COMPARATIVE ASSESSMENT OF AIR POLLUTION ACROSS AN ECOSYSTEM GRADIENT USING LICHEN-BASED BIOINDICATION

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ABSTRACT

Air pollution has emerged as a mounting threat to the environment and the agriculture sector, particularly in transitional landscapes. Therefore, air quality monitoring is important. Lichens are recognized for their high sensitivity to atmospheric pollutants. The present study investigates the potential of lichen genera as bioindicators to comparatively assess air pollution across the pollution gradient in the Gampaha district, Sri Lanka. Lichens were surveyed across three zones with distinguishable pollution levels: the Muthurajawela wetland (low pollution), Gampaha town (intermediate pollution), and the Ekala industrial zone (high pollution). Corticolous lichen samples were counted from *Cocos nucifera* trees using transparent quadrats in three randomly selected subsampling locations per site. Species diversity and Evenness were quantified using the Shannon-Wiener diversity index (H') and Pielou's species evenness index, respectively. Four dominant genera—*Chrysothrix*, *Pyxine*, *Graphis*, and *Dirinaria*—were identified, with the highest diversity (H′ = 1.26) and evenness (E = 0.91) observed in the low-pollution Muthurajawela wetland. Diversity and evenness declined with increasing pollution levels: Gampaha town (H′ = 0.98, E = 0.89) and the Ekala industrial zone (H′ = 0.46, E = 0.67). The absence of *Chrysothrix* in Gampaha and both *Chrysothrix* and *Dirinaria* in Ekala, with the lowest diversity and evenness, indicates their vulnerability to air pollutants, while *Pyxine*, a pollution-tolerant genus, was most dominant in Ekala. These findings highlight the effectiveness of lichen-based monitoring as a cost-effective and ecologically meaningful approach to assess air pollution gradients, thereby promoting sustainable agriculture in the country.

Keywords: *Air pollution, Lichen bioindicators, Shannon-Wiener index, Pielou's Evenness Index*

1. Introduction

Air pollution is the presence of harmful substances in the Earth's atmosphere. According to the National Environmental Amendment Act No. 56 of 1988 in Sri Lanka, atmospheric pollution is an undesirable change in the air's physical, chemical, and biological characteristics that will adversely affect plants, animals, human beings, and inanimate objects (National Environmental (Amendment) Act No. 56 of 1988). This phenomenon results from releasing various substances into the atmosphere, collectively known as pollutants. These pollutants may exist in gaseous, liquid, or solid forms and originate from both natural processes and anthropogenic sources.

Air pollution arises from a variety of sources, both natural and human-made. Common air pollutants include carbon monoxide, nitrogen oxides (NO_X), sulfur dioxide (SO_2), ground-level ozone (O_3), volatile organic compounds (VOCs), and particulate matter (PM). Natural sources of air pollution include dust storms, wildfires, and volcanic activity. However, most air pollution is attributable to anthropogenic activities, such as transportation, industrial processes, intensive agriculture and livestock, and energy production. The impacts of air pollution have been widely studied, revealing serious consequences for both human health and the environment. A study was conducted to assess how particulate matter (PM), nitrogen oxides, and volatile organic compounds contribute to respiratory and cardiovascular diseases, neurological disorders, and cancer (Manisalidis et al., 2020). In 2021, another study confirmed the mechanistic evidence of air pollution's effects, indicating how fine particulate matter ($PM_{2.5}$) induces oxidative stress and inflammation (Fiorin et al., 2021).

In addition to respiratory and cardiovascular illnesses in humans, air pollution also poses significant threats to agriculture. Pollutants such as ground-level ozone can damage crop tissues, reduce photosynthetic efficiency, and lower crop yields. Acid rain, resulting from sulfur dioxide and nitrogen oxides, can alter soil chemistry and degrade soil fertility, affecting long-term agricultural productivity. Furthermore, particulate matter can block sunlight and interfere with plant growth. These combined effects highlight the need for integrated air quality management to safeguard public health, food security, and ecosystem stability. The farming industry is both a contributor to and a victim of air pollution. The use of fertilizers and the raising of livestock emits ammonia and nitrogenous compounds. Ozone can inflict harm on crops by damaging plant tissue and reducing photosynthesis, leading to decreased yields. Additionally, acid rain modifies the soil pH, which in turn influences the fertility of the soil. Particulate matter inhibits plant growth by restricting sunlight. To achieve self-sustaining agribusiness and food sufficiency, the status of the air quality in agricultural areas should be closely monitored.

Due to the severity of impacts, monitoring spatial and temporal variations in air pollutants is crucial for reducing emission levels from anthropogenic sources. Various physicochemical and biological methods are employed to monitor atmospheric pollution. Physicochemical methods involve measuring the physical and chemical properties of pollutants in the air, such as their concentration, size, and chemical composition. In contrast, biomonitoring offers a more integrated measure of exposure. Unlike physicochemical methods, which solely quantify pollutant concentrations in the air, biomonitoring considers the actual uptake and accumulation of pollutants in living organisms. This provides a more comprehensive measure of exposure to pollution over time, which can be valuable in assessing the long-term health effects of exposure (Hoek et al., 2013; Brunekreef et al., 2009). Biomonitoring can also provide information about the impact of pollution on ecosystems. In the context of biomonitoring, the selection of a suitable bioindicator is an important aspect.

Bio-indicators are living organisms that offer valuable insights into the health and state of an ecosystem (Conti & Cecchetti, 2001). They can reveal long-term impacts of environmental stressors, which may be challenging to discern through other methods. By responding dynamically to changes in their surroundings, bioindicators serve as real-time sensors of ecological integrity, making them invaluable tools for environmental assessment and management.

Lichens are widely used as bio-indicators due to their sensitivity to air pollution. They can absorb pollutants such as SO_2 and NO_X from the air, which can lead to changes in their growth and appearance. Different lichen species exhibit varying levels of sensitivity to pollution, enabling them to provide information on the types and levels of pollutants present in an ecosystem (Blasco et al., 2011). For example, some lichen species are more sensitive to sulfur dioxide (SO_2), while others are more sensitive to NO_X (Lawal & Ochei., 2024; Delves et al., 2023). Owing to their sensitivity to atmospheric pollutants, lichens have been extensively employed to assess air quality in various environments, including rural, urban, and industrial areas (Mikhaylov, 2020). When utilizing lichens as bioindicators, it is essential to distinguish their morphological and functional variations as lichens come in a wide variety of shapes, colors, and applications.

In Sri Lanka, various studies have been conducted to explore the use of lichens as bioindicators in rural, semi-urban, and urban areas. A study was conducted to determine the air pollution in Colombo and Kurunegala using energy dispersive X-ray fluorescence spectrometry on *Heterodermia speciosa* (Gunathilaka et al., 2011). In this study, it was identified that the common lichen species *Heterodermia speciosa* can be used as a good indicator for analyzing atmospheric pollution. In 2015, a research team led by Prof. Weerakoon discovered nine new lichen species and 159 new records for Sri Lanka (Weerakoon, 2015). Another study investigated the potential of corticolous lichens as biomonitoring tools for estimating air pollution in the Western Province, concluding that they have good potential as indicators of air quality monitoring in a tropical environment (Attanayaka & Wijeyaratne, 2013). Furthermore, a study in the Sabaragamuwa Province assessed and correlated the use of corticolous lichens as a biomonitoring tool to estimate air pollution along suburban ecosystems, identifying a total of 89 lichen species belonging to 25 genera and 15 families, and observing a negative correlation between the index of atmospheric purity (IAP), SO_2 as well as nitrogen dioxide (NO_2) levels (Yatawara & Dayananda, 2019).

While previous research has focused on urban and rural ecosystems, the specific impacts of industrial emissions on lichen diversity and composition remain underexplored. To address this gap, the present study evaluates the potential of lichens as bioindicators to assess atmospheric pollution across varying environmental settings, ranging from minimally polluted (Muthurajawela wetland) to intermediately polluted (Gampaha town) and highly polluted (Ekala industrial zone) areas in the Gampaha district of Sri Lanka. This research holds particular relevance for the agricultural sector, as air pollutants such as SO_2, NO_x, and O_3 are known to impair photosynthesis, disrupt nutrient uptake, and degrade soil quality, ultimately affecting crop productivity. By monitoring lichen responses along this pollution gradient, the study aims to identify potential threats to neighbouring agricultural land and inform sustainable environmental practices.

The objectives of this research are to (1) identify the lichen species present in each study location and (2) quantify their abundance and diversity using established diversity indices to evaluate the air quality to promote sustainable agriculture in the Gampaha district.

2. Materials and methods

2.1 Study area

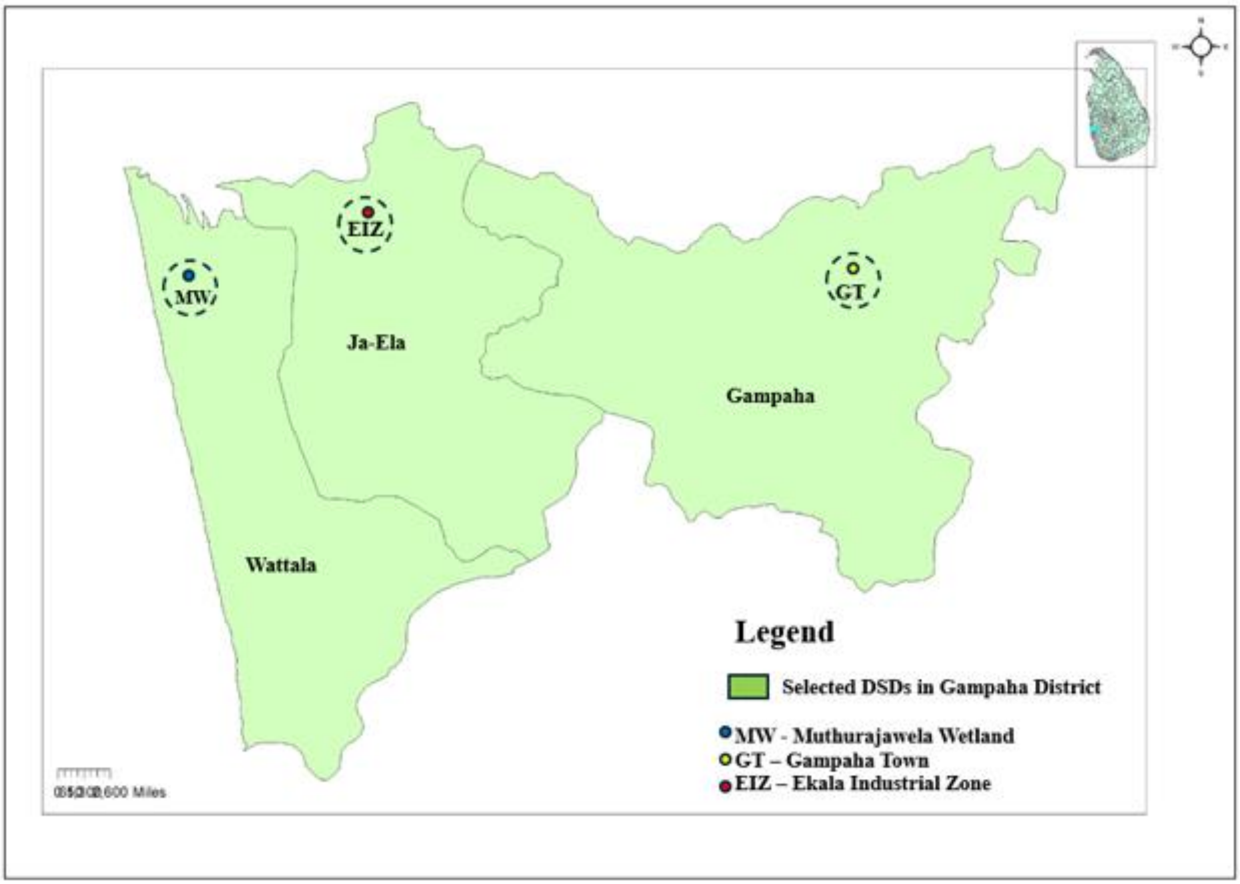
The Gampaha district (7.0713° N, 80.0088° E) in the Western Province of Sri Lanka was selected as the study area for the present study. Three study sites were selected as shown in Figure 01, considering the level of urbanization and atmospheric pollution: Muthurajawela wetland (low-polluted natural area), Gampaha town (intermediately polluted urban area), and the Ekala industrial zone (highly polluted area).

Muthurajawela is a marsh in Sri Lanka in the southern region of the Negombo lagoon. It is a protected wetland with relatively lower human activities compared to urban and industrial areas. Consequently, the air quality in this region is improved relative to more polluted regions, and thus, it can be characterized as a minimally air-polluted area.

Gampaha town is an intermediate pollution urban area influenced by moderate human activities, particularly vehicular emissions, with high levels of NO_X. Additionally, residential activities contribute to the air quality deterioration in Gampaha town, which is noticeably worse compared to less urbanized areas such as Muthurajawela, indicating the influence of anthropogenic activities in the region.

The Ekala industrial zone is one of the major industrial hubs in the Gampaha District. This highly polluted area experiences severe industrial activities, leading to significant air pollution. The zone facilitates a diverse range of industries, including textiles, chemicals, plastics, food processing, and metal processing. These industrial processes commonly release significant amounts of pollutants into the air, including particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs).

Fig 1: Map showing the three selected study sites representing a pollution gradient: MW-Muthurajawela wetland (low pollution), GT-Gampaha town (moderate pollution), and EIZ-Ekala industrial zone (high pollution), in the Gampaha District, Sri Lanka.



2.2 Sampling

A preliminary survey identified coconut trees (*Cocos nucifera*) as the most abundant tree species across all study sites. Three subsampling locations, spaced at least 100 meters apart, were established at each site to ensure spatial independence and sampling consistency. Five mature trees with a Diameter at Breast Height (DBH) > 5 cm were selected per sub-sampling location to identify available lichen species on tree trunks. The lichen samples were collected from the tree trunks at a height of 1.5 meters above the ground level using a 20 cm x 20 cm transparent quadrat, and counted in three directions (north, south, and west).

Lichen samples were carefully collected from the tree trunks using a sharp scraping blade, taking measures to minimize any damage to the bark, in accordance with the methodological approaches outlined in the existing literature (Yatawara & Dayananda, 2019). The Identification process involved the utilization of standard taxonomic keys (Weerakoon, 2015), and the findings were subsequently verified by an expert in the field to ensure accuracy of the classifications.

2.3 Determination of Diversity Indices Using Lichens

Species diversity and Shannon–Wiener diversity index (H′)

Species richness is the total number of species in a sample, and the total abundance is the total number of individuals of all species recorded within the study area (Colwell, 2009). Species diversity refers to species' variety and relative abundance within a considered ecological community.

Species richness was determined using the number of lichen species observed within the grid and the number of grid units where particular species were observed (Yatawara & Dayananda, 2019).

Species diversity was determined using the Shannon-Wiener diversity index as the equation below.

$$\mathbf{H'} = -\boldsymbol{\Sigma}\,(\boldsymbol{p_i})\,[\mathbf{ln}(\boldsymbol{p_i})]$$

Where:
H’ = Shannon-Wiener index of species diversity
$\boldsymbol{p_i}$ = proportion of total abundance represented by i^{th} species
ln($\boldsymbol{p_i}$) = natural logarithm of p_i

The Shannon-Wiener diversity index was calculated for pooled data by obtaining the mean values for each species across all sampling points within a given study site to ensure a comprehensive assessment of species diversity.

Species evenness

Species evenness is a measure of how evenly individuals are distributed among different species in an ecosystem. Species evenness was calculated using Pielou’s Evenness Index (E) as the equation below.

$$\mathbf{E} = \frac{\mathbf{H'}}{\mathbf{ln\,S}}$$

Where:
H′ = Shannon-Weiner diversity index
S = Total number of species (species richness)
ln S = Natural logarithm of species richness

Simpson's Diversity Index (D)

The Simpson's Diversity Index (D) is a commonly used biodiversity measure that accounts for both the number of species present (richness) and the relative abundance of each species (evenness). It was calculated as the equation below.

$$D = \Sigma [n_i (n_i - 1) / N (N - 1)]$$

Where:
D = The Simpson's Diversity Index
n_i = Number of individuals of species *i*
N = Total number of individuals of all species

Simpson's Reciprocal Index was calculated using **1/ D.**

2.4 Cluster analysis

A hierarchical cluster analysis was conducted to assess the similarity in lichen species composition across the three study sites. The analysis was performed using Minitab 21 statistical software. A dendrogram was generated to represent the clustering pattern of sites based on species composition.

3. Results and Discussions

Four dominant lichen genera—*Chrysothrix* (Fig 2a), *Pyxine* (Fig 2b), *Graphis* (Fig 2c), and *Dirinaria* (Fig 2d) were identified across the three study sites.

The Muthurajawela wetland, characterized by minimal pollution, exhibited the highest diversity, with all four genera present. In Gampaha town, a moderately polluted urban area, *Chrysothrix* was absent, leaving *Pyxine*, *Graphis*, and *Dirinaria* as the observed lichen genera. The Ekala industrial zone, representing the most polluted site, recorded the lowest lichen diversity, with only *Pyxine* and *Graphis* detected.

According to Fig 03, in the Muthurajawela wetland, the *Graphis* sp. (count = 904) and *Dirinaria* sp. (count = 894) exhibited comparatively similar species abundance, with *Chrysothrix* sp. (count = 672) following closely behind. The genus *Pyxine* sp. (count = 171) had the lowest abundance of the four identified species. In Gampaha town, *Chrysothrix* sp. was absent, while *Pyxine* sp. (count = 987) had a relatively higher species abundance compared to *Graphis* sp. (count = 501) and *Dirinaria* sp. (count = 287). In the Ekala industrial zone, both *Chrysothrix* sp. and *Dirinaria* sp. were absent. The genus *Pyxine* sp was highly dominant, with a species abundance of 1548, while *Graphis* sp. was relatively less abundant (Species abundance = 325).

Fig 2: Four dominant lichen genera — (a) *Chrysothrix* sp., (b) *Pyxine* sp, (c) *Graphis* sp., and (d) *Dirinaria* sp., which were identified across the three study sites.

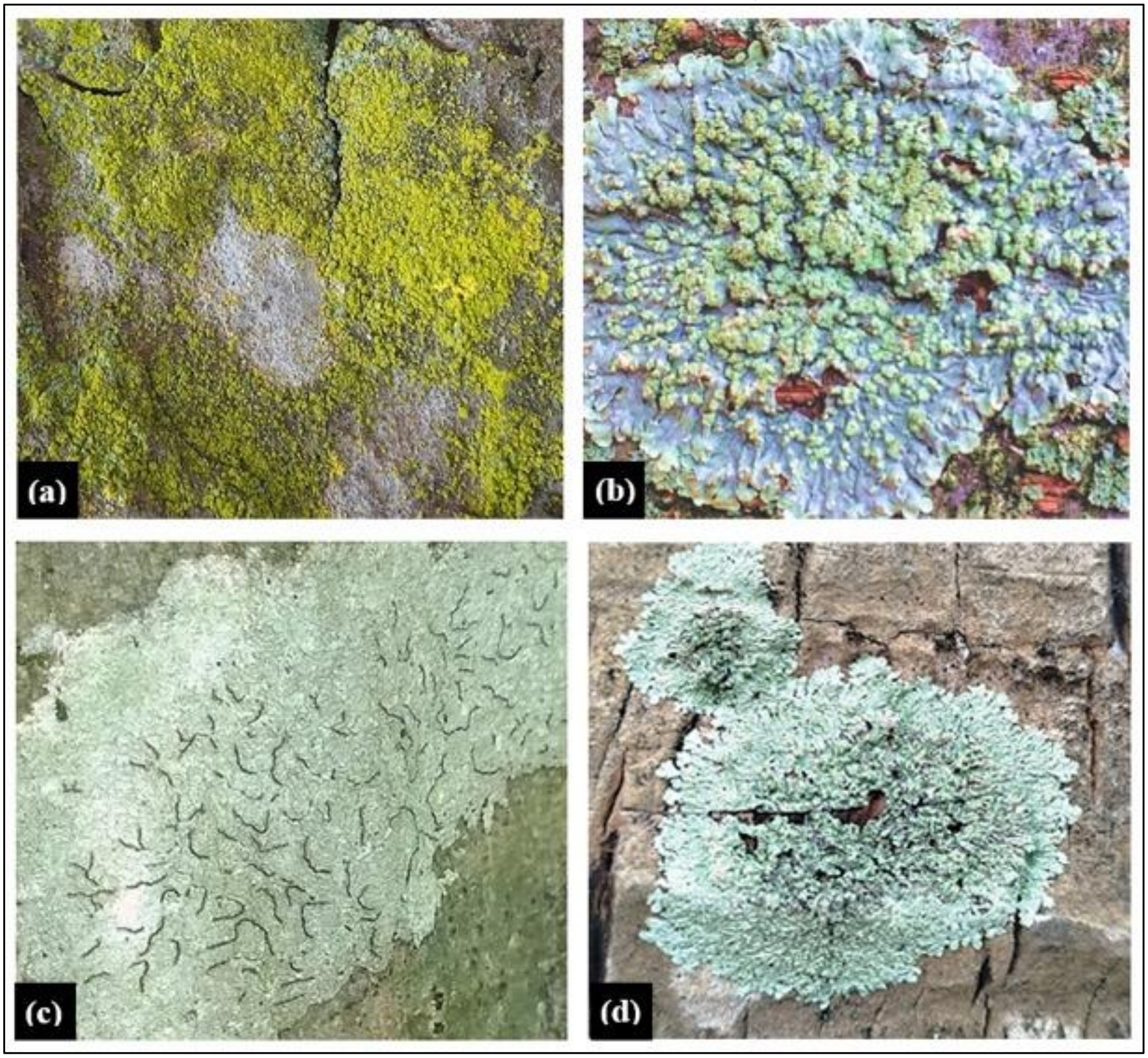


Fig 3: Species abundance of identified lichens in three sampling sites of the study.

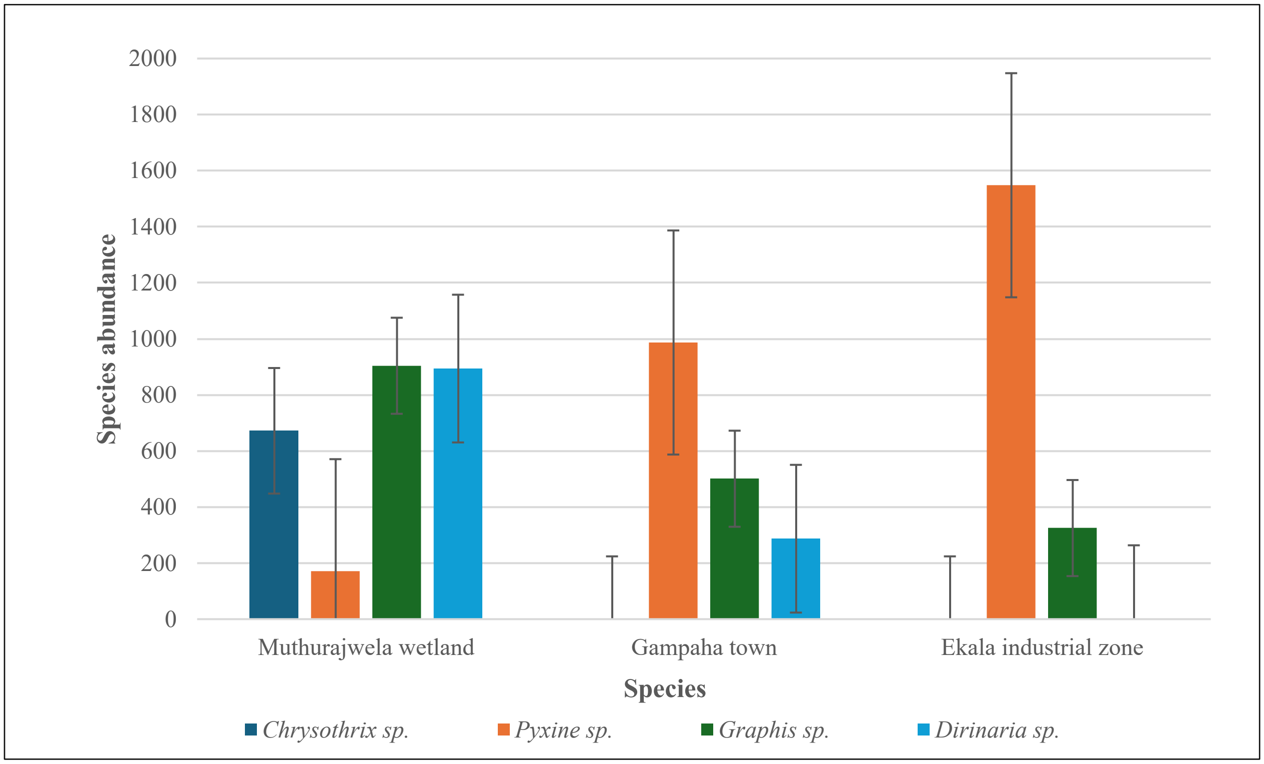


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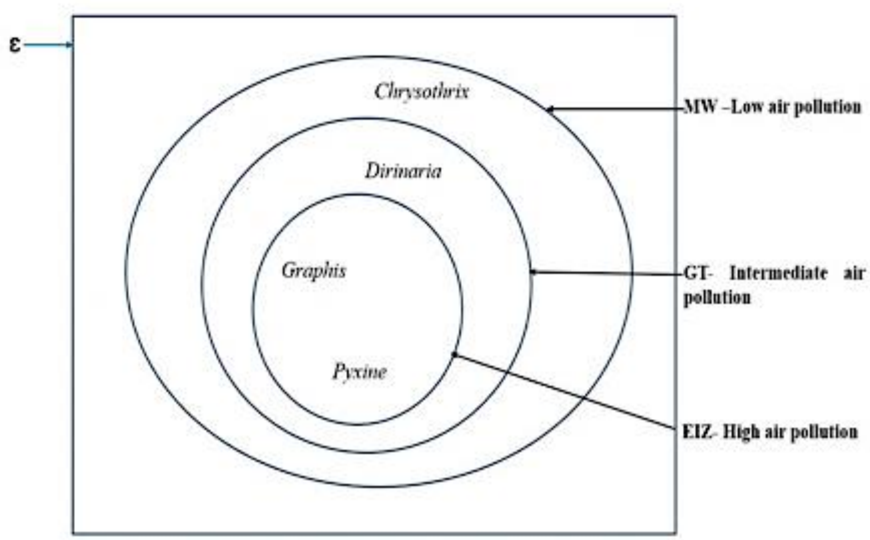
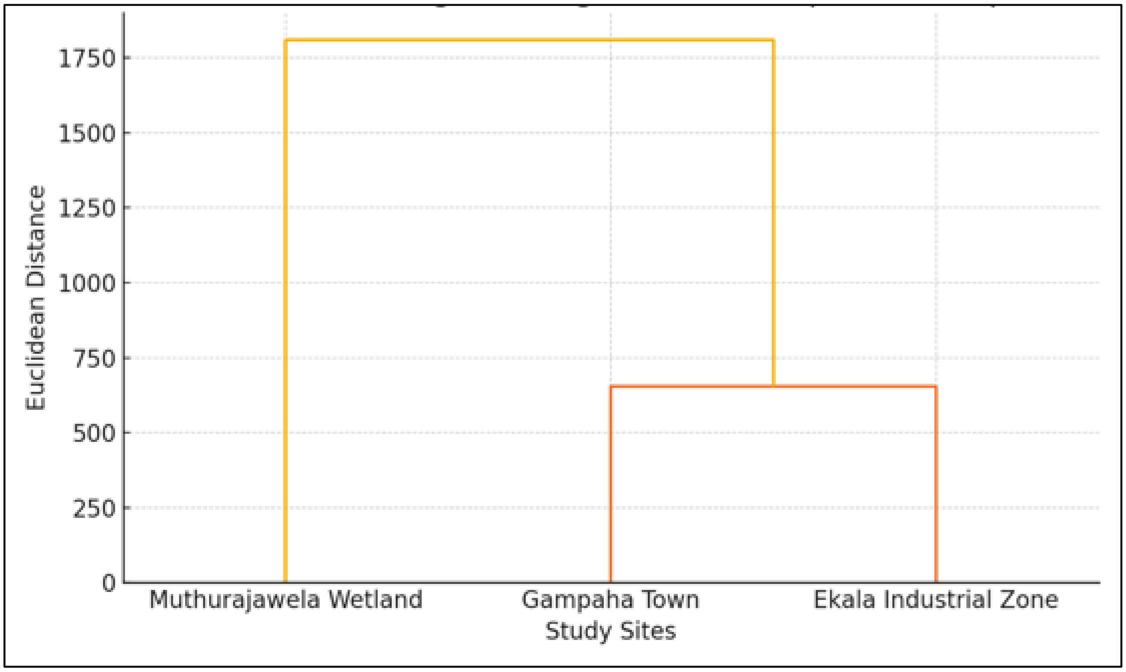
Fig 4: Zonation of collected lichen species in relation to varying levels of air pollution.



The hierarchical cluster analysis dendrogram indicates that Gampaha Town and Ekala Industrial Zone cluster together, indicating they have more similar lichen species compositions, while Muthurajawela Wetland stands separately, reflecting its distinct species distribution pattern as depicted in Fig 05.

Fig 5: Hierarchical cluster dendrogram indicating the similarity of lichen species composition among the three study sites.



According to the Shannon–Wiener diversity index (H′), the Muthurajawela wetland ecosystem exhibited the highest lichen diversity, with a value of 1.26. In Gampaha town, the diversity index was 0.98, while the lowest diversity was recorded in the Ekala industrial zone, with a value of 0.46, as indicated in Table 01.

Pielou's evenness index (E), which describes the distribution uniformity of lichens within the study sites, recorded the highest value of 0.91 in the Muthurajawela wetland. A decreasing trend in evenness was observed with increasing pollution levels, with Gampaha town reporting a value of 0.89 and the lowest evenness recorded in the Ekala industrial zone at 0.67 (Table 01).

The three study sites reported notable differences in the Simpson's Diversity Index (D) and its reciprocal (1/D). Muthurajawela wetland had the highest diversity with a D value of 0.30, which corresponded to a 1/D value of 3.32, suggesting it had a reasonably well-developed lichen community, which was relatively rich and balanced in distribution. The Ekala industrial zone had the lowest species diversity with a D value of 0.71 and a 1/D value of 1.40, which indicates a highly dominated community structure with few abundant species. The Gampaha town site had intermediate levels of species diversity, a D value of 0.41, and a 1/D value of 2.42 (Table 01).

Table 01: Estimated Shannon-Wiener diversity index (H′), Pielou's evenness index (E), and Simpson's Diversity Index (D) values for lichen species in *C. nucifera* trees in three selected study sites in Gampaha District.

Site	Shannon-Wiener diversity index (H′)	Pielou's evenness index (E)	Simpson's Diversity Index (D)	1/ D
Muthurajawela wetland	1.26	0.91	0.30	3.32
Gampaha town	0.98	0.89	0.41	2.42
Ekala industrial zone	0.46	0.67	0.71	1.40

In this study, four lichen species, belonging to the genera *Chrysothrix*, *Pyxine*, *Graphis*, and *Dirinaria,* were identified, but their abundance varied significantly depending on the pollution levels. The occurrence of various lichen species was higher in rural ecosystems than in semi-urban or urban ecosystems, as observed from a study carried out in India (Das, 2008).

In the Muthurajawela wetland, the higher diversity of lichens indicated a relatively clean air quality, as all four species were present and showing relatively high abundance. The genus *Graphis* was the dominant lichen species, followed by the genus *Dirinaria. Chrysothrix* was also reported in relatively high abundance, while *Pyxine* sp. had the lowest abundance. Generally, the genus *Graphis* is more abundant in less air-polluted environments. This species was particularly dominant in the wetland, indicating the area's lower concentration of industrial emissions. *Graphis* species are corticolous lichens dominating unpolluted environments, especially on tree barks in rural settings where air pollution levels are minimal (Conti, 2008). Due to the sensitivity of this species, the sensitivity of *Graphis species* to pollutants like SO_2 and NO_2 makes them dominant in regions with high air quality and low environmental disturbances or industrial emissions. Similarly, *Dirinaria* sp. is slightly more tolerant than *Graphis* sp., but prefers relatively clean environments, and their high numbers further indicate that pollution levels in the wetland are minimal. *Chrysothrix* sp. was also present in significant numbers, though lower than *Graphis* and *Dirinaria.* This genus is generally found in stable, undisturbed environments with high humidity (Ismail et al., 2024). Among the four identified genera, *Pyxine* sp. had the lowest species abundance in the Muthurajawela wetland. The genus *Pyxine* is a pollution-tolerant genus that tends to grow in urban and industrial zones. Its low abundance in the wetland suggests that the air quality is too clean for *Pyxine* to be dominant, reflecting that the Muthurajawela has a low-pollution environment where more sensitive lichens outgrow pollution-resistant species.

In the Gampaha town area, the absence of genus *Chrysothrix* suggests that this genus is highly sensitive to urban pollution and environmental disturbances. *Chrysothrix* sp. generally prefer stable and undisturbed habitats, indicating that the air quality and environmental conditions in Gampaha are unsuitable for their survival. This absence indicates the presence of moderate to high fluctuations in the levels of NO_2 and SO_2 in Gampaha town. In contrast, the lichen genus *Pyxine,* which is more tolerant of pollution, exhibited relatively higher species count in Gampaha. *Pyxine* is a pollution-tolerant genus and tends to dominate in areas where air quality is degraded. This increased abundance of *Pyxine* suggests that the urban environment in Gampaha has pollution levels high enough to suppress more sensitive species but still allows tolerant lichens to thrive. The presence of *Graphis* sp. and *Dirinaria* sp. in lower abundance compared to the Muthurajawela wetland indicates that these genera prefer cleaner air and are being negatively impacted by urban pollution. *Dirinaria* sp., with its moderate pollution tolerance, also exhibited a decline in abundance, confirming that while it can survive in a semi-urban environment, it does not thrive in the highly polluted urban areas of Gampaha.

In the Ekala zone, *Chrysothrix* sp. and *Dirinaria* sp., the complete absence of the lichen genera *Chrysothrix* sp. and *Dirinaria* sp. indicates their high sensitivity to industrial pollution. *Chrysothrix* sp. typically thrives in stable and clean environments but struggles to survive in harsh conditions, most likely due to exposure to high levels of NO_2 and SO_2. Similarly, *Dirinaria* sp., with its moderate pollution tolerance, was also absent, suggesting the air quality in Ekala has surpassed its tolerance threshold. *Dirinaria* generally prefers light-abundant, humid environments and may be unable to withstand dry heat or particulate matter prevalent in the industrial area (Ritchie, 2014). The complete absence of these genera confirms that Ekala has severe air pollution, making it an unsuitable habitat for sensitive and semi-tolerant lichen species. *Pyxine* sp. was more resilient due to its relatively higher tolerance to air pollutants (Banerjee et al., 2023). Various studies that have been carried out in different countries reported that *Pyxine* sp. is capable of withstanding air pollution in urban settings (Saipunkaew et al., 2005). Some *Pyxine* sp. growing within the industrial area are the most tolerant, having accumulated higher levels of heavy metals (Asta et al., 2002).

Pyxine sp. was the dominant genus in Ekala, with an exceptionally high species count. *Pyxine* has a high pollution tolerance and the ability to survive in harsh, disturbed environments. Its dominance in Ekala suggests that it is one of the few lichen genera that has the morphological features to tolerate continuous exposure to industrial pollutants. The significant increase in *Pyxine* sp. abundance indicates that the industrial zone has an environment where only the most pollution-resistant lichens can survive. It was reported in previous research that *Pyxine* was the second most abundant lichen in semi-urban ecosystems, and it was the dominant lichen genus found in urban ecosystems (Yatawara & Dayananda, 2019).

In contrast, *Graphis* sp. was present but in much lower abundance compared to *Pyxine*. The reduced number of *Graphis* species suggests that even though Graphis sp. is more adapted to low air pollution, some species in the *Graphis* genus have the tolerance to persist in polluted environments, and struggle to thrive under extreme industrial pollution levels. *Graphis* is generally sensitive to high levels of SO_2 and NO_2 emissions, and its presence in Ekala indicates that certain microhabitats within the zone may provide some favorable conditions for its survival. The identified *Graphis* species was also observed at locations distant from the core of the industrial zone.

The results from the cluster analysis show distinct patterns of the lichen species composition in the three study sites designated in the analysis. Gampaha Town and Ekala Industrial Zone formed a single cluster, which suggests these urban and industrial regions have a more virulent impact on environmental conditions that affect lichen diversity. This similarity might be due to greater air pollution, human activity, and less vegetation cover, which comes with urbanized and industrialized regions. On the other hand, Muthurajawela Wetland is clustered differently, which shows that the lichen community structure and its composition are more complex. The unusual clustering of the wetland site might be more stable, providing a range of different species that are adapted to living in wetlands.

In this study, the Shannon-Wiener diversity index (H′) and Pielou's evenness index (E) were used to determine the diversity and evenness of the lichen species found on *C. nucifera* trees across three distinct study sites. The Shannon-Wiener diversity index (H') for each location demonstrated a clear trend. Diversity was highest in the less polluted Muthurajawela wetland and decreased with increased pollution levels in Gampaha town and the Ekala industrial zone. These results align with the established understanding in previous research that lichens are sensitive to air quality changes, especially to pollutants such as SO_2 and NO_x (Gupta, 2024).

In the Muthurajawela Wetland, the Shannon-Wiener diversity index (H′) was reported as 1.26, indicating a comparatively higher level of lichen species diversity in the wetland ecosystem. The higher Pielou's evenness index (E = 0.91) suggests that those lichen species are distributed relatively evenly across the site, with no single species dominating due to low air pollutant concentrations and high air quality. According to the previous research done in Sri Lanka, the highest lichen diversity was recorded from rural ecosystems, and the low level of disturbance and relatively high moisture contents caused a low level of environmental stress for epiphytic lichen development and increased the lichen diversity in rural ecosystems (Yatawara & Dayananda, 2019).

In Gampaha Town, the Shannon-Wiener diversity index (H′) was moderate at 0.98, indicating reduced species diversity compared to the wetland site. However, the evenness index (E = 0.89) remains comparatively high, indicating that although the total number of species is lower, the identified species are still reasonably evenly distributed. This could reflect an urban environment where air pollution limits the number of lichen species, but the remaining species can coexist without one becoming overly dominant. The low diversity of lichen species in the urban area indicated the possible air pollution due to vehicular emissions.

The Ekala Industrial Zone reported the lowest Shannon-Wiener diversity index (H′ = 0.46) and a significantly lower evenness index (E = 0.67). The low diversity in this industrial zone suggests that the deterioration of air quality is associated with severe industrial activities that emit high concentrations of NO_2 and SO_2, potentially restricting the survival of lichen species. Epiphytic lichens are highly sensitive to phytotoxic gases such as NOx and SOx (Sett & Kundu, 2016). The reduced evenness index also indicates that a few species, such as the more pollution-tolerant *Pyxine* sp., may dominate the site, while other species are either absent or sparsely present. The low diversity in these highly polluted areas may be attributed to poor dispersal, unsuitable environmental conditions, and the lack of specialized habitats for lichen growth and development (Yatawara & Dayananda, 2019).

Simpson's Diversity Index (D) ranges from 0 to 1, where a value of 0 indicates infinite diversity and a value of 1 signifies no diversity, meaning only one species is present. The variation in Simpson's Diversity Index (D) and its reciprocal (1/D) across the study sites indicates variations in environmental conditions and air quality. Muthurajawela Wetland, with the highest diversity (D = 0.30), supports a well-developed lichen community due to high air quality. In contrast, the Ekala industrial zone shows the lowest diversity (D = 0.71), indicating a highly dominated community with few species, likely due to high air pollution and habitat alteration. Gampaha town, with intermediate diversity (D = 0.41), offers a mix of urban and natural air quality environments that support a moderately diverse lichen community. These variations emphasize how air quality can affect species richness and community structure in lichens.

This research offers valuable insights into the relationship between air quality and lichen diversity, with significant implications for the agricultural sector in Sri Lanka. The agriculture industry, particularly in tropical countries like Sri Lanka, is strongly linked to changes in environmental quality and air quality fluctuations, such as changes in nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) concentrations, which can affect crop productivity and ecosystem health. The findings of this study demonstrate how lichens, especially the species growing on *Cocos nucifera*, a major agricultural crop in Sri Lanka, serve as effective bioindicators to monitor air pollution across diverse landscapes, including agricultural zones. Understanding the spatial variation in lichen diversity in relation to air pollution can help agricultural specialists identify high-risk areas for pollutant accumulation, which may lead to the reduction of crop yield. This bioindicator approach promotes sustainable agricultural practices by identifying environmental stressors and enhancing agro-ecological resilience in rural, semi-urban, and urban farming regions of Sri Lanka.

4. Conclusion

This study demonstrates that lichen genera are effective bioindicators of air pollution, with their diversity and abundance closely reflecting environmental air quality across different landscapes. The clear gradient observed—from high diversity and evenness in the low-pollution Muthurajawela wetland to the low diversity in the highly polluted Ekala industrial zone underscores the sensitivity of certain lichen genera, such as *Chrysothrix* and *Dirinaria*, to atmospheric pollutants like NO_2 and SO_2. The dominance of *Pyxine* in more polluted environments highlights its tolerance and potential as a reliable indicator in degraded habitats. The use of lichen-based indices, including the Shannon-Wiener diversity index and Pielou's evenness, provides valuable quantitative insights into pollution impacts. Assessing the air quality in those selected areas is important to select the most suitable crops to grow there. Therefore, this lichen-based air quality monitoring approach also promotes sustainable agriculture in the Gampaha district. This research affirms the utility of lichen monitoring as a low-cost, ecologically sound method for air quality assessment, particularly in tropical and developing regions. Future studies should explore species-specific pollutant responses and chlorophyll content as additional tools for pollution monitoring and sustainable land use planning.

5. Acknowledgment

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