3BIO: Journal of Biological Science, Technology and Management 6(2): 256-266
e-ISSN: 2655-8777
http://journals.itb.ac.id/index.php/3bio

Biomonitoring of Air Quality Using Lichen as Bioindicator in The Greater Bandung Area, West Java

Dora Erawati Saragih[1*], Rina Ratnasih Irwanto[1] , Taufikurahman[1]

[1)] School of Life Sciences and Technology, Institut Teknologi Bandung

*) Corresponding author; e-mail: doraerawati@gmail.com
Received: 2023-12-01
Accepted for publication: 2024-11-25

Abstract

Air quality assessment in an area can be determined by conducting biomonitoring using bioindicator organisms, including lichen. Lichen is a symbiotic organism that passively absorbs nutrients and chemical compounds from the air. This research was conducted in the Greater Bandung area, including Bandung City and West Bandung Regency, to observe the abundance of lichen species so that the purity of the atmosphere could be evaluated at each research location and determine the effect of environmental variables on lichen abundance.The survey area was divided into 40 units spread over two locations in Bandung, namely Djuanda street (JD), Kebon Kawung street (KK), and two locations in West Bandung Regency, namely Padalarang street (PD) and Curug Cimahi (CC). CC locations with low levels of pollution were used as comparison areas. Lichen samples from observation locations were identified, and the number of colonies, frequency of closure, and diversity (H') were counted so that the Index of atmospheric purity (IAP) value at each observation location could be known. As many as 24 species from 14 lichen families with a total of 256 colonies were found in the four observation sites with the percentage of thallus crustose (62%), foliose (37%), and fruticose (1%). The highest lichen diversity was found in the CC area (2.62), followed by JD (1.99), PD (1.63), and the lowest in KK (0.90). The lowest IAP result was in KK (10.21), followed by PD (17.70) and JD (31.85). The location with the highest IAP was obtained at CC (46.65), indicating that the environmental conditions were still good, while other locations were polluted.

Keywords: *Biomonitoring, lichen, bioindicator, air quality*

1. Introduction

In the last few decades, there has been a decrease in air quality caused by several factors, including the use of fuel in transportation and motorized vehicles [1]. The higher the population growth in an area, the more transportation needs will increase [2]. Bandung area is densely populated area, with the growth of the transportation sector rising by 11% peryear. The ratio of the number of vehicles to the population is 3:4, with 72% of all registered cars being motorcycles [3]. This can increase air pollution due to toxic emissions suchas particulate matter (SPM10), lead, CO, hydrocarbons (HC), SOx, Ox, and NOx that are released into the environment, which results in decreased air quality and impacts public health [4]. Therefore, the government has issued an air pollution control policy to monitor ambient air quality using continuously operating devices, and the data can be observed directly. The installation devices process requires more costs and regular maintenance; therefore, its use isstill limited. Another approach as monitoring systems using physicochemical methods also limited to monitoring certain chemical compounds or pollutants and could not describe the effects of pollutants on living organisms [5]. Evaluating dynamic changes in environmental quality by observing at the response of living things systematically is a biomonitoring activity that uses the principle of repeated measurements on chemical/biochemical markers related to specific exposures to the observed bioindicators [6]. Bioindicators can reflect the quality of an environment or provide an overview of the ecological situation through its presence, absence, or behaviour closely related to a specific environmental status [7]. One of the organisms that can be used as a bioindicator is lichen. Lichen is a symbiotic organism between fungi (mycobiont) and algae (photobiont). The mycobiont component strengthens the body and absorbs water and minerals, while the photobiont

DOI: 10.5614/3bio.2024.6.2.3

Figure 1. Research Study Area

produces food by photosynthesis [8]. The interaction of these two organisms forms a unique morphology, reproduction,and classification system. Lichen is the most common organism used as an air pollution biomonitoring tool becauseit is proven effective in describing the conditions of various pollutants in the atmosphere. Lichens does not have a cuticle layer, stomata, and absorptive organs, therefore it passively absorbs water, air, and environmental nutrients into its intracellular tissues [3]. These characteristics make lichen susceptible to toxic or harmful compounds in the form ofair pollutants. In tropical countries, it has been demonstrated that environmental factors and air pollution directly affect lichen diversity and distribution [6]. Studies on lichen as a bioindicator of air quality have been carried out in various cities in Indonesia, such as Jakarta, Semarang, Pekanbaru, Kendari, and Medan. Among them is the discovery of the Lepraria incana species, a lichen species that can survive at lowto moderate air pollution intensities in Bandung [9]. Lichens respond to environmental changes by reflecting in their diversity, abundance, morphology, physiology, and pollutant accumulation in their thallus [6]. Therefore, biomonitoring ofair pollution using lichen could be based on two approaches, namely analysing the diversity of lichen and determiningheavy metals concentration in lichen thallus in areas with different levels of pollution [10]. Thus, this study utilizes these two biomonitoring approaches to monitor air qualityin four regions of Bandung Raya. This approach was carried out by analysing lichen diversity and abundance analysis to analyse lichen response to air quality in Bandung Raya and calculate the Index of Atmospheric Purity (IAP) based onthe frequency of thallus lichen closure. IAP value calculation helps determine air quality in Bandung Raya. According to [11], IAP is a quantitative analysis used to evaluate the level of pollution affecting lichens. This research was conducted in January-September 2022 in Bandung Raya area. Two locations are in the Bandung city, namely Ir. Haji Djuanda street (JD) (6^o52’22”S;107^o36’59”E) and Kebon kawung street (KK) (6^o54’45”S;107^o36’05”E), and two locations in West Bandung Regency, namely Padalarang street (PD) (6^o50’38”S;107^o29’11”E), and Curug Cimahi (CC) (6^o47’55”S;107^o34’32”E) as comparison stations (Figure 1).

2. Methodology

2.1 Data collection

Lichen samples were taken purposively at each station. 10 sample trees were chosen with a minimum distance of 3 m between trees to avoid tree shade. The area of lichen observation was carried out on the surface of the bark on the side facing the road as high as ±130 cm from the ground surface, using a transparent plastic quadrant frame measuring 25x25 cm [12]. After installing the plastic quadrant frame on the tree trunk, the type and amount of lichen in the quadrants were recorded. Lichen samples were taken by scraping the bark using a knife, then stored in an envelope and labeled/ described in the form of name, date, and place of sampling, as well as color and life form of lichen for further analysis. The coordinates of sampling station were recorded using GPS.

Environmental data collection

The environmental factors measured were air temperature and humidity, light intensity, tree bark pH, tree distance to the main road, and the volume of vehicles passing through the observation area. Air temperature and humidity measured using a sling psychrometer while for light intensity, using a lux meter. Microclimate data collection was carried out with three repetitions starts at 09.00 – 11.00 at each station. pH measurements on tree bark were carried out based on the method [13] with modifications. Research [2] suggests that the method used for calculating traffic volume is carried out at peak hours at The traffic volume calculated only motorized vehicles at peak hours suggested by (2) that is 07.00-08.00 WIB or 16.00-18.00 WIB. Measuring the distance of trees to

DOI: 10.5614/3bio.2024.6.2.3

the road is done using a rolling meter.

2.2 Data Analysis

Lichen Diversity

The lichen species were identified by observing the morphology and anatomy of the lichen [14]. Then the diversity index from each observation station was calculated by the Shanon-Weiner (H') diversity index with the formula:

$$H' = \sum_{i=1}^{s} (pi)(ln\, pi)$$

H' = Shannon-Wiener Diversity Index

Pi = ∑ni/ N

Ni = Number of individuals (species)

N = Number of individuals of all species

The calculation of lichen cover area is calculated based on the formula:

$$A = \frac{Wt}{Wi}\, x\, 1\, cm^2$$

A = Area of lichen closure

Wt = Total weight of HVS paper measured by area (mg)

Wi = Weight of HVS paper with an area of 1 cm^2

The lichen cover area is expressed in %, the closing percentage is calculated based on the formula:

$$\text{Frequency (\%)} = \frac{A}{A_k}\, x\, 100\%$$

A = Covering an area of lichen

Ak = Area squared (25 cm x 25 cm)

Calculation of the value of IAP (Index of Atmospheric Purity)

Environmental quality assessed by Index of Atmospheric Purity (IAP)[13]:

$$IAP = \frac{1}{10} \sum_{i}^{n} (Qi\, x\, fi)$$

IAP = Index of Atmospheric Purity

Qi = Ecological index (average number of species i), calculated based on the number of species found in an area divided by the total number of species found in the entire observation area.

Fi = Index of combination between frequency and lichen cover in an area

The meaning of the IAP values will be represented by table 1 [12]

Table 1. Interpretation of the IAP (Index of Atmospheric Purity) values

Pollution level	Criteria	Description
Level A	0≥IAP≤12,5	Very high pollution
Level B	12,5<IAP≤25	High pollution
Level C	25<IAP≤37,5	Moderate pollution
Level D	37,5<IAP≤50	Low pollution
Level E	IAP>50	Very low pollution

Statistic Analysis

The relationship between environmental parameters such as humidity, light intensity, temperature, tree bark pH, and tree distance from emission sources (roads) with lichen cover frequency analyzed using Spearman's correlation and factor analysis using Principal Component Analysis (PCA). This analysis is one of the mathematical models to describe the relationship between air quality and microclimatic factors that can be used to understand how changes in microclimatic. The data analyzed statistically using *Minitab 21.*

3. Results and Discussion

3.1. The proportion of lichen species based on morphology

Identification results showed that 24 species from 15 lichen families grew on tree substrates at observation stations in Bandung Raya. The number of lichens found at each stationis shown in Table 2. Lichens in Bandung Raya have varying colours, shapes, and thallus sizes. The lichen thallus colours included orange, green, grey, white, and yellow, with a talus size of ± 4-40 cm2. The most common lichens were found at observation stations CC as controls, JD, and PD, and the least was found in KK. The lichen species found were from different families, and based on the morphology of the thallus, the lichens were grouped into crustose (62%), foliose (37%), and fruticose (1%) (Figure 2).

In this study, the lichens analysed were lichens attached to tree trunks with a circumference of ≥50 cm (Table 3). Each tree species has a different canopy and bark texture, so lichens also has preference living and growing on certain tree species. Lichen cannot be found in all types of trees because, according to research conducted by [13], differences in tree bark texture

 DOI: 10.5614/3bio.2024.6.2.3

Table 2. The total number of lichen species

Lichen Species	Family	Morphological Type	∑ Colony
Cryptothecia striata	Arthoniaceae	Crustose	26
Bacidia viridifarinosa	Bacidiaceae	Crustose	17
Dirinaria applanate	Caliciaceae	Foliose	4
Dirinaria picta	Caliciaceae	Foliose	18
Buellia sp.	Caliciaceae	Crustose	5
Chrysothrix xanthina	Chrysotrichaceae	Crustose	3
Leptogium sp.	Collemataceae	Foliose	5
Collema subflaccidum	Collemataceae	Foliose	6
Graphis sp.	Graphidaceae	Crustose	17
Hemithecium chrysenteron	Graphidaceae	Crustose	4
Lecidella elaeochroma	Lecanoraceae	Crustose	7
Lecanora sp.	Lecanoraceae	Crustose	14
Megalospora tuberculosa	Megalosporaceae	Crustose	4
Parmelia sp.	Parmeliaceae	Foliose	22
Parmothrema sp.	Parmeliaceae	Foliose	16
Heterodermia japonica	Parmeliaceae	Foliose	4
Canoparmelia aptata	Parmeliaceae	Foliose	5
Phlyctis argena	Phlyctidaceae	Crustose	23
Fulgensia sp.	Phlyctidaceae	Crustose	17
Physcia sp.	Physciaceae	Foliose	12
Pyxine cocoes	Physciaceae	Foliose	15
Lepraria incana	Stereocaulaceae	Crustose	50
Xanthoria sp.	Teloschistaceae	Foliose	3
Ramalina sp.	Ramalinaceae	Fruticose	4

Table 3. Lichen-growing substrate tree

Tree Species	Research Area			
	JD	KK	PD	CC
Artocarpus altilis	√	√	√	√
Swietenia mahagoni	√	–	–	–
Filicium decipiens	–	√	√	–
Roystonea regia	√	–	√	–
Mimusops elengi	–	–	√	–
Ficus benjamina	–	√	–	–
Maesopsis eminii	–	–	√	√
Schima wallichii	√	–	–	–
Toona sureni	–	–	–	√
Eucalyptus deglupta	–	–	–	√
Pterocarpus indicus	–	√	–	–
Samanea saman	√	√	√	–
Diospyros celebica	–	–	–	√

DOI: 10.5614/3bio.2024.6.2.3

Figure 2. Crustose thallus lichen: (a) *Lepraria incana*, (b) *Phlyctis argena*, (c) *Chrysothrix xanthina*, (d) *Lecidella elaeochroma*, (e) *Fulgensia* sp., (f) *Lecanora* sp., (g) *Graphis* sp., (h) *Buellia* sp., (i) *Hemithecium chrysenteron*, (j) *Cryptothecia striata*, (k) *Megalospora tuberculosa*, (l) *Bacidia viridifarinosa*

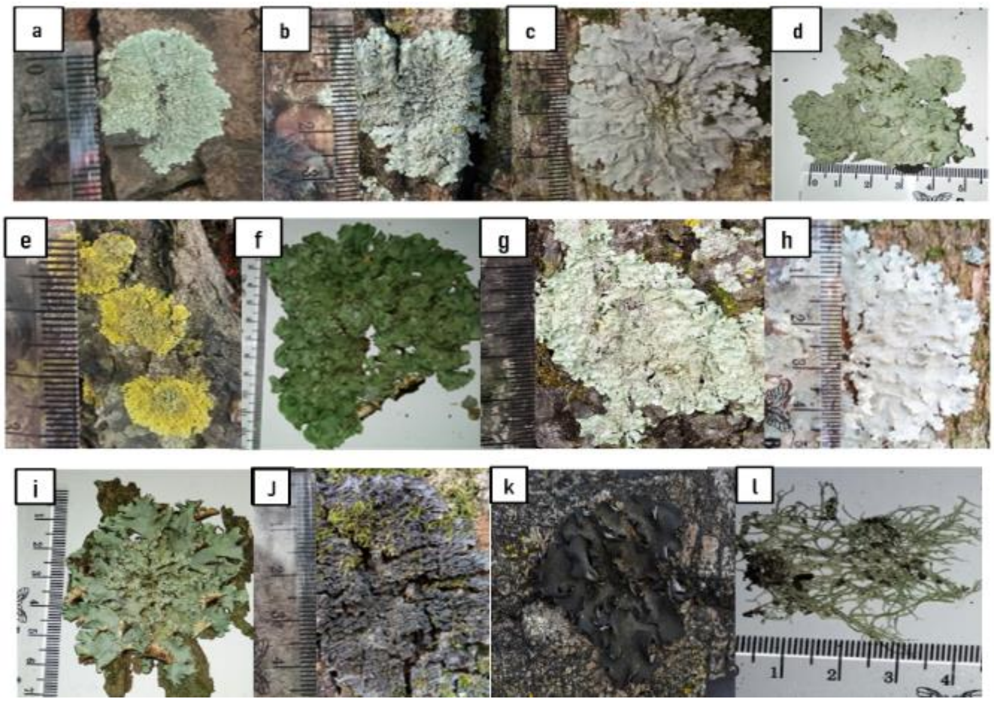

Figure 3. Foliose and fruticose thallus lichen: (a) *Dirinaria applanata*, (b) *Dirinaria picta*, (c) *Pyxine cocoes*, (d) *Parmelia* sp., (e) *Xanthoria* sp., (f) *Parmotrema* sp., (g) *Canoparmelia aptata*, (h) *Physcia* sp., (i) *Heterodermiajaponica*, (j) *Collema subflaccidum* (k) *Leptogium* sp. (l) *Ramalina* sp.

DOI: 10.5614/3bio.2024.6.2.3

affect lichen growth regardless of the various pollutant factors exist around the study site. Differences in the type and texture of tree bark as a lichen substrate affect the type of lichen that can grow.

Lichens in Bandung Raya have varying in colours, shapes, and thallus sizes. The lichen thallus colours included orange, green, grey, white, and yellow with a thallus size of ± 4-40 cm^2. The highest number of lichens were found at the CC observation station as a control, following by station JD,PD, and the least in KK. Based on the morphology of the thallus, the crustose type has a higher number and found in allobserved tree species in Bandung Raya site. Crustose lichen isa type of lichen that is strongly attached within a colony shapeto be rounded although sometimes has an irregular shape. The variation of lichen with a basic crustose form can be seen in figure 2.

Lichen foliose is a type of lichen with a thallus shape like a leaf blade. This type of lichen is commonly found in the CC area, and lichen fruticose is member of Ramalinaceae witha light green thallus. This species is often seen hanging from the bark of tree trunks at an altitude of > 1.2 meters from the ground. Research by [15] shows that this species grows in an open areas with low levels of air pollution, therefore, this species could also indicate of air pollution (Figure 3).

Number of Colonies and Frequency of Lichen Closure

Based on the number of colonies, species *L. incana*, *D. picta*, and *P. cocoes* had colonies that could be found in all observation sites. Meanwhile, *Ramalina* sp., *H. japonica*, *M. tuberculosa*, *H. chrysenteron*, and *D. applanate* were only found at one observation area and had fewer colonies than other species. The presence and absence of lichen species in an area indicate the potential of these species to become bioindicators of environmental quality. At each observation station, several lichen species have a higher frequency of closure than other species, related to the tolerance range of lichens to survive in various air pollution conditions and surrounding environmental conditions. Based on figure 4, it can be seen that the species in the KK and PD locations have fewer species than in JD and CC locations. Species in urban areas such as KK and PD areas are generally tolerant of air pollution. In general, susceptible species in this area experience an increase in frequency as air pollution increases.

The total frequency of lichen cover is much influenced by environmental factors such as humidity, light intensity, temperature [12], pH of tree bark, and tree distance to emission sources (roads), where the higher frequency of lichen cover indicates its ability to survive in the surrounding environment. In addition, lichen species are more chemically protected to

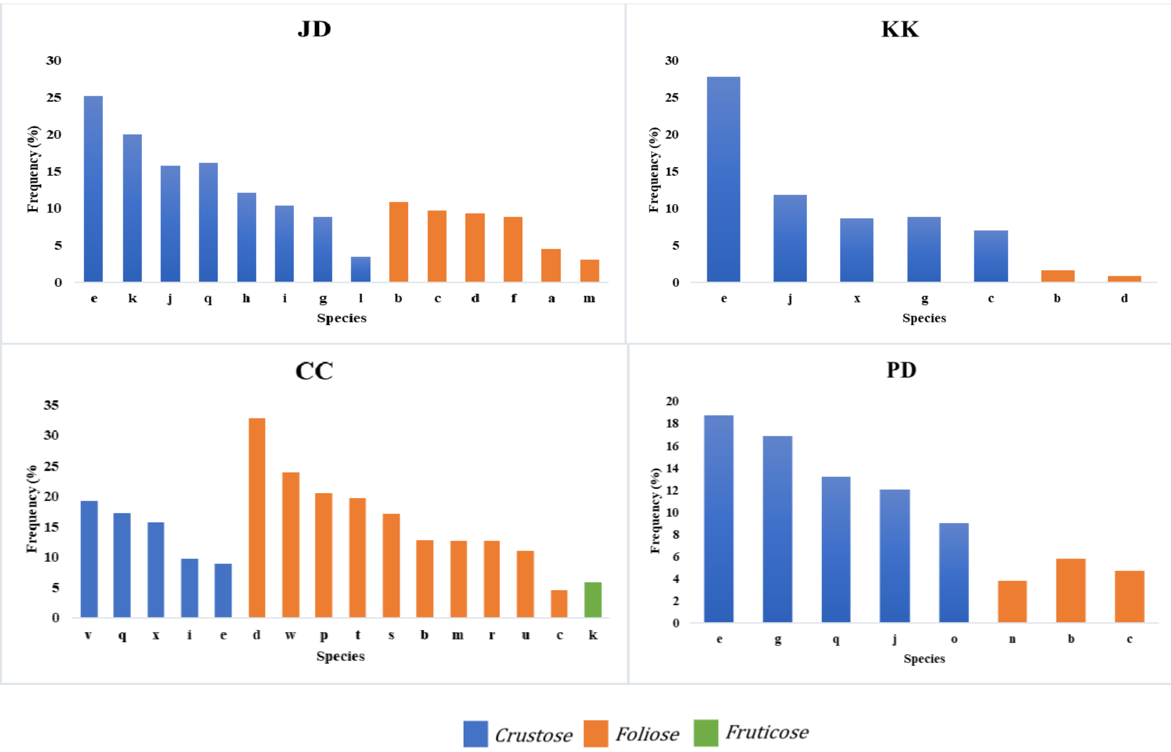

Figure 4. Frequency of lichen cover in all observation areas: (a) *Dirinaria applanata*, (b) *Dirinaria picta*, (c) *Pyxine cocoes*, (d) *Parmelia* sp., (e) *Lepraria incana*, (f) *Xanthoria* sp., (g) *Phlyctis argena*, (h) *Chrysothrix xanthina*, (i) *Lecidella elaeochroma*, (j) *Fulgensia* sp., (k) *Lecanora* sp., (l) *Graphis* sp., (m) *Collema subflaccidum*, (n) *Buellia* sp.,(o) *Hemithecium chrysenteron*, (p) *Parmotrema* sp., (q) *Cryptothecia striata* (r) *Ramalina* sp., (s) *Leptogium* sp., (t) *Canoparmelia aptata*, (u) *Physcia* sp., (v) *Megalospora tuberculosa*, (w) *Heterodermia japonica*, (x) *Bacidia viridifarinosa*

 DOI: 10.5614/3bio.2024.6.2.3

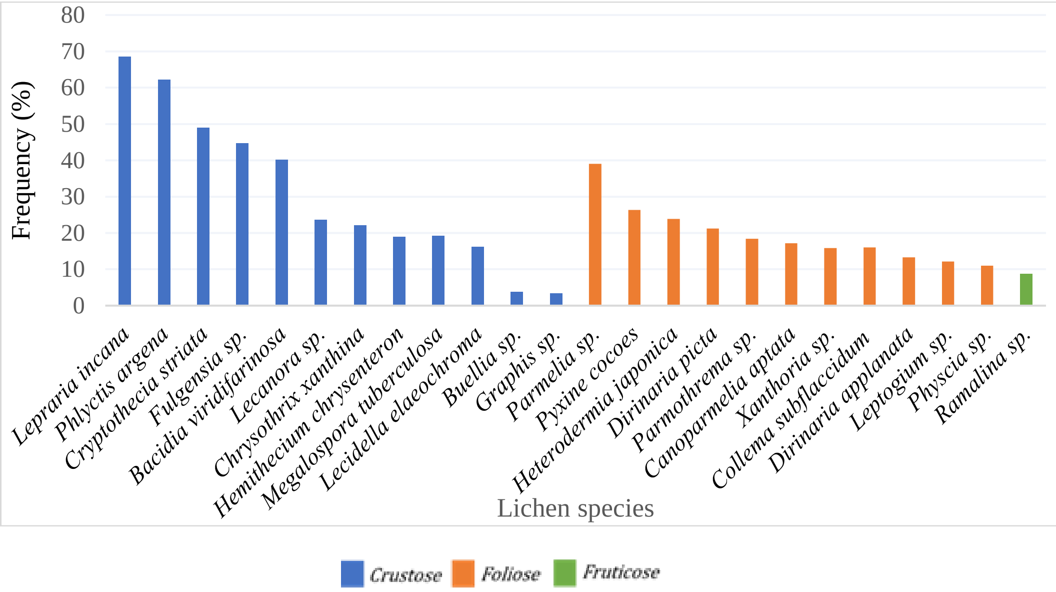

Figure 5. The total frequency of lichen cover

live in urban areas with higher pollution levels, drier, and more light intensity [12]. Figure 5 shows that there are three lichen species with the highest total coverage frequency for the crustose type, namely *L. incana* (68%), *P. argena* (62%), and *C. striata* (49%). In contrast, the foliose type is *P. cocoes* (39%), *Parmelia* sp. (26%), *D. Picta* (24%). This shows that the six lichen species were most often found in the observed trees. This indicates that the tolerance range of the six lichen species is large enough to grow in various environmental conditions. Lichens that are rarely found at observation stations are shown to have low-frequency values, including *Ramalina* sp. (0.09%), *Graphis* sp. (0.04%), and *Buellia* sp. (0.03%).

3.2. Correlation of lichen presence on microclimate factors, substrates, anthropogenic

The environmental conditions of an area can affect the diversity of lichens in that area. In this study, Principal Component Analysis (PCA) is a statistical technique that can be used to reduce the dimensionality of data while preserving as much variability as possible. In the context of studying the presence of lichens, PCA can help identify the most important factors (variables) influencing lichen distribution, such as microclimate conditions, substrates, and anthropogenic influences. According to [3], lichen species richness is affected by the humidity, light intensity, and temperature of an area which is indicated by lower lichen species richness in drier places. To determine the correlation between the frequency of lichen cover and environmental factors consisting of average humidity, light intensity, temperature, pH of tree bark, and tree distance to emission sources (roads), the Spearman correlation statistical test was carried out (Table 4). The results show that humidity, tree bark pH, and tree distance to anthropogenic sources (roads) strongly correlate with lichen covering frequency. Humid air conditions indicate an increase in the frequency of lichen closure. The neutral pH of the substrate supports this because the acidity of the substrate is also affected by the distance of the substrate from anthropogenic sources. Meanwhile,light intensity, temperature, and vehicle volume negatively correlate with the frequence of thallus lichen closure. High light intensity will increase air temperature, decreasing the

Table 4. Correlation of lichen presence on microclimate factors,

Variable	Temperature	Light intensity	Distance	Vehicle volume	pH of tree bark	Humidity	Fr (%)
Temperature	1						
Light intensity	0.84**	1					
Distance	-0.614**	-0.768**	1				
Vehicle volume	0.660**	0.758**	-0.918**	1			
pH of tree bark	-0.489*	-0.625**	0.862**	-0.763**	1		
Humidity	-0.656*	-0.580	0.452	0.562	0.514*	1	
Fr (%)	-0.489*	-0.625**	0.862**	-0.763**	0.718**	0.614**	1

** Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).

DOI: 10.5614/3bio.2024.6.2.3

frequency of thallus lichen closure [11].

The PCA results presented in Figure 6 show that *Lepraria incana*, *Phlyctis argaena*, *Fulgensia* sp., are in quadrant IV, together with *Ficus benjamina* and *Pterocarpus indicus*. Thevariables that characterise this quadrant are temperature andlight intensity. The three species are lichens identical to urbanareas with higher temperatures and light intensity, such as theenvironmental conditions in the KK area. In addition, researchby [16] showed that lichens that are tolerant to air pollution,such as *Lepraria* sp. and *P. Argaena*, will increase in the amountand frequence of thallus lichen closure along with increasingtemperature and light intensity with high transport activity. Asin the Philippines, *Lepraria* sp. predominates in cities close to intense transport circulation This happens because the talus can accumulate elements such as heavy metals up to 97% [17].*Graphis* sp., *D. applanate*, *Parmelia* sp., *Lecanora* sp., *Xanthoria* sp., *Buellia* sp., *Physcia* sp., *B. viridifarinosa*, *M.tuberculosa*, *H. chrysteron*, *C. striata*, *L. elaeochroma* species are in quadrant II, together with *Swietenia mahagoni*, *Schimawallichii*, and *Samanea saman*. Tree-to-road distance and tree bark pH characterised this quadrant. It is suspected that the 12species can be found in tree substrates which are more acidicand close to roads such as the JD area. Research conducted by [3] stated that species that are close to highways found more acidic substrates have the potential to neutralise heavy metals in the air.

In quadrant I, *C. sublaccidum*, *C. aptata*, *H. japonica*, *Leptogium* sp., *Ramalina* sp., and *Parmothrema* sp. were found along with *Eucalyptus deglupta*, *Diospyros celebica*, *Toona sureni*. The variable that characterises this quadrant is air humidity. The presence of these species predominates in shady areas with high air humidity, such as the CC area. On the other hand, fruticose lichens, like *Ramalina* sp. found in quadrant I, namely lichen species is affected by moisture. This occurs because *Ramalina* sp. could not be found in all observation stations. After all, this group usually lives in moreundisturbed areas with higher moisture levels and a non-acidicbark pH [13]. Findings of several species, such as *Ramalina* sp. and *Leptogium* sp., which are only found in the CC area, shows that the area still has good air quality because this lichen is sensitive to acidification by air pollution [4]. CC hasmore closed-canopy trees than other areas, making it easier fororganisms to grow. In Mediterranean forests, the growth and development of lichens are closely linked to environmental conditions such as low human disturbance, high shrub cover, and areas with steeper slopes. These factors contribute to creating more stable microclimates and lower levels of humanactivity, which are favorable for lichen communities. Forexample, lichen diversity tends to be higher in forests with dense canopies and lower human impact, as seen in certain oakforests in Spain. Shaded north-facing slopes and areas with reduced disturbance provide optimal conditions for epiphytic

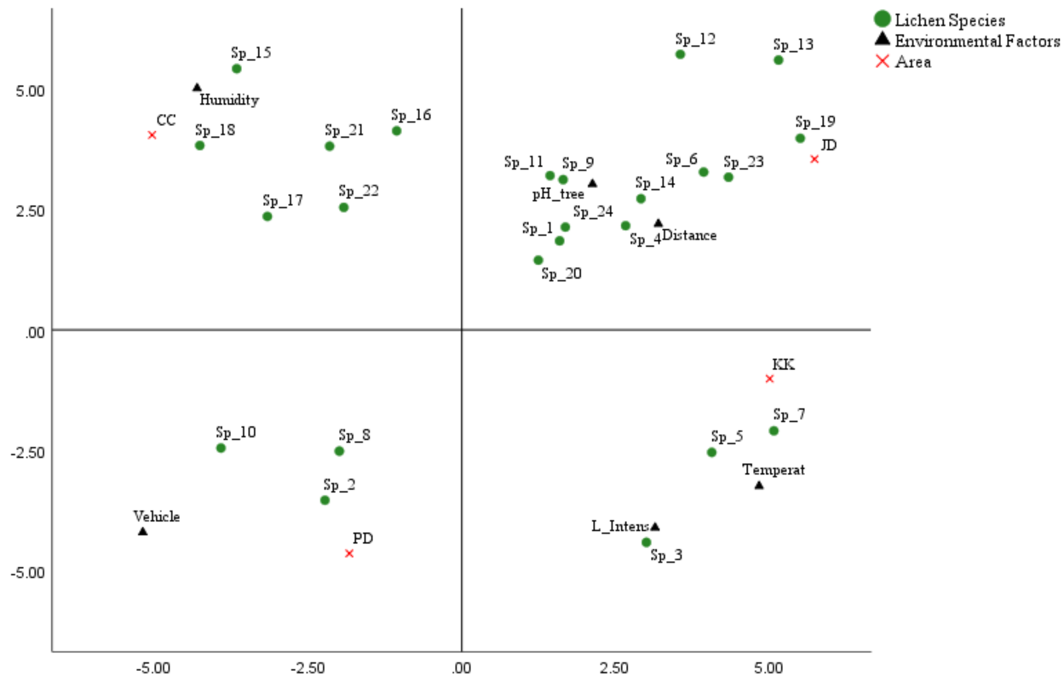

Figure 6. PCA results for lichen species data. **Quadrant I (CC Area)** consists of Sp 15: C. *sublaccidum*, Sp 16: C. *aptata*, Sp 17: H. *japonica*, Sp_18: *Leptogium* sp., Sp 21: *Ramalina* sp., Sp 22: *Parmothrema* sp.; **Quadrant II (JD Area)** consists of Sp 1 *Graphis* sp., Sp 4: D. *applanate*, Sp 6: *Parmelia* sp., Sp 9: *Lecanora* sp., Sp 11: *Xanthoria* sp., Sp 12: *Buellia* sp., Sp 13: *Physcia* sp., Sp 14: B. *viridifarinosa*., Sp 19: M. *tuberculosa*, Sp 20: H. *chrysteron*., Sp 23: C. *striata*., Sp 24: L. *elaeochroma*.; **Quadrant III (PD Area)** consist of Sp 2: P. *cocoes*, Sp 8: L. *elaeochroma*, Sp 10: H. *chrysenteron*; **Quadrant IV (KK Area)** consist of Sp 3: L. *incana*, Sp 5: P. *argaena*, Sp 7: *Fulgensia* sp.

DOI: 10.5614/3bio.2024.6.2.3

lichens, allowing them to thrive due to higher air humidityand less exposure to direct sunlight [18]. In temperate forestsof India, *Quercus semecarpifolia* trees in open canopy forests exhibit the highest lichen cover, with figures reaching up to 70%, while trees in closed canopy forests show only about 40% lichen cover. This variation in lichen cover is influenced by several factors, including tree canopy openness, tree size, and the physical properties of the tree bark [19].

In quadrant IV, *C. xanthina*, *P. cocoes* and *D. picta* were found together with *Roystonea regia*, *Artocarpus altilis*, and *Filicium decipiens*. The variable that characterises this quadrant is the volume of vehicles. .these three species allow it to live in areas with high traffic volumes. Species *L. incana*, *P. cocoes*, *P. argaena*, *Fulgensia* sp., *C. xanthina*, and *D. picta* have the potential as bioindicators of medium-high air pollution because these species are lichens whose existence is found close to anthropogenic sources with high traffic density like in KK, PD, and JD.

the species diversity index value in KK and PD is included in criterion H'<1 namely low lichen species diversity. Based on the dominance index at JD and CC observation stations, the dominance of lichen species is low because there are no dominant lichen species in the area, while in PD and KK, the dominance of lichen species is moderate because there are several lichen species that dominate in the area.

Understanding an organism's pattern of diversity and dominance is critical in conservation and management. In recent years, the design of lichen diversity in Bandung Raya shows that the index value of lichen species tends to decrease along with poor air quality. Ecological factors are essential in lichen species' growth, development, distribution, and diversity. Variations in microclimate conditions, incredibly light, water, and nutrient intensity, driven by local disturbance sources such as roads or agriculture, different land uses, or habitat fragmentation, can affect lichen diversity. A study by [19] stated that metal concentrations accumulated in lichens

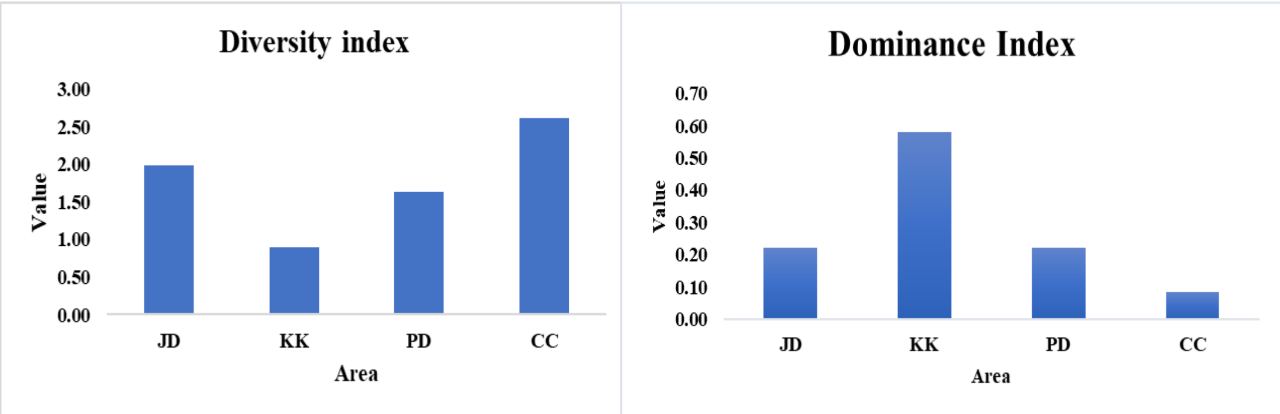

Figure 7. Diversity and dominance Index of lichen

Table 5. Index of Atmospheric Purity measurement results

Area	IAP	Pollution level	Description
Djuanda street	24,85	Level B	High pollution
Kebon Kawung street	10,21	Level A	Very high pollution
Padalarang street	17,70	Level B	High pollution
Curug Cimahi	46,65	Level E	Very low pollution

3.3. Diversity Index and Lichen Dominance

Diversity and lichen dominance can be taken as an estimate of air quality. The higher the diversity value and the lower the dominance value indicate good environmental conditions and vice [17]. In figure 7, the index value of lichen species diversity in CC is included in the index criteria H'>3, which indicates very abundant lichen diversity, JD has an index value of 1<H'<3 which is great lichen diversity, while

correlated with distance to the source of pollution, climatic factors, and land cover, significantly impacting lichen diversity. One of the primary markers of anthropogenic pollution on earth is the decrease in lichen diversity demonstrated at the end of the 19^{th} century in Paris.

DOI: 10.5614/3bio.2024.6.2.3

3.4. Index of Atmospheric Purity

According to the categorization of air quality levels proposed by [3] ba sed on the IAP value, the observation stations with the highest to lowest levels of air pollution are KK, PD, JD, and CC (Table 5). The four observation stations show differences in vehicle emissions caused by differences in traffic volume and good air environmental conditions so that living organisms such as lichens can be maintained. This is to research conducted by [18] that highly disturbed city sites (urban areas with high disturbance) fall into the same category, namely levels A and B. In addition to the high traffic intensity and density that causes air pollution, urban areas also have limited availability of substrates, resulting in changes in microhabitat conditions that can affect biodiversity and lichen frequency. Lichen biodiversity and frequency will generally increase as the distance from the emission source are further away, and the IAP value will increase with the distance from urban areas. The distinguishing factor of the IAP value at these four observation stations is the difference in land use. According to [3] IAP in industrial areas, toll roads, and other urban areas tend to be lower than in areas with natural environmental conditions. Apart from the CC area, the other three regions have the same land use, so it is also observed that the IAP value reflects the similarity of lichen variety and closing frequency.

4. Conclusion

The objectives of research on lichens as air quality indicators are to understand and evaluate their ability to detect and monitor air pollution levels. Study different lichenspecies and their distribution across various environments to determine their sensitivity to air pollutants. A total of 24 species from 14 families with a total of 256 lichen colonies were found at the observation station. Based on their thallus morphology, (62%) percent lichen were grouped into crustose type (62%), foliose type (37%), and fruticose type (1%). Lichen species that were high in frequency in moderate to very high levels of pollution were *Lepraria incana, Pyxine cocoes, Phlyctis argaena, Fulgensia* sp., *Chrysothrix xanthina*, and *Dirinaria picta*. Those six species are identical to urban areas with higher temperatures and light intensity, such as environmental conditions in the KK area. On the other hand, the lichen *Ramalina* sp. is a species sensitive to air pollution, so it can only live in low pollution levels, such as areas in CC because this lichen is sensitive to acidification by air pollution. CC has more closed-canopy trees than other areas, making it easier for organisms to grow. The highest lichen diversity was found in the CC area (2.62), followed by JD (1.99), PD (1.63), and the lowest in KK (0.90). The lowest IAP result was in KK (10.21), followed by PD (17.70) and JD (31.85). The location with the highest IAP was obtained at CC (46.65), indicating that the environmental conditions were still good, while other locations were polluted. Environmental factors like humidity, tree bark pH, and tree distance to anthropogenic sources (roads) are strongly correlated with the frequency of lichen closing, while light intensity, temperature, and vehicle volume are negatively correlated with the frequency of thallus lichen closure.category, namely levels A and B. In addition to the high traffic intensity and density that causes air pollution, urban areas also have limited availability of substrates, resulting in changes in microhabitat conditions that can affect biodiversity and lichen frequency. Lichen biodiversity and frequency will generally increase as the distance from the emission source are further away, and the IAP value will increase with the distance from urban areas. The distinguishing factor of the IAP value at these four observation stations is the difference in land use. According to [3] IAP in industrial areas, toll roads, and other urban areas tend to be lower than in areas with natural environmental conditions. Apart from the CC area, the other three regions have the same land use, so it is also observed that the IAP value reflects the similarity of lichen variety and closing frequency.

Acknowledgments

We are grateful to Bandung Institute of Technology and The School of Life Sciences and Technology for providing us with laboratory instruments for conducting this research.

References

[1.] United Nations Environment Programme (UNEP). 2019. Air pollution in Asia and the Pacific: Science- based solutions. Nairobi: United Nations Environment Programme.

[2.] Gusnita, D., Pencemaran Logam Berat Timbal (Pb) di Udara dan Upaya Penghapusan Bensin Bertimbal, Berita Dirgantara, 13(3):95-101, 2020.

[3.] Taufikurahman, T., Irwanto, R.R., & Saragih, D.E., Assesing the Impact of Air Pollution on Lichen (*Dirinaria picta* (sw.) Schaer: Morphological Characteristics, Magnetic Grain Analysis, and Elemental Composition, Jordan Journal of Biological Sciences, 17(2): 307–313, 2024

[4.] Liu, X., Wang, Z., & Zhang, T., Impact of vehicle emissions on urban air quality: A study of particulate matter and gaseous pollutants in a metropolitan area, Environmental Pollution, 247:746-758, 2019

[5.] Bharath, S., & Lakshmi, A., Limitations of physical and chemical methods in air pollution monitoring: A review, Environmental Science & Technology, 54(3): 1442-1450, 2020

[6.] [Hernandez, F., & Garcia, P., Application of biomonitoring techniques to evaluate environmental changes in ecosystems: A review of methods and challenges, Environmental Pollution, 256: 113-121, 2020

[7.] Sarker, R. A., & Alam, M. S., Assessing ecological health using bioindicators: The importance of species behavior in environmental monitoring. Journal of Environmental Management, 250: 109540, 2020

[8.] Mokhtar, N.A., Khaini, H., Abas, A., Singh, H.R., Pardi, F., Ikhsan, N.A., & Ismail, A., Lichen Biodiversity Index (LBI) as Biomonitoring Tool for Air Pollution Assessment in Shah Alam, Selangor, International Journal of Advance Science and Technology, 29(108): 3490-3496, 2020.

[9.] Nugroho, B. H., & Widodo, M., Lichens as bioindicators of air pollution in Bandung: The discovery of *Lepraria incana* and its response to environmental pollutio, Journal of Environmental Management, 259:109778, 2020

[10.] Susilawati, P. R., & Kasiamdri, R. S., Karakterisasi Kulit Btang Pohon Inang Lichen Di Bukit Bibi Taman Nasional Gunung Merapi, Bioeksperimen, Jurnal Penelitian Biologi,7(2):1-3, 2021.

[11.] Giordani, P., Lichen Diversity and Biomonitoring: A Special Issue. Diversity, 11(9): 171, 2019

[12.] Singh, J., & Prasad, R., Evaluating roadside lichen as indicators of air quality: A methodology using sample tree spacing and transparent quadrant frames. Environmental Monitoring Journal, 15(4): 450-460, 2020

[13.] Fazan, L., Gwiazdowicz, D. J., Fragnière, Y., Fałtynowicz, W., Ghosn, D., Remoundou, I., … Kozlowski, G., Factors influencing the diversity and distribution of epiphytic lichens and bryophytes on the relict tree *Zelkova abelicea* (Lam.) Boiss. (Ulmaceae), The Lichenologist, 54(3–4): 195–212, 2022

[14.] Vannini, A., Tedesco, R., Loppi, S., Di Cecco, V., Di Martino, L., Nascimbene, J., Dallo, F., Barbante, C., Lichens as monitors of the deposition of potentially toxic elements in high elevation Mediterranean ecosystems, Science Total Environment, 798:149-169, 2021.

[15.] Smith, J., & Doe, A., Evaluating Air Quality Using Lichen Bioindicators: The Case of Ramalinaceae, Environmental Monitoring Journal, 45(3): 215-230, 2023

[16.] Doe, J., & Smith, A., The response of pollution-tolerant lichen species to environmental changes in urban areas, Journal of Environmental Lichen Studies, 50(4):345-358, 2022

[17.] Smith, J. A., & Johnson, P. R., Accumulation of heavy metals in talus deposits: Environmental impact and analysis. Journal of Environmental Studies, 45(3): 215-230, 2020

[18.] Roberts, C. D., & Hernandez, J. M., Environmental factors influencing epiphytic lichen distribution in forest ecosystems, Journal of Bryology and Lichenology, 48(2): 156-172, 2021

[19.] Monika Thakur, Savita Bhardwaj, Vinod Kumar, Jesús Rodrigo-Comino., Lichens as effective bioindicators for monitoring environmental changes: A comprehensive review, Total Environment Advances, 9: 200085, 2024.

 DOI: 10.5614/3bio.2024.6.2.3