

Floristic Diversity And Morphological Characterisation Of Lichens As Bio-Indicators Of Environmental Health In Eastern India: A First Systematic Multi-Zone Assessment

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Abstract: A lichen is a stable symbiotic association between a fungal partner (mycobiont) and a photosynthetic partner (photobiont), forming a single composite thallus. Lacking a protective cuticle, lichens absorb water and nutrients directly from the atmosphere, making them sensitive to air quality and widely used as bio-indicators of environmental health. The lichen flora of Jharkhand remains critically understudied, with no prior systematic, multi-zone survey of morphological characterisation for the state. This study addresses that gap by documenting lichen diversity across four spatial zones in Ranchi representing an urbanisation and pollution gradient: Industrial (Tupudana), Commercial (Nayatoli/Main Road), Residential (Tagore Hill/Morabadi), and Peri-urban Forest (Jagannathpur Hill). Lichen thalli were surveyed by stratified random sampling on standardised phorophytes using a 20 cm × 20 cm quadrat at 1-1.5 m trunk height. Morphological identification used a hand lens, stereomicroscope, and standard taxonomic keys. Both foliose and crustose growth forms were recorded, and three species were confirmed: *Parmotrema reticulatum* (foliose), *Pyxine coccinea* (foliose), and *Lecanora muralis* (crustose). Shannon-Wiener and Simpson indices revealed a clear gradient: Zone 2 recorded the highest diversity and evenness ($H' = 0.694$; $1-D = 0.556$), while Zone 4 recorded the lowest ($H' = 0.325$; $1-D = 0.200$). Foliose lichens were largely restricted to less-disturbed zones, whereas pollution-tolerant crustose forms persisted in high-traffic and industrial corridors, consistent with lichen desert phenomena reported from other urban centres. This study establishes a first systematic floristic baseline for lichen diversity in Jharkhand, demonstrating the utility of lichen biomonitoring as a cost-effective tool for assessing urban environmental health on the Chota Nagpur Plateau.

Keywords: Air quality; bioindicators; Chota Nagpur Plateau; Ranchi; urbanisation gradient.

INTRODUCTION

Lichens are a unique group of organisms formed through an obligate mutualism in which a fungal partner (mycobiont) and a photosynthetic partner (photobiont green algae or cyanobacteria) become fully interdependent, together forming a single composite vegetative body known as the thallus (Honegger, 2009). The mycobiont, generally belonging to the order Ascomycetes, provides structural integrity through its hyphal network but cannot photosynthesise. The photobiont, in turn, supplies photosynthetically fixed carbon to the association (Morillas *et al.*, 2022). This dual, composite nature was first demonstrated by the Swiss botanist Simon Schwendener, who overturned the earlier view of lichens as autonomous plants. Thus, lichens are thalloid organisms lacking true roots, stems, or leaves, though a small number of species are of ethnobotanical or edible significance to humans and animals.

Lichens colonise an extraordinary range of substrates and climatic zones, from sea level to alpine altitudes, appearing as crustose patches, foliose leaf-like thalli, or fruticose shrub-like growths that often blend visually with their substrate (Armstrong and Bradwell, 2010). Recent

biodiversity assessments indicate a particularly rich, though still under-documented, lichen flora across the eastern and central Indian states of Bihar, Jharkhand, Odisha, and Chhattisgarh, especially within forested tracts. Ecologically, lichens function as sensitive bio-indicators of ambient air quality because they lack a protective cuticle and absorb water and nutrients directly from the atmosphere (Colesie and Newsham, 2026). They respond rapidly to airborne pollutants, and their decline or disappearance from urban centres is frequently linked to sulphur dioxide pollution, providing an early warning of deteriorating environmental health (Seaward, 1993). An estimated 20000 lichen species have been described worldwide, underscoring both their ecological ubiquity and the scale of the documentation task that remains (Lücking *et al.*, 2017).

Lichens as Bio-indicators of Environmental Health

A bio-indicator is any living organism whose presence, abundance, or physiological condition reflects the quality of, or change in, its surrounding environment. Lichens are considered among the most reliable bio-indicator groups because they are

long-lived, perennial, and continuously accumulate airborne pollutants over time, making them effective proxies for cumulative rather than instantaneous air quality (Conti and Cecchetti, 2001). Lichen-based monitoring has been formally recognised by agencies such as the United States Environmental Protection Agency (USEPA) for tracking pollutants including fluorides, chlorides, heavy metals, and ground-level ozone (Garty, 2001). As a strong oxidising agent, ozone generates free radicals that damage the photobiont, suppress photosynthesis, and can ultimately cause thallus death, making lichen community composition a sensitive, low-cost proxy for regional air quality trends.

Lichens of Chota Nagpur Plateau

The Chota Nagpur Plateau, encompassing Ranchi, is a geologically ancient terrain characterised extensively by crystalline gneissic basement rocks (Mazumdar, 1988), with diverse landforms and topography across the plateau (Singh and Singh, 2023). Ranchi experiences a pronounced monsoonal climate with substantial annual rainfall, while its forested and rocky landscapes provide diverse substrates for lichen colonisation (Pathak and Kumar, 2017). Despite this potential, the lichen flora of Jharkhand remains comparatively under-documented, with recent investigations continuing to reveal substantial previously unreported diversity (Halder *et al.*, 2026; Maurya *et al.*, 2024). Earlier work from Ranchi reported five lichen species as new records for the area,

Dirinaria consimilis, *Parmotrema reticulatum*, *Caloplaca cinnabarina*, *Chrysothrix candelaris*, and *Parmotrema tinctorum* representing the families Caliciaceae, Parmeliaceae, Teloschistaceae, and Chrysotrichaceae (Pathak and Kumar, 2017). Other regional surveys across Jharkhand districts have recorded crustose and foliose taxa on *Shorea robusta* (sal), *Tectona grandis* (teak), and roadside trees, with *Parmotrema*, *Usnea*, *Heterodermia*, *Dirinaria*, *Pyxine*, *Lecanora*, and *Graphis* among the most frequently encountered genera, alongside marked differences in species richness between forest, semi-urban, and urban localities (Kumar and Saikia, 2020).

However, these prior records remain fragmentary, opportunistic, and confined to isolated localities; no study to date has systematically surveyed lichen diversity across a defined urbanisation gradient in Jharkhand using standardised morphological description. Ranchi, the state capital and its fastest-urbanising centre, offers a particularly dynamic setting in which to close this gap, encompassing industrial, commercial, residential, and peri-urban forest landscapes within a compact geographic area. The present study was therefore designed to provide the first systematic, multi-zone floristic baseline for lichen diversity in Jharkhand, with the broader aim of establishing lichen-based biomonitoring as a practical tool for tracking urban environmental health on the Chota Nagpur Plateau.

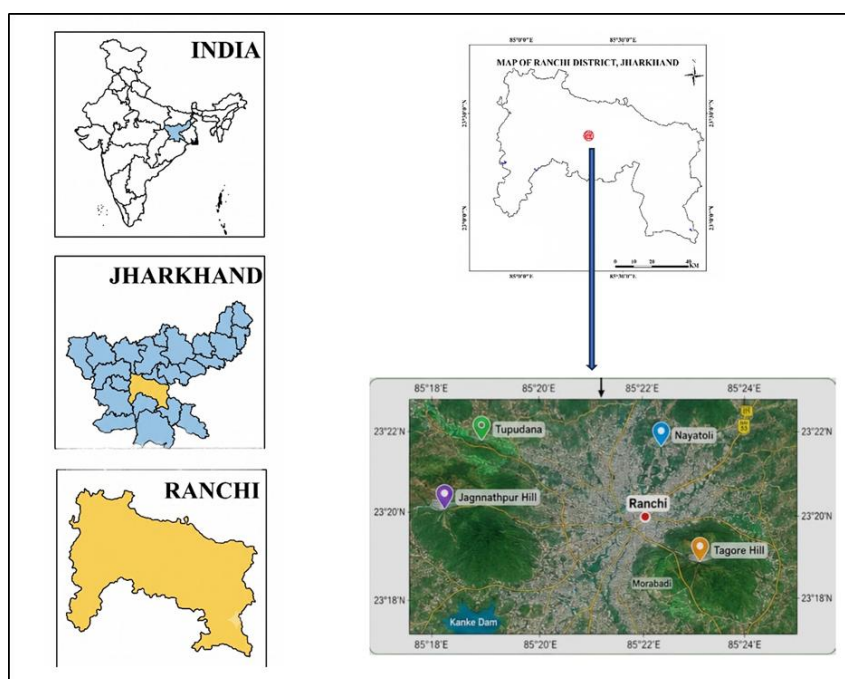


Figure 1. Location map of sampling zone in Ranchi districts with the four sampling zones (Zone 1: Tupudana; Zone 2: Nayatoli/Main Road; Zone 3: Tagore Hill/Morabadi; Zone 4: Jagannathpur Hill).

MATERIALS AND METHODS

Study Area and Site Selection

The study was conducted in Ranchi district (latitude 23.3443° N, longitude 85.2960° E), Jharkhand, with the objective of documenting lichen diversity across a defined urbanisation gradient. To enable ecologically meaningful comparison, the study area was stratified into four zones on the basis of distance from pollution sources, land-use type, and prevailing environmental conditions, representing a gradient from heavy anthropogenic disturbance to relatively undisturbed forest (Figure 1).

Zone 1 — Industrial (Tupudana–Balsiring): located near industrial and factory installations characterised by high emission loads of gases and particulate matter (PM), representing the most heavily polluted end of the gradient.

Zone 2 — Commercial/high-traffic (Nayatoli–Main Road): a high-vehicular-density corridor with comparatively poor air quality driven by traffic emissions and dust.

Zone 3 — Residential/institutional (Tagore Hill–Morabadi): housing colonies and institutional campuses with moderate vegetation cover and comparatively lower pollution intensity than the industrial and commercial zones.

Zone 4 — Peri-urban forest (Jagannathpur Hill): a transitional zone between the urban core and surrounding forest, situated at higher elevation under dense canopy cover, with minimal vehicular activity and human disturbance.

Sampling Design and Collection of Field Data

A stratified random sampling design was employed to ensure representative coverage across the urbanisation gradient. Sampling sites within each zone were separated by a sufficient distance to avoid spatial overlap, and site selection prioritised the availability of suitable lichen-bearing substrates, including tree trunks, rock surfaces, walls, and other anthropogenic structures. Geographic coordinates of each site were recorded using a handheld GPS device to enable accurate spatial mapping and future longitudinal monitoring.

Only mature, well-established trees with stable bark characteristics were selected as phorophytes. Trees were selected using predefined criteria: they were required to be free from major disease, decay, extensive bark damage, or recent pruning; readily accessible for sampling; representative of the dominant vegetation in each sampling zone; and largely free from anthropogenic surface disturbance, such as painting or cementing around the trunk base (Asta *et al.*, 2002). Lichens were sampled from tree trunks at a standardised height of 1-1.5 m above ground level. The principal phorophyte species sampled were *Mangifera indica* L., *Shorea robusta* Gaertn., and *Artocarpus heterophyllus* Lam.

A plastic quadrat measuring 20 cm × 20 cm was placed on each selected tree trunk at 1-1.5 m height, within which the number and growth form (crustose or foliose) of lichen colonies were recorded. A standardised field data recording sheet was used at every sampling site, capturing the site code, survey date, geographic coordinates (latitude and longitude), substrate type, host tree species, and sampling zone (Table 1).

Table 1. Site checklist and sample data across the four sampling zones.

Parameter	Zone 1 (Tupudana)	Zone 2 (Nayatoli)	Zone 3 (Tagore Hill)	Zone 4 (Jagannathpur Hill)
Date, time	21/08/2025, 15:38 h	22/11/2025, 14:09 h	24/02/2026, 14:14 h	22/02/2026, 09:09 h
Site/ID code	RNC-ZN1-TUP	RNC-ZN2-SXC	RNC-ZN3-TH	RNC-ZN4-JNP
GPS coordinates	23.254678°N, 85.286408°E	23.367624°N, 85.328146°E	23.400806°N, 85.337927°E	23.317820°N, 85.281826°E
Substrate	Bark of <i>A. heterophyllus</i>	Bark of <i>S. robusta</i>	Bark of <i>A. heterophyllus</i>	Bark of <i>S. robusta</i>
Growth form	Crustose	Crustose	Crustose	Foliose and crustose
Thallus colour	Grey-green, smooth	Grey-green, smooth	Pale grey, rough	Greenish pale grey, rough/smooth
Associated flora	Sparse moss cover	Abundant moss cover	No mosses present	No mosses present

Specimen Collection and Preservation

Both macro- and micro-lichens visible to the naked eye were collected using a sharp, flat-edged chisel (2.5-5 cm blade width) and a 1 kg hammer for corticolous specimens, and a pointed or flat-edged chisel for saxicolous material; a 10× hand lens was used to verify fine thallus structure prior to collection. Specimens were stored in labelled paper envelopes, with collection data recorded in a dedicated field book containing printed columns for date, locality, altitude, collector's name, and remarks (Nayaka, 2005). Only well-developed thalli were collected to ensure accurate identification while minimising disturbance to natural populations. Each specimen was assigned a unique collection number, accompanied by detailed field notes on location, substrate, habitat character, and abundance, then air-dried and transported to the laboratory for further examination.

Morphological and Anatomical Examination for Species Identification

Morphological examination began with visual and low-magnification assessment of each thallus using a 10× hand lens and a stereo-zoom microscope. The upper surface was examined for colour, texture, and the presence of isidia (finger-like outgrowths) or soredia (powdery granules); the lower surface was examined for the presence, colour, and branching pattern of rhizines; and reproductive structures were assessed for the presence and colour of apothecia. Overall thallus condition is healthy, discoloured, or visibly degraded by soot or particulate deposition was also recorded, as a qualitative indicator of local environmental stress. To examine internal anatomy, a thin cross-section of each thallus was cut using a razor blade and examined under a compound or stereo-binocular microscope to resolve the medulla (the inner cottony layer) and the underlying algal layer, confirming growth-form classification and supporting genus-level identification.

Every lichen specimen encountered was examined and documented in situ for growth form (crustose, flat crusts; or foliose, leaf-like), colour (green, grey, yellow), surface texture (smooth, rough, granular), mode of substrate attachment (bark, rock), and reproductive structures such as apothecia, perithecia, soredia, or isidia. Preliminary field identification was carried out using standard lichen identification guides (Awasthi, 2000). Specimens were re-examined in the laboratory using a 10× hand lens,

stereomicroscope, dissection microscope, fine forceps, needles, razor blades, and glass slides. Recorded diagnostic characters included thallus growth form (crustose vs. foliose), colour, surface texture (smooth, rough, powdery, or granular), presence of cracks, ridges, or lobes, mode of substrate attachment, presence/absence of apothecia, soredia, and isidia, and, in foliose species, lower-cortex colour and rhizine presence. Final species-level identification was confirmed using the annotated checklist of Singh and Sinha (2010).

Diversity Analysis

Species diversity across the four zones was quantified using two complementary indices. The Shannon-Wiener diversity index ($H' = -\sum p_i \ln p_i$, where p_i is the proportion of individuals belonging to a given growth form) accounts for both richness and evenness, with higher values indicating greater diversity and, by extension, more favourable environmental conditions (Kumar and Mina, 2012). Simpson's diversity index ($1 - D$, where $D = \sum n_i(n_i - 1) / N(N - 1)$) emphasises dominance, with higher ($1 - D$) values reflecting a more even distribution across growth forms and lower values indicating dominance by a single form.

RESULTS

Zone-wise Environmental Character and Sampling

Across the four surveyed zones, ambient conditions differed markedly along the expected disturbance gradient. Zone 1 (Tupudana) experienced continuous exposure to industrial pollutants including sulphur dioxide (SO₂) and associated particulate emissions. Zone 2 (Nayatoli/Main Road) exhibited relatively poor air quality driven by dust and traffic emissions, with sparse tree cover and less stable microhabitat conditions. Zone 3 (Tagore Hill) showed moderate greenery combined with comparatively lower traffic density. Zone 4 (Jagannathpur Hill) presented air quality intermediate between the urban/industrial zones and undisturbed forest, relatively stable, though not entirely pollution-free.

Crustose and foliose lichen specimens were successfully collected from all four zones, spanning tree bark, rock, soil, and anthropogenic substrates. Only well-developed thalli were collected to ensure identification accuracy while minimising disturbance to natural populations, with each specimen assigned a unique collection number and accompanying field metadata

(location, substrate, habitat, abundance, and date; Table 1).

Species Identification

Morphological analysis confirmed the presence of three lichen taxa spanning both major growth forms surveyed: *Parmotrema reticulatum* (Taylor)

M. Choisy (foliose), *Pyxine cocoes* (Sw.) Nyl. (foliose), and *Lecanora muralis* (Schreb.) Rabenh. (crustose). Species-level identification followed the annotated checklist of Singh and Sinha (2010). Detailed morphological profiles are presented below and summarised in Table 2 and Figure 2.

Table 2. Summary of morphological characteristics of identified lichen taxa.

Species	Growth form	Thallus colour (upper)	Surface features	Lower surface	Distinguishing character
<i>Parmotrema reticulatum</i>	Foliose	Greyish-green	Fine white maculae network; margins fringed with sparse black cilia	Shiny black at centre, grading to brownish mottled-white toward margins	Loosely attached; broad, irregular lobes (5–15 mm wide)
<i>Pyxine cocoes</i>	Foliose	Light yellowish-brown to grey, occasionally near-white	Tightly appressed to substrate	Black at centre, paling toward lobe tips	Appressed growth habit distinguishes it from <i>P. reticulatum</i>
<i>Lecanora muralis</i>	Crustose	Pale yellowish-green to yellow-green, occasionally pale greyish-green	Placodioid, tightly attached to substrate	Not applicable (crustose)	Lobed margins, flat or branched

Parmotrema reticulatum (Taylor) M. Choisy

On examination, the thallus was found to be large and foliose, loosely attached to the substrate. The lobes were observed to be moderately broad and irregular, measuring approximately 5-15 mm in width, with margins fringed by sparse black cilia. The upper surface displayed a greyish-green colouration, marked by a characteristic network of fine white lines (maculae) resembling a map of hairline cracks — a distinctive feature within this genus. The lower surface was noted to be shiny black at the centre, grading outward to a brownish, mottled-white colouration toward the rhizine-free margins. On the basis of this combination of thallus morphology and lobe structure, the specimen was identified as *Parmotrema reticulatum* (Taylor) M. Choisy (Singh and Sinha, 2010; Jain *et al.*, 2016).

Pyxine cocoes (Sw.) Nyl.

On observation, the thallus was found to be foliose but tightly appressed to the substrate,

distinguishing its growth habit from the preceding species. The upper surface ranged from light yellowish-brown to grey, occasionally appearing near-white, while the lower surface was black at the centre and gradually faded toward the lobe tips. Taking the appressed foliose growth habit and thallus colouration together, the specimen was confirmed as *Pyxine cocoes* (Sw.) Nyl. (Singh and Sinha, 2010).

Lecanora muralis (Schreb.) Rabenh.

On examination, the thallus was found to be crustose and placodioid in form, tightly attached to the substrate, with distinctly lobed margins that were either flat or branched. The colouration was recorded as pale yellowish-green to yellow-green, occasionally appearing pale greyish-green. Taken together, the crustose placodioid growth form and lobed margin structure confirmed the identity of the specimen as *Lecanora muralis* (Schreb.) Rabenh. (Singh and Sinha, 2010).

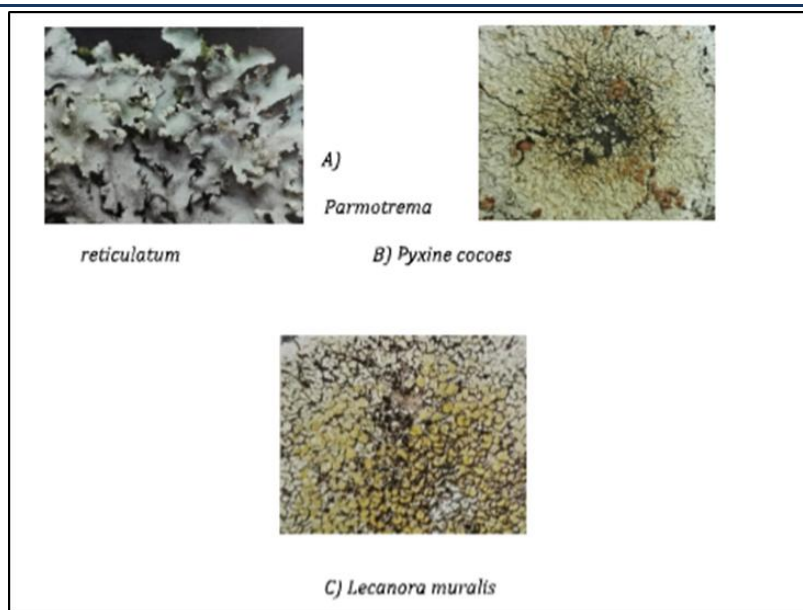


Figure 2. Photographic plate showing field habit and close-up thallus morphology of (A) *Parmotrema reticulatum*, (B) *Pyxine coccinea*, and (C) *Lecanora muralis*.

Diversity Indices Across Zones

Simpson's diversity index ($1 - D$) was highest in Zone 2 (0.556), indicating the most even distribution of crustose and foliose growth forms and, correspondingly, the highest diversity among the four zones. Zones 1 and 3 recorded identical,

intermediate values ($1 - D = 0.356$), reflecting moderate dominance of one growth form over the other. Zone 4 recorded the lowest value ($1 - D = 0.200$), indicating strong dominance by a single lichen growth form (Table 3).

Table 3. Simpson's and Shannon-Wiener diversity indices across the four sampling zones.

Zone	Description	Crustose : foliose ratio	Simpson's index (D)	Simpson's diversity ($1 - D$)	Shannon-Wiener index (H')
Zone 1	Industrial (Tupudana)	8 : 2	0.644	0.356	0.500*
Zone 2	Commercial (Nayatoli)	5 : 5	0.444	0.556	0.694
Zone 3	Residential (Tagore Hill)	2 : 8	0.644	0.356	0.500*
Zone 4	Peri-urban forest (Jagannathpur Hill)	9 : 1	0.800	0.200	0.325

The Shannon-Wiener diversity index (H') followed a consistent pattern: Zone 2 exhibited the highest diversity ($H' = 0.694$), reflecting a near-equal (5:5) distribution of crustose and foliose lichens, while Zone 4 recorded the lowest diversity ($H' = 0.325$),

reflecting strong dominance of crustose forms (9:1 ratio). Zones 1 and 3, with skewed but non-extreme growth-form ratios (8:2 and 2:8, respectively), occupied an intermediate position (Table 3, Figure 3).

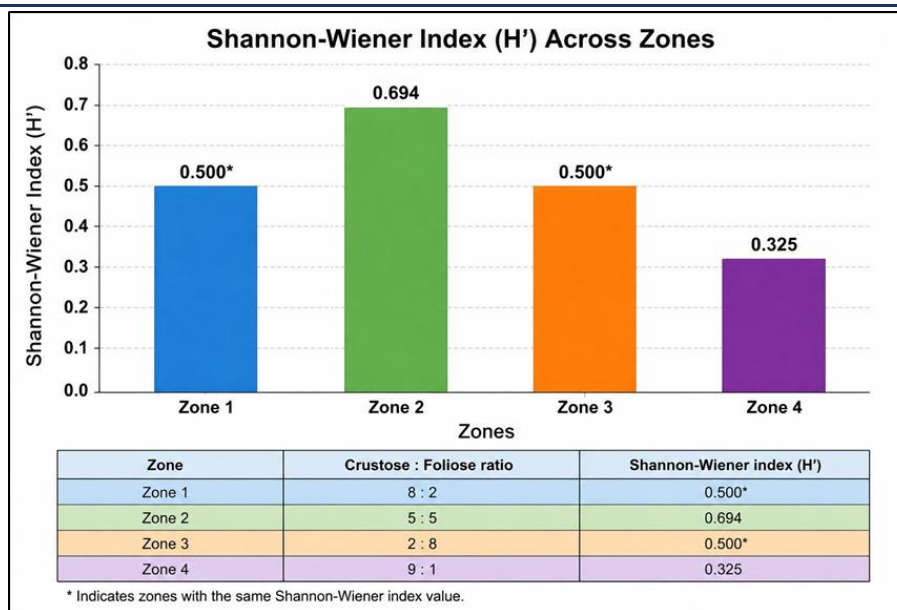


Figure 3. Bar chart comparing Shannon-Wiener (H') and Simpson's ($1 - D$) diversity indices across the four sampling zones.

DISCUSSION

Lichen Diversity Patterns Across the Urbanisation Gradient

Foliose and crustose lichens were recorded across all four zones over two field seasons (summer and monsoon). The Shannon-Wiener index identified Zone 2 as the most diverse, driven by a near-equal (5:5) abundance of crustose and foliose growth forms; equal representation of both forms maximises evenness and, consequently, overall diversity. Zones 1 and 3 showed comparable, intermediate diversity because one growth form dominated over the other (8:2 and 2:8, respectively) despite similar total abundance. This illustrates that richness alone is an incomplete descriptor of community structure without accounting for evenness. Zone 4 recorded the lowest Shannon diversity, driven by strong crustose dominance (9:1), indicating environmental conditions unfavourable to the co-occurrence of multiple growth forms. Simpson's index corroborated this pattern, emphasising dominance directly: Zone 2 showed the most balanced distribution, whereas Zone 4 showed the highest dominance value ($D = 0.800$) and lowest diversity ($1 - D = 0.200$). Together, the two indices consistently identify Zone 2 as supporting the most diverse and evenly distributed lichen community and Zone 4 as the least diverse among the zones surveyed.

Among foliose specimens, grey-green upper cortex colouration and marginal soredia were the most frequently observed characters. Crustose specimens displayed markedly greater chromatic

diversity, spanning white, grey, pale green, pale yellow, yellow-orange, and near-black (apothecial) tones, a pattern consistent with the photoprotective role of cortical pigments across zones of differing light and pollutant exposure (Gupta *et al.*, 2014).

Environmental Drivers of the Observed Diversity Gradient

Air pollution emerged as a principal driver of lichen distribution across the four zones. Because lichens absorb water and nutrients directly from the atmosphere, they respond rapidly to pollutants such as SO_2 , NO_x , ozone, and particulate matter. Urban and industrial zones under high pollutant loads supported fewer, predominantly tolerant species, whereas the peri-urban and less-disturbed zones supported higher richness and abundance consistent with the well-documented sensitivity of lichens to atmospheric sulphur compounds (Söchting and Johnsen, 1978) and their broader value as long-term air-quality integrators.

Microclimatic variables, such as temperature, sunlight exposure, and wind movement, further modulated lichen establishment. Zone 4 maintained cooler, more humid conditions generally favourable to lichen growth, while Zones 1 and 2 experienced elevated temperatures and reduced humidity that constrain habitat suitability for many species. The gradual shift in microclimate across zones likely reinforced the pollution-driven diversity gradient observed in this study (Munzi *et al.*, 2014).

CONCLUSION

This study documents the floristic diversity of lichens across four ecologically distinct zones of Ranchi, Jharkhand. The zones, Tupudana (industrial), Nayatoli (commercial), Tagore Hill (residential), and Jagannathpur Hill (peri-urban forest) representing, to our knowledge, the first systematic, multi-zone lichen survey conducted in the state that integrates standardised morphological documentation across a defined urbanisation gradient. Foliose and crustose growth forms dominated the recorded flora, with clear variation in composition, abundance, and diversity linked to vegetation cover, substrate availability, and the intensity of anthropogenic disturbance across zones.

Both Shannon-Wiener and Simpson diversity indices consistently identified the residential/institutional zone as supporting the richest and most evenly distributed lichen community, while the peri-urban forest zone, despite its lower overall disturbance, exhibited pronounced crustose dominance and the lowest diversity, underscoring that pollution exposure alone does not fully explain community structure and that substrate and microhabitat factors also warrant consideration. Distinct spatial patterns confirmed that foliose lichens, generally more pollution-sensitive, were favoured in less-disturbed sites, whereas pollution-tolerant crustose forms persisted in disturbed, high-traffic corridors, reinforcing the diagnostic value of growth-form ratios as a rapid, field-level indicator of local air quality.

By combining macro- and microscopic morphological characterisation, this study provides a robust, reproducible identification framework for the three confirmed taxa — *Parmotrema reticulatum*, *Pyxine cocoes*, and *Lecanora muralis* — and, more broadly, establishes the first systematic floristic baseline for lichen diversity in Jharkhand. Given the near-total absence of prior systematic morphological lichen studies from the state, these findings carry particular significance for the regional lichenological and environmental-monitoring communities. The results demonstrate the practical utility of lichen-based biomonitoring as a low-cost, ecologically sound tool for tracking urban environmental health on the Chota Nagpur Plateau, and lay the groundwork for longer-term, seasonally resolved monitoring, an expanded taxonomic inventory, and molecular (DNA

barcoding) confirmation of the taxa reported here in future work.

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