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Lichen Biodiversity Index (LBI) for the Assessment of Air Quality in an Industrial City in Pahang, Malaysia

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Abstract: Lichen is a well-documented useful biological indicator for monitoring air pollution using various methods such as the biodiversity of lichens. However, the use of lichen biodiversity to estimate air pollution levels in industrial areas, particularly in Malaysia, is still weak, and the determinants of its diversity are unknown. As a result, the purpose of this research is to analyse air pollution in Malaysia's industrial urban area using the lichen biodiversity index and its determining factor. This research was carried out at Gebeng, Pahang, Malaysia. A total of 14 sample locations were chosen, each with three replication stations. The Lichen Biodiversity Index (LBI) approach was employed in this study to estimate the degree of air pollution in Gebeng. This study also investigated three potential determinants of lichen biodiversity: carbon monoxide (CO) concentration, relative humidity (%), and vehicle motor frequency (per hour). The LBI was plotted and analysed using the Geographical Information System (GIS) programme ArcGIS 10.8.1, and the determining variables were identified using Pearson's Correlation Coefficient software PAST 4.03. This study discovered a total of 11 lichen species known as metropolitan lichen. The average LBI across Gebeng is 19.5 (moderate alteration). In the industrial region, CO has an inversely significant relation with lichen biodiversity (r = −0.7433), relative humidity has a significant relation with lichen biodiversity (r = 0.8249), and vehicle motors are not significant as a determining factor for lichen biodiversity (r = 0.2068). This study demonstrates that lichen, with its diversity of species in one place, can be utilised to measure and quantify the degree of air pollution in industrial areas. In addition to that, in the context of an industrial city, vehicle motors do not have a significant impact on lichen biodiversity due to the existence of other pollutants sources from industrial activities. Relative humidity is a sign of clean air and humid surroundings, which is good for lichen growth; meanwhile, higher CO concentration will restrict the growth of sensitive-type lichen and will only allow the resistant type of lichen to grow.

Keywords: biological indicators; environmental monitoring; environmental management; lichens; urban ecosystem

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1. Introduction

Air pollution is one of the most serious issues worldwide [1]. There are no regions of the earth where human-made substances cannot be discovered [2]. The quantity of these substances, as well as their application, is constantly expanding. Some are extremely persistent, with half-lives that can last decades. As a result, monitoring changes in environmental quality and status is critical to ensuring that humans are always aware of how much the environment is changing as a result of anthropogenic activity [3]. Biomonitoring is a field that bridges the gap between environmental monitoring and public health surveillance [4]. The use of organisms to assess environmental pollution, such as that of surrounding air or water, is known as biomonitoring. It can be accomplished qualitatively by seeing and noting changes in organisms, or quantitatively by detecting chemical build up in organism tissues [5].

Other than humans, numerous species of organisms are commonly utilised as biomonitors for air pollution, the most known of which being lichens [6]. Lichens are creatures that are the result of a symbiotic interaction between a fungus (mycobiont) and one or more photosynthetic partners, such as algae or cyanobacteria (photobiont) [7,8]. Furthermore, several lichen species have been linked to basidiomycete yeasts [9]. Lichens are good biomonitors for semi-volatile organic air pollutants, notably polyaromatic hydrocarbons (PAHs), because of their capacity to respond to air pollutants at varied levels, their slow growth rate, their longevity, and their ability to detect the presence and concentrations of these pollutants [10–12]. Lichens have been employed as biomonitors for air pollution in a variety of ways, including lichen biodiversity [13], lichen transplanting techniques [14], and lichen physiological changes [15].

Lichens are found all over the world under a range of environmental circumstances. According to Devkota et al. [16], lichens are the toughest and most resilient living creatures, able to thrive practically everywhere and in any situation, from sea level to high alpine heights, in a variety of weather circumstances, and on almost any surface. Lichens are plentiful in rain forests [17] and temperate woodlands, growing on bark, leaves, mosses, or other lichens and hanging from branches, "dwelling on thin air" [18]. They can be found on rocks, walls, gravestones, roofs, exposed soil surfaces, rubber, bones, and in soil as part of biological soil crusts [19]. Lichens have evolved to thrive in some of the most hostile settings on the planet, including arctic tundras [20], scorching dry deserts [21], rocky beaches [22], and poisonous slag heaps [23]. Lichens may even grow between the grains of solid rock. Lichen biodiversity is mostly determined by environmental elements such as water, air, nutrients, pH substrate, temperature, and light intensity [4]. Because of the differences in susceptibility to air contaminants, Brunialti et al. [24] propose that lichen biodiversity may be utilised as one of the approaches to evaluate air pollution. There are lichens that are susceptible to certain air pollutants such as sulphur and nitrogen, and lichens that are resistant and can thrive in polluted environments.

The fact that lichen biodiversity varies according to the quantity of air pollution in its surroundings makes lichen an ideal biomonitor for assessing air [25]. Furthermore, the widespread distribution and abundance of lichen in practically any environment makes it easier and more efficient to analyse the health of any ecosystem, including the urban ecology [26]. This study hypothesizes that the lichen diversity in industrial areas is affected by microclimatic factors such as humidity and temperature. According to Carillo et al. [27], lichens need multiple supports from their surrounding to survive. As a result, the aim of this research is to use lichen biodiversity to biomonitor air pollution in Malaysian industrial areas while also determining the determinant factor for its abundance. To achieve those aims, this study asks these following questions: (i) What are the lichen species that can be found in the industrial areas of Malaysia? (ii) What is the level of air pollution of industrial areas in Malaysia by using lichen biodiversity? and (iii) What is the determinant factor for lichen biodiversity in industrial areas of Malaysia?

2. Research Methodology

2.1. Area of Study

This research was carried out in the industrial city of Gebeng, Pahang, Malaysia. Gebeng is a small town and major industrial sector in the Malaysian state of Pahang. Gebeng is similarly close to the Kuantan port and seaside area, and its coordinates are 3°58′0″ N, 103°26′0″ E [28]. Gebeng has been developed into an industrial area since the 1970s, and numerous industries such as and consisting of small- and medium-scale industries, such as wood processing industries, metal works factories, concrete ducting company, petrochemical companies (Petronas, BP, Kaneka, and so on), and the most controversial industry—Lynas Advanced Materials Plant (Australian rare-earths mining company)—have been located here since then [29].

Gebeng's yearly average temperature in 2021 is 32 °C at its highest and 23 °C at its lowest. The yearly precipitation totals are 274.01 mm, whereas the annual relative humidity average is 79%. According to Wahab et al. [28], the amount of air pollution in Gebeng in 2021 will be moderate, with $PM_{2.5}$ concentrations 1.6 times the WHO annual air quality guideline value.

2.2. Lichen Sampling Procedure

Lichens were collected from the Gebeng Industrial City Area (Table 1 and Figure 1). In total, 14 grids of 2 × 2 cm squares (Figure 2) were established to guarantee that the data obtained was distributed evenly over the Gebeng region. Purposive sampling was used to pick 14 sample locations from 14 square grids utilising a few criteria such as: (i) area with buildings or human activities, (ii) area with trees (diameter > 80 cm), and (iii) area with light penetration [10]. According to Pinho et al. [30], these characteristics are necessary and critical in order to biomonitor the amount of air pollution using lichen since lichens require light, substrate (for example, a tree), water, and nutrients in order to survive and develop. For each sampling site, 3 sampling locations were selected to replicate the sampling procedure and part of the quality assurance of the sampling procedure.

Lichen species and frequencies were sampled using a quadrat sampling size of 50 × 10 cm. The quadrat was put on the tree bark at a height of 100–200 cm above the ground in each of the four wind directions (north, south, east, and west). The chosen trees were planted within 100 metres of air pollution sources such as car motors, industrial buildings, and others [10].

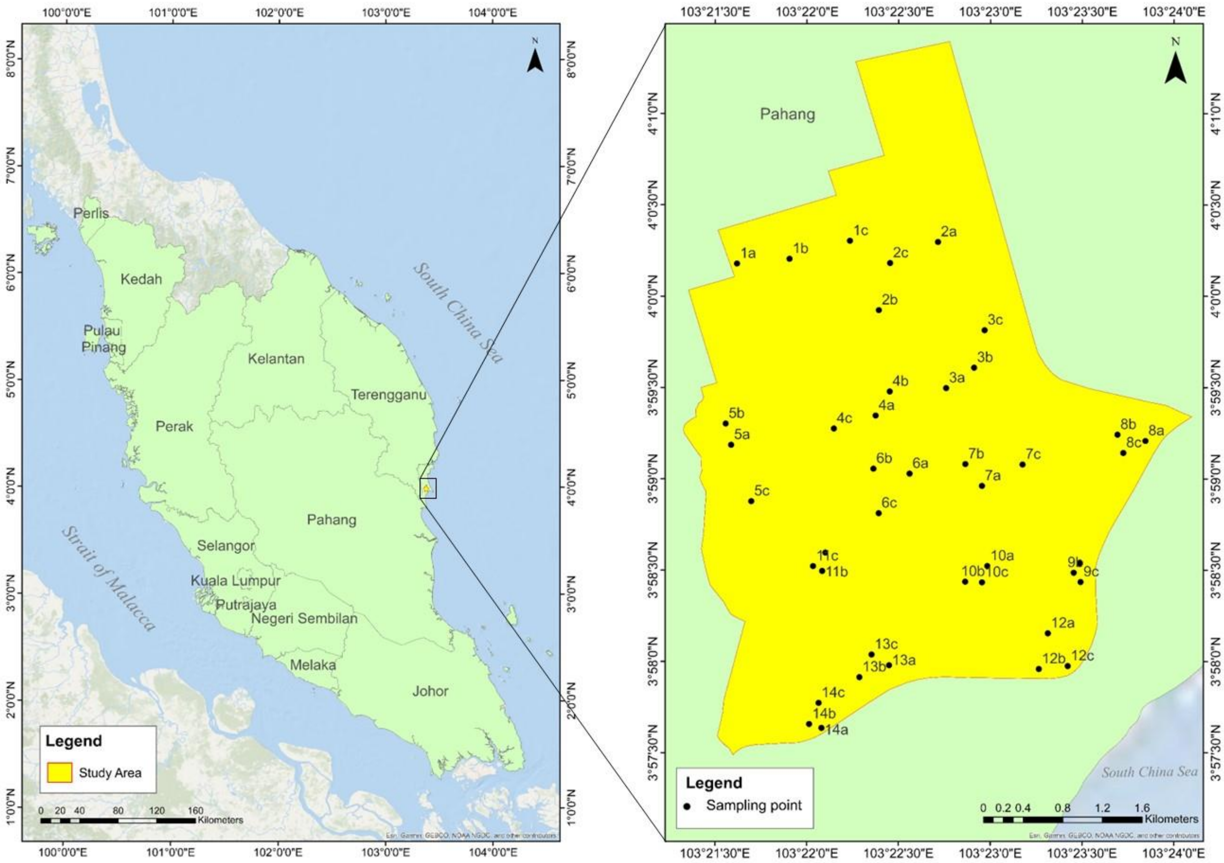


Figure 1. Map of Study Area. (a—sampling replicate no. 1; b—sampling replicate no. 2; c—sampling replicate no. 3).

Figure 2. Map of Sampling Site in Gebeng, Kuantan. Source: ArcGIS Software Version 10.8.1.

Table 1. Coordinates of Sampling Sites.

Sampling Site	Name of Location	Coordinate
1	RE Gebeng Sdn. Bhd.	4.0029637° N 103.3636357° E 4.0036229° N 103.3658488° E 4.0050440° N 103.3705615° E
2	Lynas Malaysia	4.0049390° N 103.3785562° E 3.9987167° N 103.3731907° E 3.9992495° N 103.3729715° E
3	CSWIND Malaysia Sdn. Bhd.	3.9912251° N 103.3787365° E 3.9937249° N 103.3751424° E 3.9962357° N 103.3743924° E
4	Petronas Gas Berhad Utilities Gebeng	3.9921141° N 103.3757083° E 3.9922202° N 103.3756801° E 3.9923616° N 103.3756061° E
5	Basf Petronas Chemical Sdn. Bhd.	3.9864222° N 103.3597773° E 3.9882875° N 103.3591614° E 3.9812758° N 103.3616049° E
6	Kaneka Malaysia	3.9834756° N 103.3761391° E 3.9842863° N 103.3774886° E 3.9762636° N 103.3490307° E
7	Eastman Chemical (Malaysia) Sdn. Bhd.	3.9826786° N 103.3825614° E 3.9829572° N 103.3826941° E 3.9826608° N 103.3825764° E
8	Tiong Nam Warehouse	3.9878838° N 103.3952623° E 3.9879514° N 103.3965504° E 3.9878952° N 103.3957176° E
9	Wilmar Kuantan Edible Oils Sdn. Bhd.	3.9746450° N 103.3930330° E 3.9747594° N 103.3908987° E 3.9757413° N 103.3905413° E
10	Petronas Chemicals MTBE Sdn. Bhd.	3.9748818° N 103.3844654° E 3.9717461° N 103.3785602° E 3.9693463° N 103.3817782° E
11	Rwana Engineering Sdn. Bhd.	3.9767816° N 103.3689227° E 3.9748667° N 103.3676778° E 3.9719629° N 103.3682534° E
12	Mieco Manufacturing Sdn. Bhd.	3.9690814° N 103.3775131° E 3.9691168° N 103.3777595° E 3.9690459° N 103.3778725° E
13	Kuantan Industrial Training Institute	3.9646958° N 103.3747102° E 3.9659955° N 103.374883° E 3.9700012° N 103.3734090° E
14	Medan Selera Gebeng	3.9604182° N 103.3692908° E 3.9606573° N 103.3676818° E 3.9630870° N 103.3682286° E

2.3. Lichen Identification Procedure

Lichen samples were collected and taken to the National University of Malaysia (UKM) lab for identification [31]. Lichen identification was accomplished by examining lichen morphological features using stereoscopic and optical microscopes. The lobes, thallus, pycnidia, rhizines, ciliates, and apothecia of lichens were carefully examined. The acid (lichen's secondary metabolites) was detected using a spot test in the medulla and brain [32]. All data obtained from both procedures (morphological observation and spot test) were documented and entered into the UKM Lichen Herbarium in Malaysia.

2.4. Lichen Biodiversity Index (LBI)

The Lichen Biodiversity Index (LBI) is a tool for measuring air pollution established by Cioffi [33] and improved by Abas and Awang [10] to adapt to tropical lichen diversity, especially tropical urban lichen. The LBI assesses the quantity and frequency of lichen species on a certain environment and converts the data into a condition. The LBI values recorded in each station were interpreted in terms of deviations from 'natural' conditions, using the scales of environmental naturality/alteration calibrated for trees in Kuala Lumpur, Malaysia, as follows: 0 = very high alteration 1–10 = high alteration, 11–20 = moderate alteration, 21–30 = low alteration/low naturality, 31–40 = moderate naturality, 41–50 = high naturality, and 51 and above = very high naturality (Table 2).

Table 2. Lichen Biodiversity Index (LBI).

Colour	LBI	Condition
	0	Very High Alteration
	1–10	High Alteration
	11–20	Moderately High Alteration
	21–30	Low Alteration
	31–40	Moderately High Naturality
	41–50	High Naturality
	51 and above	Very High Naturality

2.5. Relative Humidity Measurement

The quantity of moisture in the air is measured as relative humidity. It is stated as a percentage of the total quantity required to fully saturate the air at the same temperature. A digital hygrometer was used to record the relative humidity at each sample site [34]. A hygrometer is a device that measures the amount of water vapour in a room or space using various materials and measurements. The measurements were obtained three times at each sample point between 10 a.m. and 2 p.m.

2.6. Carbon Monoxide Concentration

The carbon monoxide concentration was recorded using the GC210 Portable Gas Detector. The sampling was conducted at each of the sampling sites between 10.00 a.m. to 2.00 p.m., as this the optimum period for carbon monoxide emission in an urban area in Malaysia [35].

2.7. Vehicle Motor Frequencies

A portable counter was used to count the frequencies of the vehicle motors. Sampling was done at each sampling site by standing along the roadside and recording all vehicle motors such as cars, motorbikes, trucks, and buses. The sampling lasted around 6 min, from 10 a.m. until 2 p.m. [36].

2.8. Data Analysis

The LBI data was captured and analysed using the Geographical Information System (GIS) interpolation analysis approach using the ArcGIS software version 10.8.1. The technique of constructing a surface based on values at isolated sample locations is known as interpolation analysis. Sample points are sites where data on a phenomenon is collected and geographical coordinates are recorded [31].

The Pearson's Correlation Coefficient was used to examine the significant association between the LBI and other parameters such as relative humidity, CO content, and vehicle motor frequency. This test was performed using Past Software Version 4.03, where the significant value is $p > 0.05$ and the variable strength is considerably strong when 0.5 > r 1.0. [8].

3. Results

3.1. Lichen Species Distribution in Gebeng

Based on Table 3, this study has found 11 of lichen species where the most dominant species is *Graphis scripta* (found at 13 sites out of 14) and the lowest species distributed in Gebeng is *Lecanora helva* (found at 3 sites out of 14). The other species that has been found in Gebeng are *Amandinea efflorescens*, *Chrysothrix xanthina*, *Dirinaria applanata*, *Dirinaria picta*, *Graphis librata*, *Lepraria usnica*, *Pheaographis brasiliensis*, *Pramotrema praesorediosum*, *Pyxine berteriana*, and *Pyxine cocoes*.

Table 3. List of Species Found at each Sampling Site.

Lichen Species	**Sampling Site**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Amandinea efflorescens				/	/	/	/				/	/	/	
Chrysothrix xanthina	/	/			/			/			/	/	/	/
Dirinaria applanata			/		/		/	/			/		/	/
Dirinaria picta			/	/	/		/	/		/	/	/	/	/
Graphis librata	/	/	/	/		/			/	/			/	/
Graphis scripta		/	/	/	/	/	/	/	/	/	/	/	/	/
Lecanora helva								/			/	/		
Lepraria usnica						/	/		/		/	/	/	/
Pheaographis brasiliensis				/	/		/	/		/	/		/	/
Pramotrema praesorediosum				/		/	/		/	/	/		/	/
Pyxine berteriana		/				/				/		/	/	/
Pyxine cocoes		/				/	/		/		/		/	/

3.2. Lichen Biodiversity Index (LBI) of Gebeng

Table 4 shows that the lowest LBI value for Gebeng is 9.5 (sampling site no. 2) and the highest value is 45.5 (sampling site no. 13). The average LBI value for Gebeng is 20.51. Based on Figure 3, most areas in Gebeng are categorized as moderately low alteration (57.2%), followed by low alteration areas (28.6%), moderately high naturality area (7.1%), high naturality (4.8%), and the lowest being high alteration (2.3%).

Table 4. LBI Value for each Sampling Site.

Sampling Site	**Name of Location**	**LBI**
		19
1	RE Gebeng Sdn. Bhd.	13.5
		13.5
		12
2	Lynas Malaysia	20.5
		12.5
		9.5
3	CSWIND Malaysia Sdn. Bhd.	21
		14.5

Table 4. *Cont.*

Sampling Site	Name of Location	LBI
4	Petronas Gas Berhad Utilities Gebeng	13.5 18.5 12.5
5	Basf Petronas Chemical Sdn. Bhd.	24 25.5 18
6	Kaneka Malaysia	18 15 21.5
7	Eastman Chemical (Malaysia) Sdn. Bhd.	25.5 20 31
8	Tiong Nam Warehouse	18 13.5 15.5
9	Wilmar Kuantan Edible Oils Sdn. Bhd.	27 12.5 11
10	Petronas Chemicals MTBE Sdn. Bhd.	25.5 15.5 13
11	Rwana Engineering Sdn. Bhd.	11 27.5 23.5
12	Mieco Manufacturing Sdn. Bhd.	36 43.5 32.5
13	Kuantan Industrial Training Institute	45.5 11.5 25.5
14	Medan Selera Gebeng	16 31.5 27

3.3. Multiple Variable Measurement

Table 5 shows the data of multiple variables that has been measured alongside lichen diversity in Gebeng, Kuantan. Three variables have been measured and determined which are relative humidity (%), concentration on carbon monoxide (ug/m^3), and vehicle motor frequency (per hour). In terms of relative humidity, the highest value was recorded at sampling sites no. 13 and no. 14 with 83%; meanwhile, the lowest value was recorded at sampling site no. 2 with 71%. On the other hand, for CO concentration, the highest concentration was recorded at sampling site no. 3 with 1633 ug/m^3, and the lowest value was recorded at sampling site no. 14 with 317 ug/m^3. The highest value for motor vehicles frequency was recorded at sampling sites no. 13 with 12, 164 motor vehicles per hour and the lowest value was recorded at sampling site no. 12 with 199 motor vehicles per hour.

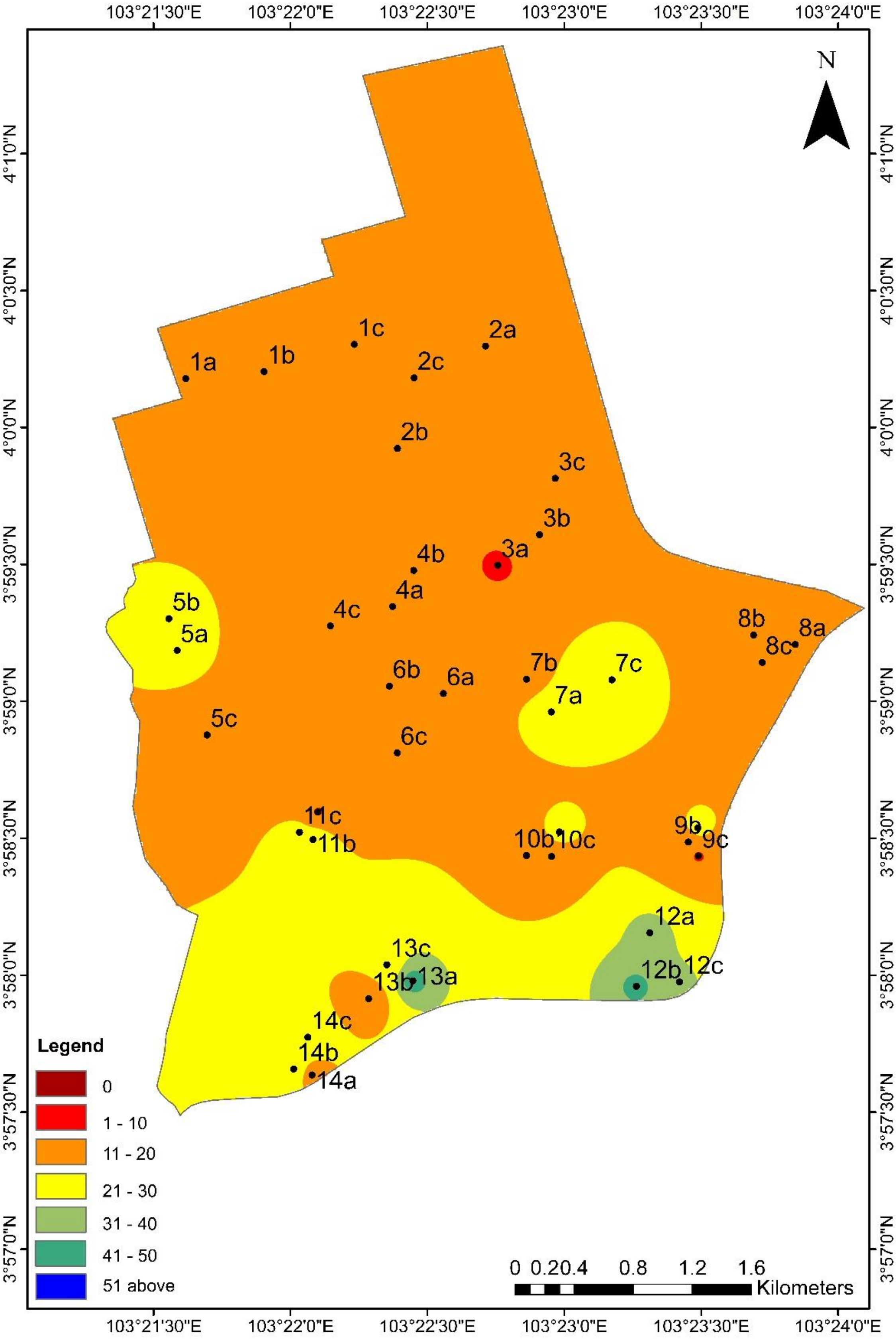


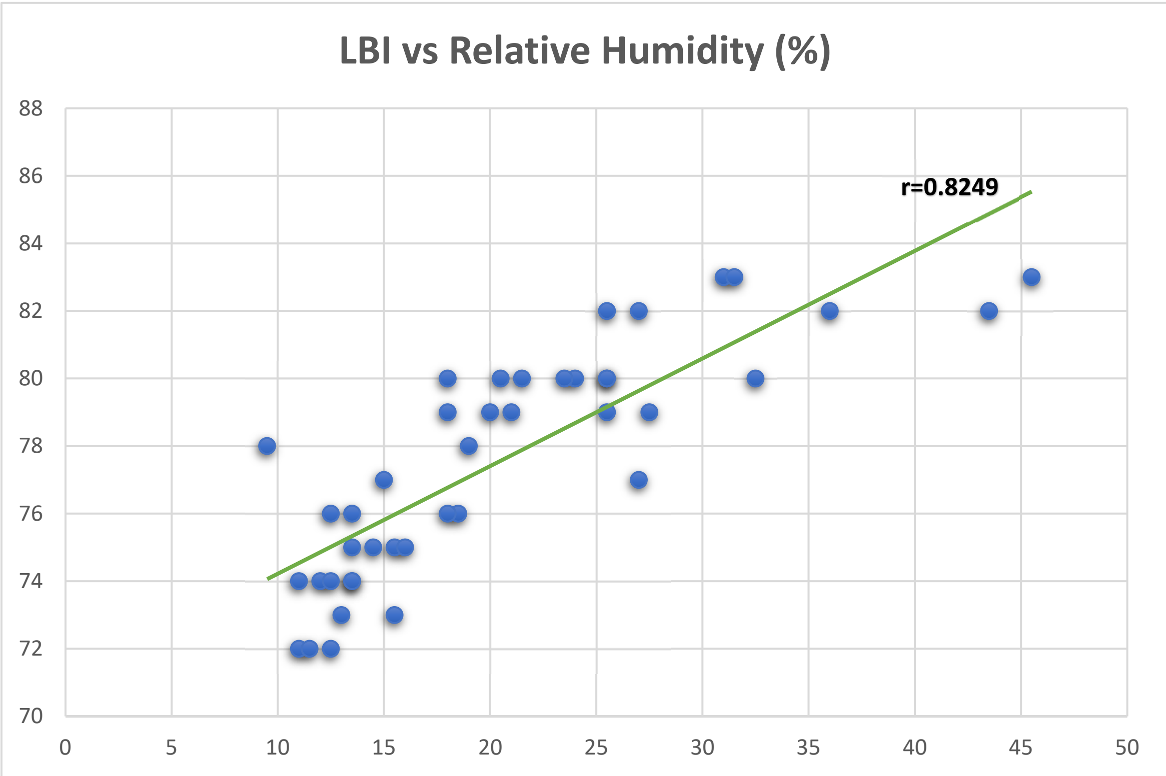
Figure 3. Lichen Biodiversity Index Mapping at Gebeng, Kuantan. a, b and c in Figure 3 are the sampling replicate for each sampling plot which have 3 replication each.

Table 5. Level of Relative Humidity, CO, and Vehicle Motor frequency in Gebeng, Kuantan.

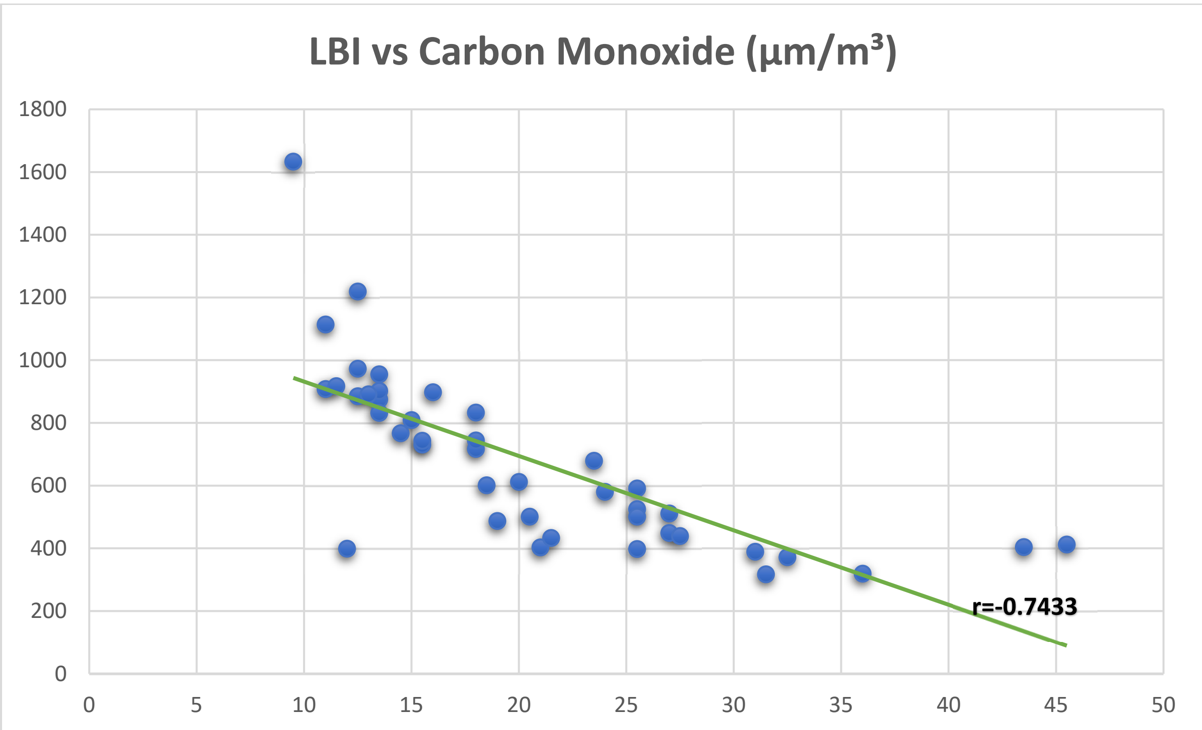
Sampling Site	Relative Humidity (%)	CO (ug/m^3)	Vehicle Motor Frequency (per Hour)
1	78	487	1263
	76	875	1988
	74	902	864
2	74	399	2017
	80	501	914
	71	1219	616
3	78	1633	559
	79	403	810
	75	767	897
4	75	832	4132
	76	601	4382
	74	973	3814
5	80	580	2122
	82	591	3448
	80	717	3139
6	79	833	5059
	77	809	1188
	80	433	1398
7	79	398	492
	79	612	622
	83	389	877
8	76	744	2291
	74	955	3400
	75	731	2798
9	77	449	8448
	76	885	2255
	72	1114	4689
10	80	525	1309
	73	743	488
	73	891	1092
11	74	908	3081
	79	439	311
	80	679	199
12	82	319	1983
	82	404	1443
	80	372	2005
13	83	412	12164
	72	917	9451
	80	501	9198
14	75	898	7227
	83	317	7543
	82	511	687

3.4. Analysis of Relationship between Lichen Diversity and Multiple Factors

Figure 4a shows the relationship between the LBI value vs Relative Humidity where the r value recorded is 0.8249 ($r > 0.5$). This means that the relationship between LBI value vs Relative Humidity is significantly strong. Figure 4b shows the relationship between LBI value and CO concentration where the r value is -0.7433 ($r > -0.5$). This means that the relationship between the LBI value vs CO concentration is inversely strong. Lastly, Figure 4c shows the relationship between LBI value and motor vehicles frequency where the r value is 0.2068 ($r < 0.5$). This means that the relationship between LBI value and motor vehicles frequency is weak.

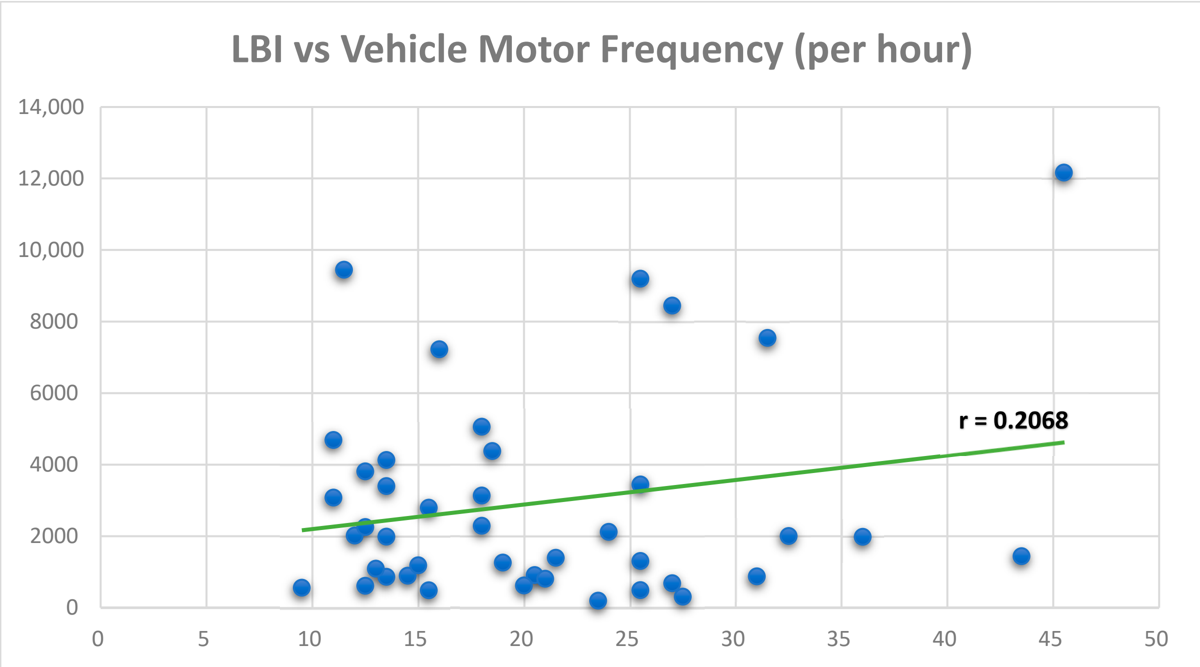


(**a**)



(**b**)

Figure 4. *Cont.*



(**c**)

Figure 4. (**a**) Relationship between LBI Value vs. Relative Humidity. (**b**) Relationship between LBI Value vs. CO Concentration. (**c**) Relationship between LBI Value vs. Vehicle Motor Frequency.

4. Discussion

Lichen species in urban areas are often less diverse than those in natural areas. Because of the tough conditions in metropolitan areas, the types of lichen species that may thrive there are quite limited. The urban region is noted for being a source of pollution and having a lack of green space. According to Monge-Nájera [19], the majority of lichen species that may develop and thrive in urban areas are classified as nitrophyte (nitrogen lover) and acidophyte (sulphur lover). More than 70% of the lichen species discovered in Gebeng are from the families Caliciaceae and Graphidaceae, including *Dirinaria picta*, *Dirinaria applanata*, *Graphis scripta*, *Graphis librata*, and others. This lichen species is recognised as a pollution resistance lichen because it can thrive in polluted conditions in metropolitan areas [10]. This study also discovered that no fruticose lichen grows in the Gebeng region, only crustose and foliose lichen. To thrive, fruticose lichen requires high humidity and clean air [37]. These are the total opposites of the circumstances in Gebeng.

The distribution of lichen diversity has historically been linked to the air quality of the surrounding region using several techniques, one of which is the lichen biodiversity index, or LBI [33]. According to this study, the average LBI score for the Gebeng region is 20.51, indicating fairly low change. Furthermore, more than half of the Gebeng region was classified similarly. As a result of their industrial and commercial operations, the majority of the Gebeng region may be classified as having low to moderate levels of pollution. However, based on the current growth pattern in the Gebeng area, this state may deteriorate from low to moderate levels of pollution [29]. According to Wahab et al. [28], the Kuantan City development plan, which includes Gebeng, shows that more over 30% of Kuantan City would be developed as an industrial district by 2025. As a result, Gebeng's air quality was projected to improve.

This study assessed numerous factors that might impact the distribution of lichen variety, such as relative humidity, CO concentration, and vehicle motor frequency. The majority of high relative humidity sample sites are also surrounded by lush greenery, such as secondary forests, grass field areas, and so on. Furthermore, with less active traffic and wind movement, these conditions aid in boosting relative humidity in certain specific locations. According to Golkar et al. [38], relative humidity has a strong association with the vegetation in that location. This is due to the creation of oxygen from vegetative plants via photosynthesis, as well as plants such as trees and shrubs providing shade to the region, which aids in the prevention of water loss from the air via the evaporation process [39]. On the other hand, locations with a high concentration of CO are densely packed with industrial and commercial buildings, as well as asphalted roads. According to Mohd Shafie and Mahmud [40], the source of CO is cars, trucks, and other vehicles or apparatuses that use fossil fuels. Furthermore, CO may be created by domestic activities such as cooking, as well as industrial furnaces [41]. In terms of vehicle motor frequency, a large number has been reported in areas with asphalted roads and substantial human activity, such as commercialization and population settlements. According to Khan et al. [42], vehicle motors are more common in areas with strong road access and a centre for human activity.

This study also demonstrated that various variables have a major impact on lichen diversity. In this situation, the relative humidity and CO content of the environment have had a substantial impact on the lichen. High relative humidity percentages indicate that the surrounding air contains a lot of water. Furthermore, water has an important role in the growth of many lichen species, which require a lot of water to survive. In the instance of CO concentration, a high concentration of CO indicates that the air will become more acidic. As a result, lichen species that cannot thrive in acidic conditions, particularly fruticose and foliose lichen, will develop slower [43]. However, lichen diversity is not considerably influenced by the frequency of vehicle motors for a variety of reasons, including pollution from vehicle motors being blown away by wind movement and diluted by evaporated water in the surrounds. According to Leh et al. [44], even though vehicle motors emit a large amount of pollution into the atmosphere, variables such as wind movement and humidity can mitigate their impact.

5. Conclusions

This study indicates that lichen varieties may be utilised to biomonitor industrial air quality. This study also reveals that certain industrial factors, such as relative humidity and CO concentration, have a considerable impact on lichen diversity. This study discovered 11 lichen species in the Gebeng region, the majority of which are crustose-type lichens. Furthermore, the air quality in the Gebeng region is classified as fairly low change. This study also investigates the relationship between lichen diversity and other environmental variables such as relative humidity, CO concentration, and vehicle motor frequency, discovering that lichen diversity has a strong relationship with relative humidity and an inverse relationship with CO concentration. However, the relationship with vehicle motor frequency is weak.

This research faced several limitations such as, no control plot from non-industrial areas that can be compared with the current data from this study. Therefore, it is strongly recommended in the future to include the non-industrial area control plot in a related study. Second, this study only focuses on lichen species that were already identified and recorded in the herbarium. Therefore, in future studies, researchers may need to add a proper lichen identification technique to ensure all lichen species will be recorded.

This research advocates for improved planning in the Gebeng region to guarantee that air quality does not deteriorate. This study suggests a few actions that the local authority should take, such as (i) increasing the growth of vegetative plants, (ii) increasing the green space area, particularly in industrial areas, (iii) developing a systematic development plan, particularly in terms of expanding the industrial and commercialization areas, and (iv) implementing a green building initiative in the Gebeng area.

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References

1. Landrigan, P.J.; Fuller, R. Global health and environmental pollution. *Int. J. Public Health* **2015**, *60*, 761–762. [CrossRef] [PubMed]
2. Butnariu, M. Global Environmental Pollution Problems. *Environ. Anal. Ecol. Stud.* **2018**, *1*, 94–95. [CrossRef]
3. Zaman, N.A.F.K.; Kanniah, K.D.; Kaskaoutis, D.G.; Latif, M.T. Evaluation of machine learning models for estimating $PM_{2.5}$ concentrations across Malaysia. *Appl. Sci.* **2021**, *11*, 7326. [CrossRef]
4. Abas, A. A systematic review on biomonitoring using lichen as the biological indicator: A decade of practices, progress and challenges. *Ecol. Indic.* **2021**, *121*, 107197. [CrossRef]
5. Protano, C.; Owczarek, M.; Antonucci, A.; Guidotti, M.; Vitali, M. Assessing indoor air quality of school environments: Transplanted lichen *Pseudovernia furfuracea* as a new tool for biomonitoring and bioaccumulation. *Environ. Monit. Assess.* **2017**, *189*, 358. [CrossRef]
6. Abas, A.; Khalid, R.M.; Rosandy, A.R.; Sulaiman, N. Lichens of Pulau Pangkor, Perak, Malaysia. *Malays. For.* **2019**, *82*, 59–66.
7. Honegger, R. Developmental biology of lichens. *New Phytol.* **1993**, *125*, 659–677. [CrossRef]
8. Abas, A.; Mazlan, S.M.; Latif, M.T.; Aiyub, K.; Muhammad, N.; Nadzir, M.S.M. Lichens reveal the quality of indoor air in Selangor, Malaysia. *Ecol. Process.* **2021**, *10*, 1–8. [CrossRef]
9. Spribille, T.; Tuovinen, V.; Resl, P.; Vanderpool, D.; Wolinski, H.; Aime, M.C.; Schneider, K.; Stabentheiner, E.; Toome-Heller, M.; Thor, G.; et al. Basidiomycete yeasts in the cortex of ascomycete macrolichens. *Science* **2016**, *353*, 488–492. [CrossRef]
10. Abas, A.; Awang, A. Air pollution assessment using lichen biodiversity index (LBI) in Kuala Lumpur, Malaysia. *Poll. Res.* **2017**, *36*, 242–249.
11. Boonpeng, C.; Sriviboon, C.; Polyiam, W.; Sangiamdee, D.; Watthana, S.; Boonpragob, K. Assessing atmospheric pollution in a petrochemical industrial district using a lichen-air quality index (LiAQI). *Ecol. Indic.* **2018**, *95*, 589–594. [CrossRef]
12. Abas, A.; Sulaiman, N.; Adnan, N.R.; Aziz, S.A.; Nawang, W.N.S.W. Using lichen (*Dirinaria* sp.) as bio-indicator for airborne heavy metal at selected industrial areas in Malaysia. *Environment* **2019**, *12*, 85–90.
13. Boonpeng, C.; Polyiam, W.; Sriviboon, C.; Sangiamdee, D.; Watthana, S.; Nimis, P.; Boonpragob, K. Airborne trace elements near a petrochemical industrial complex in Thailand assessed by the lichen Parmotrema tinctorum (Despr. ex Nyl.) Hale. *Environ. Sci. Pollut. Res.* **2017**, *24*, 12393–12404. [CrossRef] [PubMed]
14. Abas, A.; Aiyub, K.; Awang, A. Biomonitoring Potentially Toxic Elements (PTEs) Using Lichen Transplant Usnea misaminensis: A Case Study from Malaysia. *Sustainability* **2022**, *14*, 7254. [CrossRef]
15. Matos, P.; Pinho, P.; Aragón, G.; Martínez, I.; Nunes, A.; Soares, A.M.V.M.; Branquinho, C. Lichen traits responding to aridity. *J. Ecol.* **2015**, *103*, 451–458. [CrossRef]
16. Devkota, S.; Dymytrova, L.; Chaudhary, R.P.; Werth, S.; Scheidegger, C. Climate change-induced range shift of the endemic epiphytic lichen Lobaria pindarensis in the Hindu Kush Himalayan region. *Lichenologist* **2019**, *51*, 157–173. [CrossRef]
17. Anthony, P.A.; Holtum, J.A.M.; Jackes, B.R. Shade acclimation of rainforest leaves to colonization by lichens. *Funct. Ecol.* **2022**, *16*, 808–816. [CrossRef]
18. Ellis, C.J. Oceanic and temperate rainforest climates and their epiphyte indicators in Britain. *Ecol. Indic.* **2016**, *70*, 125–133. [CrossRef]
19. Monge-Nájera, J. Relative humidity, temperature, substrate type, and height of terrestrial lichens in a tropical paramo. *Rev. De Biol. Trop.* **2019**, *67*, 206–212. [CrossRef]
20. Lee, Y.M.; Kim, E.H.; Lee, H.K.; Hong, S.G. Biodiversity and physiological characteristics of Antarctic and Arctic lichens-associated bacteria. *World J. Microbiol. Biotechnol.* **2014**, *30*, 2711–2721. [CrossRef]
21. Warren, R.J.; Casterline, S.; Goodman, M.; Kocher, M.; Zaluski, R.; Battaglia, J.H. Long-term lichen trends in a rust belt region. *J. Urban Ecol.* **2019**, *5*, juz011. [CrossRef]
22. Fraser, R.H.; Pouliot, D.; van der Sluijs, J. UAV and High Resolution Satellite Mapping of Forage Lichen (*Cladonia* spp.) in a Rocky Canadian Shield Landscape. *Can. J. Remote Sens.* **2022**, *48*, 5–18. [CrossRef]
23. Sueoka, Y.; Sakakibara, M.; Sera, K. Heavy metal behavior in lichen-mine waste interactions at an abandoned mine site in Southwest Japan. *Metals* **2015**, *5*, 1591–1608. [CrossRef]
24. Brunialti, G.; Frati, L.; Calderisi, M.; Giorgolo, F.; Bagella, S.; Bertini, G.; Chianucci, F.; Fratini, R.; Gottardini, E.; Cutini, A. Epiphytic lichen diversity and sustainable forest management criteria and indicators: A multivariate and modelling approach in coppice forests of Italy. *Ecol. Indic.* **2020**, *115*, 106358. [CrossRef]

25. Winkler, A.; Contardo, T.; Lapenta, V.; Sgamellotti, A.; Loppi, S. Assessing the impact of vehicular particulate matter on cultural heritage by magnetic biomonitoring at Villa Farnesina in Rome, Italy. *Sci. Total Environ.* **2022**, *823*, 153729. [CrossRef]
26. Rosli, N.S.; Zulkifly, S. Application of Index of Atmospheric Purity (IAP) along elevation gradients in Gunung Jerai, Kedah, Malaysia. *Environ. Monit. Assess.* **2022**, *194*, 1–10. [CrossRef]
27. Carrillo, W.; Calva, J.; Benítez, Á. The Use of Bryophytes, Lichens and Bromeliads for Evaluating Air and Water Pollution in an Andean City. *Forests* **2022**, *13*, 1607. [CrossRef]
28. Wahab, S.U.K.A.; Samah, M.A.A.; Sabuti, A.A.; Yunus, K.; Chowdhury, A.J.K.; John, A.; Hamid, A.A.A. Environmental forensic study: Tracing of pollution sources using environmetric technique in balok and tunggak rivers near gebeng industrial area, Kuantan, Pahang, Malaysia. *Desalin. Water Treat.* **2020**, *191*, 118–125. [CrossRef]
29. Zakaria, M.H.; Mustapha, I.; Amran, M.; Hassan, S.; Ikbar, A.W.M.; Bakar, F.A.A. Case study of environmental impact analysis (EIA) exercise on the development of gebeng wind farm Pahang, Malaysia. *J. Adv. Res. Dyn. Control. Syst.* **2020**, *12*, 1859–1865. [CrossRef]
30. Pinho, P.; Augusto, S.; Branquinho, C.; Bio, A.; Pereira, M.J.; Soares, A.; Catarino, F. Mapping lichen diversity as a first step for air quality assessment. *J. Atmos. Chem.* **2004**, *49*, 377–389. [CrossRef]
31. Abas, A.; Awang, A.; Aiyub, K. Analysis of heavy metal concentration using transplanted lichen Usnea misaminensis at Kota Kinabalu, Sabah (Malaysia). *Appl. Ecol. Environ. Res.* **2020**, *18*, 1175–1182. [CrossRef]
32. Brodo, I.M. Microchemical Methods for the Identification of Lichens. *Bryologist* **2003**, *106*, 345. [CrossRef]
33. Cioffi, M. Air quality monitoring with the lichen biodiversity index (LBI) in the district of Faenza (Italy). *EQA Int. J. Environ. Qual.* **2009**, *1*, 1–6.
34. Lee, S.W.; Choi, B.I.; Woo, S.B.; Kim, J.C.; Kim, Y.G. Development of a low-temperature low-pressure humidity chamber for calibration of radiosonde humidity sensors. *Metrologia* **2019**, *56*, 025009. [CrossRef]
35. Razli, S.A.; Abas, A.; Ismail, A.; Othman, M.; Mohtar, A.A.A.; Baharudin, N.H.; Latif, M.T. Epiphytic microalgae as biological indicators for carbon monoxide concentrations in different areas of Peninsular Malaysia. *Environ. Forensics* **2020**, *23*, 314–323. [CrossRef]
36. Zulaini, A.A.M.; Muhammad, N.; Asman, S.; Hashim, N.H.; Jusoh, S.; Abas, A.; Din, L. Evaluation of transplanted lichens, *Parmotrema Tinctorum* and *Usnea diffracta* as bioindicator on heavy metals accumulation in southern Peninsular Malaysia. *J. Sustain. Sci. Manag.* **2019**, *14*, 1–13.
37. Notov, A.A. Fruticose lichens: Structural diversity, taxonomic characteristics and evolution. *Wulfenia* **2014**, *21*, 21–31.
38. Golkar, F.; Al-Wardy, M.; Saffari, S.F.; Al-Aufi, K.; Al-Rawas, G. Using OCO-2 satellite data for investigating the variability of atmospheric CO_2 concentration in relationship with precipitation, relative humidity, and vegetation over Oman. *Water* **2020**, *12*, 101. [CrossRef]
39. Battisti, L.; Pomatto, E.; Larcher, F. Assessment and mapping green areas ecosystem services and socio-demographic characteristics in Turin Neighborhoods (Italy). *Forests* **2020**, *11*, 25. [CrossRef]
40. Mohd Shafie, S.H.; Mahmud, M. Urban air pollutant from motor vehicle emissions in kuala lumpur, malaysia. *Aerosol. Air Qual. Res.* **2020**, *20*, 2793–2804. [CrossRef]
41. Zheng, B.; Chevallier, F.; Ciais, P.; Yin, Y.; Deeter, M.N.; Worden, H.M.; He, K. Rapid decline in carbon monoxide emissions and export from East Asia between years 2005 and 2016. *Environ. Res. Lett.* **2018**, *13*, 044007. [CrossRef]
42. Khan, J.; Ketzel, M.; Kakosimos, K.; Sørensen, M.; Jensen, S.S. Road traffic air and noise pollution exposure assessment—A review of tools and techniques. *Sci. Total Environ.* **2018**, *634*, 661–676. [CrossRef] [PubMed]
43. Root, H.T.; Jovan, S.; Fenn, M.; Amacher, M.; Hall, J.; Shaw, J.D. Lichen bioindicators of nitrogen and sulfur deposition in dry forests of Utah and New Mexico, USA. *Ecol. Indic.* **2021**, *127*, 107727. [CrossRef]
44. Leh, O.L.H.; Marzukhi, M.A.; Kwong, Q.J.; Mabahwi, N.A. Impact of urban land uses and activities on the ambient air quality in Klang Valley, Malaysia from 2014 to 2020. *Plan. Malays.* **2020**, *18*, 239–258. [CrossRef]