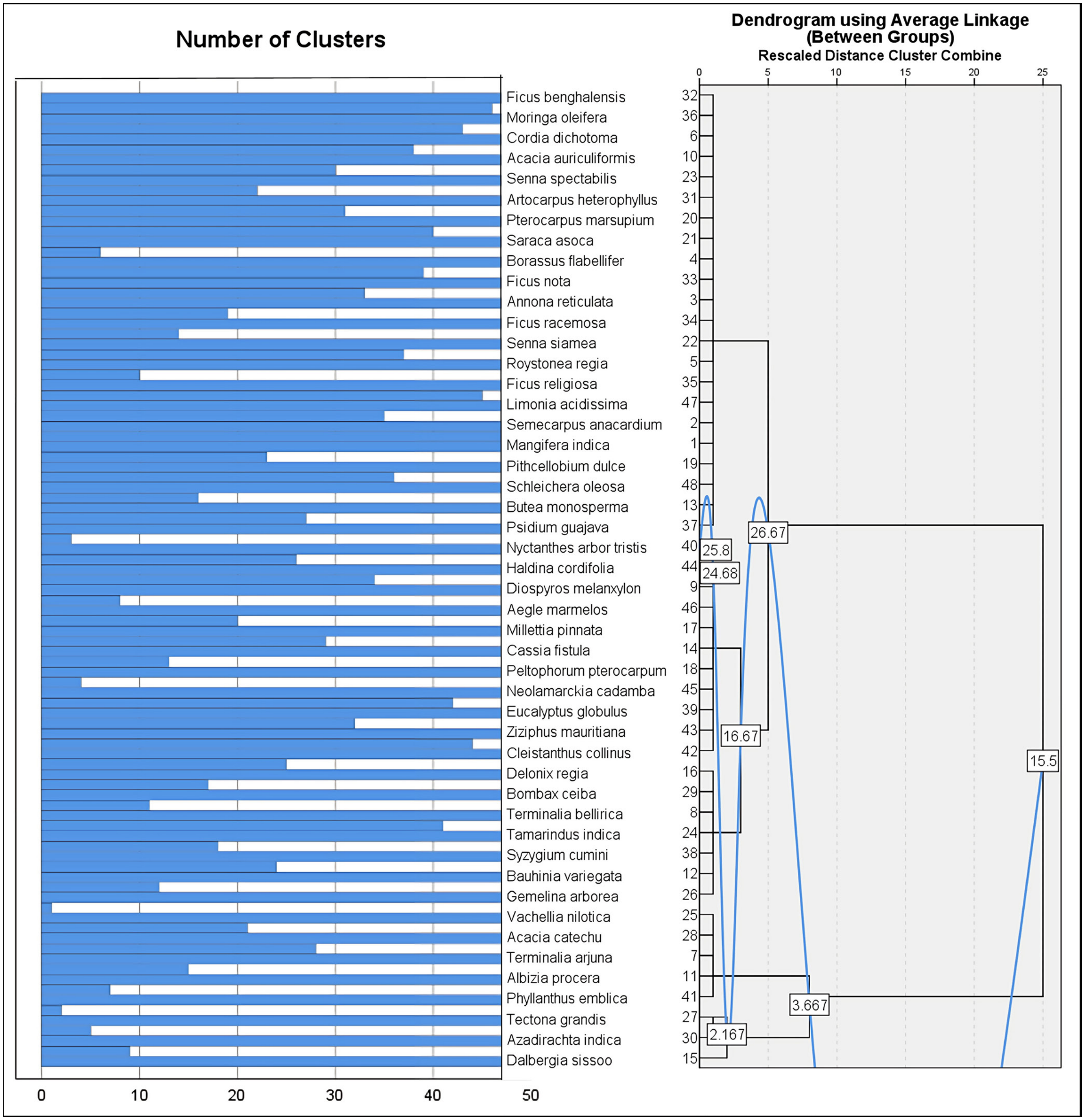

Figure 6: Hierarchical cluster analysis based on IVI (Importance Value Index) of the studied 48 tree species in Nandini Limestone Mines through dendrogram using average linkage (Between groups)

sissoo Roxb., *Azadirachta indica* A. Juss, *Tectona grandis* Linn. f., and *Albizia procera* (Roxb.) Benth.) having high IVIs. The length of the branches connecting different clusters or species is crucial. Longer branches imply greater dissimilarity between the connected species or clusters (Cluster 1, 2 and 3 are dissimilar to Cluster 4 and 5), while shorter branches indicate more similarity (Cluster 2 and 3 are the closest to each other). Species like *Azadirachta indica* A. Juss and *Dalbergia sissoo* Roxb. are connected at a relatively low rescaled distance, suggesting close connection with each other with highest IVIs compared to other species in the study area.

4. CONCLUSION

The findings emphasize the need for continued monitoring and management to ensure the long-term sustainability of these ecosystems. The comprehensive data on species composition and diversity can serve as a baseline for future studies and track changes over time, thereby informing more effective conservation and restoration practices. This assessment also highlights the necessity of integrating biodiversity considerations into mining practices to minimize ecological damage and enhance the natural recovery processes, ultimately leading to more sustainable outcomes for the mined areas.

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