Distribution pattern of corticolous lichens in different areas of Kathmandu valley, Nepal

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This study attempts to document the lichen species and their distribution in different areas of Kathmandu valley, Nepal. Twenty sampling sites with different degrees of air pollution categorized as disturbed (industrial, heavy traffic and residential areas) and undisturbed areas (clean area) were selected for the study. Sampling was done using the quadrat method. To enumerate the total number of lichen species found in Kathmandu valley, lichen specimens were collected from inside as well as outside the quadrats. A total of 97 species of corticolous lichens belonging to 21 families and 44 genera were recorded from the study sites. Parmeliaceae was the largest family followed by Graphidaceae. The importance value analysis showed that *Candelaria concolor* (115.2), *Dirinaria aegialita, Lepraria* sp.*, Phaeophyscia hispidula var. hispidula* and *Physcia sorediosa* (106.02) are the most common and dominant lichen species in Kathmandu valley. Among the most common and dominant lichen species, *Candelaria concolor, Dirinaria aegialita, Phaeophyscia hispidula var. hispidula* and *Physcia sorediosa* were found concentrated in heavy traffic areas whereas *Lepraria* sp. in the industrial areas. A higher number of lichen species (70%) was recorded in undisturbed areas than in disturbed areas (50%). These study confirm that the distribution of lichen flora is strongly influenced by degrees of pollution. This in turn suggests that lichens can be used as bio indicators of air quality in the Kathmandu valley.

Keywords Coverage, flora, importance value, pollution, quadrat

Lichens, vital components of the ecosystem, are distinct mutualistic groups of autotrophic organisms (Baniya & Bhatta, 2021). They are widely distributed and highly diversified. They occur in a wide range of habitats throughout the world and are considered pioneer colonizers of the terrestrial ecosystem (Negi and Upreti, 2009). Some species of lichens are found in both the freshwater stream and marine intertidal zones (Hawksworth, 2000). Based on where they occur, lichens can be categorized into corticolous (on the tree bark), follicolous (on the leaf), saxicolous (on the rock) and terricolous (on the soil) lichens. The thallus of lichens shows morphological variation and exists in different growth forms such as crustose, leprose, squamulose, foliose and fruticose (Upreti *et al.*, 2015).

Lichens have the ability to obtain water and nutrient directly from their surrounding air. As a consequence, they are more sensitive to changing environmental conditions (Gausalaa, 2014). Hence, alteration in lichens diversity is assumed to indicate the changes in environmental conditions (Shukla *et al.*, 2014). Furthermore, the changes in topographical variables and environmental factors are reported to affect the

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distribution, diversity and abundance of the lichens (Hauck, 2011). Therefore, lichens are globally recognized and utilized as bioindicators of a variety of environmental conditions (Garty, 2001; Gupta *et al.*, 2014; De Silva & Senanayake, 2015). Besides, lichens are of high economic value and are used as food, medicines, natural remedies, perfumes, dyes, etc. (Upreti *et al.*, 2015; Devkota *et al.*, 2017; Crawford, 2019; Yang *et al.*, 2021). Furthermore, lichens are chemically rich and produce more than 1000 different types of secondary metabolites. Among them, more than 90% are unique to themselves and show a variety of biological activities (Elix & Stocker-Wörgötter, 2008).

Globally, about 20,000 species of lichens are known so far, of which India harbors 2,963 species (Islary *et al.*, 2022). The lichens of different parts of Nepal had been studied by various native and foreign lichenologists for several years and 1,129 taxa have been recorded so far (Baniya *et al.*, 2022). Sharma (1995) estimated 2,000 lichen species in Nepal. The copious presence of lichens in the country is due to the diverse topographic condition together with varied climatic conditions (Jha *et al.* 2017). Although several lichenological explorations have been undertaken in the central, western and eastern regions of Nepal (Sharma, 1995; Baniya *et al.*, 2001; Olley & Sharma, 2013; Rai *et al.*, 2016; Chongbang *et al.*, 2018), only a few have undertaken a thorough collection of lichens from the Kathmandu valley (Baniya & Bhatta, 2021). Hence, the present study aims to enumerate the corticolous lichens in Kathmandu valley and analyze their distribution pattern in areas with different degrees of pollution i.e., disturbed (industrial, heavy traffic, residential) and undisturbed (clean) areas within Kathmandu valley.

Materials and methods

Study areas

The study areas were located in the Kathmandu valley ($27^0$42' N and $85^0$20' E) of Bagmati Province, central Nepal. Twenty sampling sites under four study areas with different degrees of air pollution categorized as disturbed (industrial, heavy traffic and residential areas) and undisturbed areas (clean areas) were selected for the study (Figure 1). Sampling was done during dry season i.e., October 2016 – January 2017. As we were interested in corticolous (bark-inhabiting) lichens, sampling sites were chosen based on the availability of lichens on the bark of the host trees.

Collection of lichen specimens

Specimens of lichens were collected from all the sampling sites. At each site, five old and big trees (having more than 80-120 cm trunk diameter) were selected within the area of 100 x 100 m based on the availability of lichens on the tree barks. Sampling was carried out by placing a quadrat of 20 x 20 cm (having 4 sub-quadrats of 10 x 10 cm) on four sides of the tree trunk at a height of 1.5 m (breast height) above the ground level, without overlapping (Asta *et al.*, 2002; Pinokiyo *et al.*, 2008; Conti, 2008). The standard size of the quadrat was determined by the species-area curve method (Asta *et al.*, 2002). Altogether 400 quadrats were laid on 100 trees in 20 sampling sites (i.e., 20 quadrats in each sampling site). The coverage and frequency of each lichen species within each quadrat were recorded. All the available lichen specimens were collected from each quadrat. To enumerate the lichen species found in Kathmandu valley, specimens present outside of the quadrats were also collected. For this, specimens present on any trees with an area of 100 x 100 m at each sampling site (up to ca. 2200 m altitudes in clean areas) were collected. Altogether 230 lichen specimens, including 136 specimens inside the quadrats, were collected from 20 sampling sites under four study areas (industrial, heavy traffic, residential and clean areas) of Kathmandu Valley. Forest conservation rules and strategies were followed while collecting the specimens and a very small quantity of lichen specimens was collected for identification. The collected specimens together with their primary identification information like color, substrate type, quadrat number, collection number, and name of the sampling site were placed in individual paper bags and curated according to the standard protocol of Awasthi (2000).

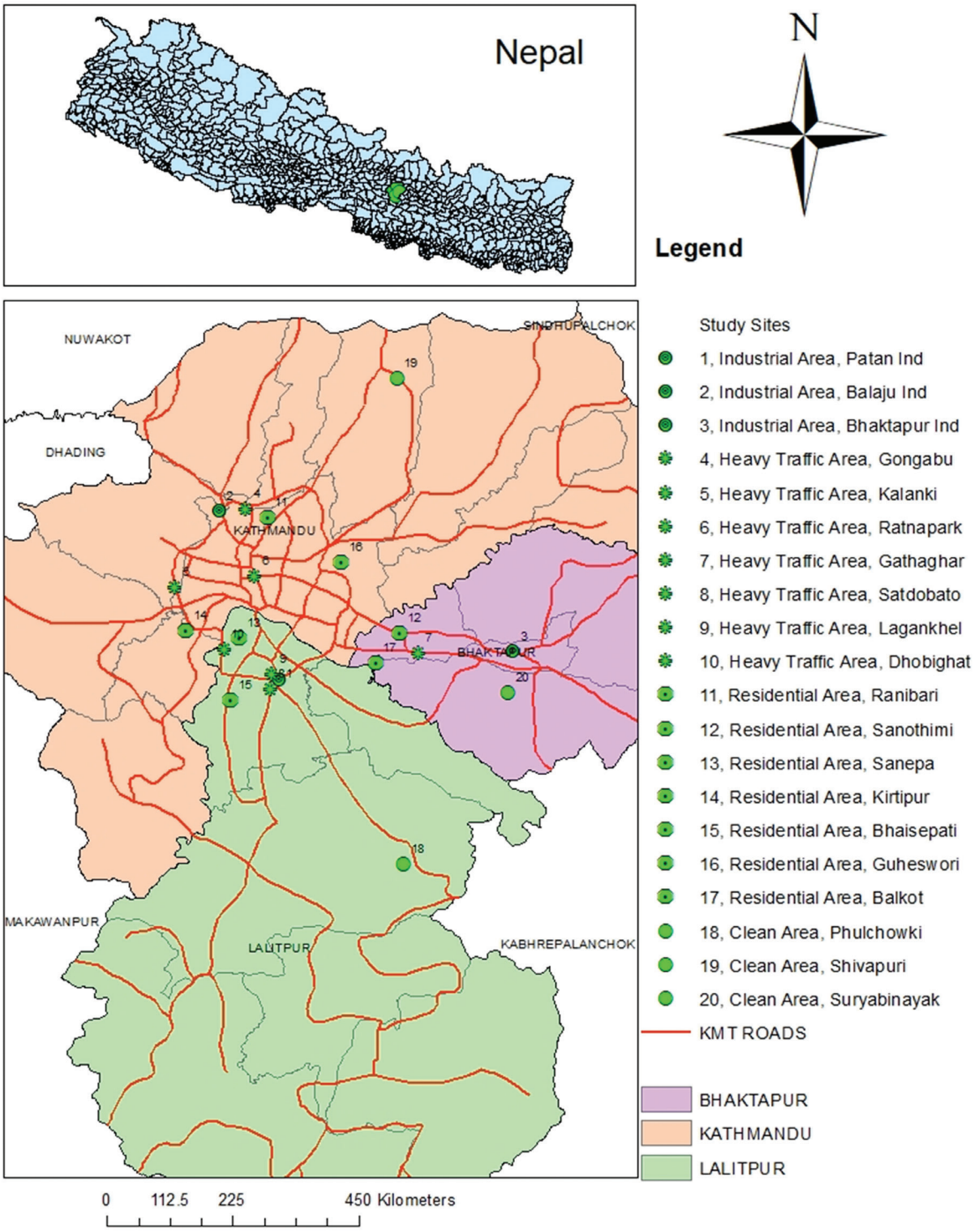

Figure 1: Map of the study area showing the location of 20 sampling sites

Lichen identification

Identification of lichen specimens was carried out at the lichenology laboratory of the Council of Scientific & Industrial Research-National Botanical Research Institute, Lucknow, India. The lichen specimens were identified on the basis of their morphology, anatomy and chemistry. The morphological and anatomical details of the specimens were studied using standard light microscopy techniques under Stereomicroscope LEICA™ S8APO and optical microscope LEICA™ DM500 respectively. The chemistry of the lichens was studied by spot color test, UV-light and thin layer chromatography (TLC) with solvent system A using protocol of Elix and Ernst-Russel (1993) and Orange *et al.* (2001).

Authentication and documentation of identified lichen species

Identification, changes of nomenclature and novelties of the species were authenticated using monographs, relevant keys, literature and checklists (Awasthi, 1991, 2007; Wolseley & Aptroot, 2009; Jagadeesh Ram & Sinha, 2009, 2011; Singh & Sinha, 2010; Mishra *et al.*, 2011; Aptroot, 2012; Olley & Sharma, 2013; Ingle *et al.*, 2017; Kantvilas *et al.*, 2018). Nomenclature changes with current name of each species was also checked using the website address (http://www.indexfungorum.org/Names/Names.asp). After identification, the herbarium of each species was prepared following the protocol of Nayaka (2014) and labeled with the name and family of species, detail of locality, date of collection, name of collector and collection number. All the prepared herbaria were deposited at the National Herbarium and Plant Laboratories, Godawari, Kathmandu, Nepal.

Calculation of importance value

Assemblage of lichens was quantitatively analyzed by determining their importance values. The importance values (IV) of lichen species were calculated according to Printos *et al.* (1993, 1995), which were the sum total of relative coverage (RC) and relative frequency (RF).

IV = RC + RF

The RC and the RF were calculated by using the following formulae.

RC = (coverage of individual species/sum of coverage of all species) x 100

RF = (frequency of individual species/sum of frequency of all species) x 100

Results

Lichen species found in Kathmandu valley

A total of 97 species of epiphytic lichens (including 61 species inside the quadrats) belonging to 21 families and 44genera were identified (Table 1). Among the families reported, Parmeliaceae was the largest family with 8 genera and 20 species followed by Graphidaceae with 7 genera and 20 species. Physciaceae, a very common family reported from all the study areas including areas with high anthropogenic activities, was the third largest family with 5 genera and 16 species. The photobiont study showed that the lichen species with green algae (*Trebouxia* and *Trentepohlia*) as photobiont dominated the study areas. The cyanophycean lichens with blue-green algae (photobiont – *Nostoc*) exhibited their poor distribution as represented by only one family Collemataceae with two species and reported from shady and moist places of the Balaju industrial site, Ranibari site and Suryabinayak site.

Table 1: Lichen species found in Kathmandu valley showing their family name, name of lichen species, their accession number and growth form

SN	Name of family	Name of lichen species	Accession number	Growth form
1	Parmeliaceae	*Bulbothrix isidiza* (Nyl.) Hale	17-174B	Foliose
		Bulbothrix meizospora ((Nyl.) Hale	17-176	Foliose
		Bulbothrix setschwanensis (Zahlbr.) Hale	16-126	Foliose
		Canoparmelia pustulescens (Kurok.) Elix.	16-096A	Foliose
		Canoparmelia texana (Tuck.) Elix & Hale	16-116	Foliose
		Hypotrachyna cirrhata (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch	17-145	Foliose
		Hypotrachyna majoris (Vain.) Hale	17-181	Foliose
		Hypotrachyna physcioides (Nyl.) Hale	17-177	Foliose
		Myelochroa subaurulenta (Nyl.) Elix & Hale	17-172	Foliose
		Myelochroa xantholepis (Mont. & Bosch) Elix & Hale	16-096B	Foliose
		Parmelinella wallichiana (Taylor) Elix & Hale	17-168	Foliose
		Parmotrema austrosinense (Zahlbr.) Hale	16-028	Foliose
		Parmotrema praesorediosum (Nyl.) Hale	16-026A	Foliose
		Parmotrema pseudonilgherrense (Asahina) Hale	17-175	Foliose
		Parmotrema reticulatum (Taylor) Choisy	16-094	Foliose
		Parmotrema tinctorum (Nyl) Hale	16-069	Foliose
		Remototrachyna awasthii (Hale & Patwardhan) Divakar & A. Crespo	16-061	Foliose
		Remototrachyna flexilis (Kurok.) Divakar & A. Crespo	16-100	Foliose
		Usnea eumitrioides Motyka	17-146	Fruticose
		Usnea orientalis Motyka	17-205A	Fruticose
2	Graphidaceae	*Allographa cleistoblephara* (Nyl.) Lücking & Kalb	16-016	Crustose
		Allographa leprographa (Nyl.) Lücking & Kalb	16-133A/c	Crustose
		Diorygma hieroglyphicum (Pers.) Staiger & Kalb	16-148	Crustose
		Diorygma junghuhnii (Mont. & Bosch.) Kalb, Staiger & Elix	16-089	Crustose
		Graphina anguina (Mont.) Müll. Arg	16-093A/b	Crustose
		Graphis antillarum Vain	17-207C	Crustose
		Graphis breussii G. Neuwirth & Lücking	16-093C	Crustose
		Graphis cincta (Pers.) Aptroot	16-046	Crustose
		Graphis galactoderma (Zahlbr.) Lücking	17-158B	Crustose
		Graphis lineola Ach.	16-109B	Crustose
		Graphis paradisserpens Sipman and Lücking	16-093A/a	Crustose
		Graphis paraserpens Lizano and Lücking	16-182	Crustose
		Graphis perticosa (Kremp) A. W. Archer	16-163A	Crustose
		Graphis pinicola Zahlbr.	17-200A	Crustose
		Graphis proserpens Vain	17-149	Crustose
		Graphis stenotera Vain.	16-093B	Crustose
		Pallidogramme chrysenteron (Mont.) Staiger, Kalb & Lücking	17-163B	Crustose
		Pallidogramme divaricoides (Räs.) Pushpi Singh & Kr.P. Singh	16-089B	Crustose
		Phaeographis leiogrammodes (Kremp.) Mull. Arg.	17-196A	Crustose
		Thalloloma subvelata (Stirt.) D.J. Galloway	17-196B	Crustose

SN	Name of family	Name of lichen species	Accession number	Growth form
3	Physciaeae	*Heterodermia diademata* (Taylor) D.D.Awasthi	16-132	Foliose
		Heterodermia firmula (Linds.) Trevis.	16-088A	Foliose
		Heterodermia incana (Stirt.) D.D.Awasthi	17-221	Foliose
		Heterodermia speciosa (Wulfen) Trevis.	17-142	Foliose
		Hyperphyscia adglutinata Var. *pyrithrocardia* (Mull. Arg.) D.D. Awasthi	16-120	Foliose
		Hyperphyscia minor (Fée) D.D. Awasthi	16-059	Foliose
		Hyperphyscia isidiata Moberg	16-108D	Foliose
		Phaeophyscia hispidula var. *hispidula* (Ach.) Essl.	16-003A	Foliose
		Phaeophyscia pyrrhophora (Poelt) D.D. Awasthi & M. Joshi	16-127A	Foliose
		Physcia abuensis D.D. Awasthi & S.R. Singh	16-068	Foliose
		Physcia aipolia (Ehrh. ex Humb.) Fürnr	16-029	Foliose
		Physcia crispa (Nyl)	16-014	Foliose
		Physcia dubia (Hoffm.) Lettau	16-064A	Foliose
		Physcia integrata (Nyl.) Arnold	16-98	Foliose
		Physcia sorediosa (Vain.) Lynge	16-010B	Foliose
		Polyblastidium japonicum (M. Satô) Kalb	17-195	Foliose
4	Arthoniaceae	*Arthothelium subruanum* Makhija & Patw	17-160	Crustose
		Herpothallon flavominutum Jagad. Ram, G.P. Sinha & Elix	16-091	Crustose
		Herpothallon granulosum Jagad. & G.P. Sinha	17-197	Crustose
		Herpothallon himalayanum Jagad. & G.P. Sinha	16-089C	Crustose
		Herpothallon isidiatum Jagad. and G. P. Sinha		Crustose
		Herpothallon philippinum (Vain.) Aptroot & Lücking	16-042	Crustose
		Herpothallon sticticum Jagad. & G.P. Sinha	17-186	Crustose
		Stirtonia psoromica Aptroot & Wolseley	17-207A	Crustose
5	Ramalinaceae	*Bacidia incongruens* (Stirt.) Zahlbr.	16-090A	Crustose
		Bacidia rubella (Hoffm.) A. Massal	17-190	Crustose
		Phyllopsora corallina (Eschw.) Müll. Arg.	16-066B	Squamulose
		Phyllopsora furfuracea (Pers.) Zahlbr.	17-153	Squamulose
		Ramalina conduplicans Vain.	17-144	Fruticose
6	Caliciaceae	*Dirinaria aegialita* (Afzel. ex Ach.) B.J. Moore	16-010B/b	Foliose
		Dirinaria consimilis (Stirt.) D.D. Awasthi	16-123A/b	Foliose
		Pyxine reticulata (Vain.) Vain.	16-035	Foliose
		Pyxine subcinerea Stirt.	16-123B	Foliose
7	Pertusariaceae	*Lepra leucosorodes* (Nyl.) I. Schmitt, B.G. Hodk. & Lumbsch	16-147	Crustose
		Pertusaria melastomella Nyl	17-164	Crustose
8	Lecanoraceae	*Lecanora achroa* Nyl.	16-095	Crustose
		Lecanora chlarotera Nyl.	17-182E	Crustose
		Lecanora interjecta Mull. Arg.	17-166A	Crustose
		Lecanora leprosa Fée Essai	17-182B	Crustose
9	Cladoniaceae	*Cladonia cervicornis* (Ach.) Flot.	17-151A	Fruticose
		Cladonia corniculata Ahti & Kashiw.	17-151B	Fruticose
		Cladonia subradiata (Vain.) Sandst.	17-154	Fruticose
10	Candelariaceae	*Candelaria concolor* (Dicks.) Arnold	16-001	Foliose
		Candelaria indica (Hue) Vain.	16-124A	Foliose

SN	Name of family	Name of lichen species	Accession number	Growth form
11	Collemataceae	*Leptogium burnetiae* Dodge	17-171	Foliose
		Leptogium wilsonii Zahlbr.	16-015	Foliose
12	Pyrenulaceae	*Pyrenula astroidea* (Fée) R.C. Harris	16-186	Crustose
		Pyrenula submastophora Ajay Singh & Upreti	16-92	Crustose
13	Byssolomataceae	*Byssoloma subdiscordans* (Nyl.) P. James	16-90	Crustose
14	Leprocaulaceae	*Leprocaulon coriense* (Hue) Lendemer & B.P. Hodk.	16-087B	Crustose
15	Teloschistaceae	*Opeltia flavorubescens* (Huds.) S.Y. Kondr. & Hur	16-046B/b	Crustose
16	Chrysothrichaceae	*Chrysothrix candelaris* (L.) J.R. Laundon	16-020	Leprose
17	Coccocarpiaceae	*Coccocarpia erythroxyli* (Spreng.) Swinscow & Krog	17-178	Foliose
18	Coenogoniaceae	*Coenogonium lutescens* (Vezta & Malcolm) Malcom	17-154	Crustose
19	Malmideaceae	*Malmidea granifera* (Ach.) Kalb, Rivas Plata & Lumbsch	17-171A	Crustose
20	Stereocaulaceae	*Lepraria* sp.	16-018	Leprose
21	Trypetheliaceae	*Polymeridium submuriforme* Aptroot	16-072	Crustose

Among the 44 genera reported, *Graphis* was the largest genus with 11 species followed by *Herpothallon* and *Physcia* with six species each, and *Parmotrema* with five species (Table 1).

The study of growth forms revealed that Kathmandu valley has almost an equal number of crustose (44 species) and foliose (43 species) lichens (Table 1). The crustose lichens (45%) dominated the areas followed by foliose lichens (44%) (Figure 2). The foliose and crustose lichens showed their diversity in all the disturbed and undisturbed areas including high elevation in clean areas. Whereas, the fruticose form of lichens was reported only from the high elevation in clean areas.

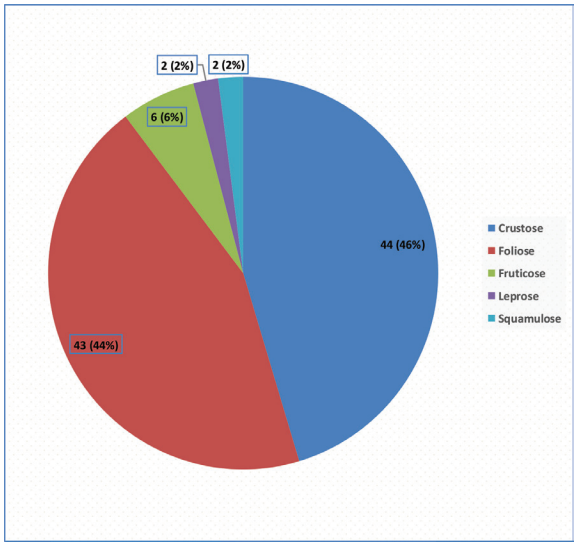

Figure 2: Lichen species found in Kathmandu valley by their growth forms

Importance value (IV) of lichen species

The study revealed that there is considerable variation in lichen species composition and abundance among 20 sampling sites across four study areas of Kathmandu Valley (Table 2). Among the 61 species identified inside the quadrats, 43 (70%) species were reported from clean (undisturbed) areas while 31 (50%) species were reported from disturbed areas (industrial, heavy traffic and residential areas). The most common and dominant species of the Valley were *Candelaria concolor* (IV ranges from 3.5 to 115.2), *Dirinaria aegialita* (IV ranges from 14.2 to 45.9), *Lepraria sp.* (IV ranges from 5.9 to 74.1), *Phaeophyscia hispidula var. hispidula* (IV ranges from 7.3 to 67.7) and *Physcia sorediosa* (IV ranges from 9.4 to 106.02) (Table 2). These species were reported from all the study areas and have a high importance value in most of the sampling sites of disturbed areas (industrial, heavy traffic and residential areas) than in undisturbed (clean) areas. Among the all species recorded in quadrates, *Candelaria concolor* was found with the highest importance value (115.2) at heavy traffic areas followed by *Physcia sorediosa* (106.02) in the same area and both species were reported from 95% of sampling sites, with exception of the Phulchoki sampling site, a clean area. Contrary to this, the species like

Bacidia incongruens and *Remototrachyna flexilis* have the lowest importance value (1.0) followed by *Hypotrachyna cirrhata* (2.3) and *Leptogium burnetiae* (2.4) in clean areas. Among the species of all twenty sampling sites, 52.5% of the species were confined to only one sampling site. The rest of the species were relatively restricted in particular sites.

Table 2: Impotance Value of lichen species (n = 20) for each sampling site in the study areas. (* name of sampling site: figure 1)

Name of lichen species	Industrial areas			Heavy traffic areas							Residential areas							Clean areas		
	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Allographa cleistoblephara											2.7									
Allographa leprographa																			32.5	
Bacidia incongruens																		1.0		
Bulbothrix isidiza																		9.2		21.1
Bulbothrix setschwanensis																		9.6	10.1	
Byssoloma subdiscordans																		14.3		
Candelaria concolor	90.3	11.5	7.3	15.2	55.3	64.4	16.0	115.2	22.9	100.5	5.5	22.1	23.3	24.6	10.1	22.2	17.7		5.4	3.5
Candelaria indica																			13.7	
Canoparmelia pustulescens																		6.5	24.5	24.8
Canoparmelia texana			20.1						16.2		12.2		15.3	3.5		33.3	4.8			
Chrysothrix candelaris						7.5	6.9		15.3			12.0	16.1	2.2	16.1		17.0			
Diorygma hieroglyphicum																			10.3	
Diorygma junghuhnii																5.7		30.5		
Dirinaria aegialita	24.5			45.91		14.2	15.3		21.0		20.0	35.9		42.8	17.7	42.1	16.1			15.4
Dirinaria consimilis																			15.4	
Graphina anguina																		8.6		
Graphis breussii																		2.8		
Graphis cincta		10.2											5.4				5.2		1.5	
Graphis lineola																	5.5			
Graphis stenotera																		4.2		
Herpothallon flavominutum																		18.6		
Herpothallon granulosum																	10.0			44.2
Herpothallon himalaya																		11.8		
Herpothallon isidiatum		41.8																		
Herpothallon philippinum											21.5						55.4			
Heterodermia diademata																		11.0	2.3	
Heterodermia firmula																		10.4		
Heterodermia speciosa																		11.4		

Name of lichen species	Industrial areas			Heavy traffic areas							Residential areas							Clean areas		
	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hyperphyscia adglutinata Var. *pyrithrocardia*							32.0		30.0					7.2		12.9				
Hyperphyscia isidiata																	6.7			
Hyperphyscia minor		25.3		4.77			30.3				21.8						9.4		6.1	
Hypotrachyna cirrhata																		2.3		
Lecanora achroa																		16.7	5.4	
Lecanora chlarotera		4.7																		
Lepraria sp.		27.4	74.1	41.14			29.9	15.9	28.9	16.8	34.5	21.7		21.2	45.6	5.9				11.0
Leptogium burnetiae																				2.4
Leptogium wilsonii		3.0									13.9									
Lithocalla ecorticata					38.70															
Myelochroa xantholepis																		5.0		
Opeltia flavorubescens		5.2																		
Pallidogramme divaricoides																		11.8		
Parmotrema austrosinense												7.1								
Parmotrema praesorediosum						2.9	19.4		5.3			7.8	12.4		6.6		6.6			
Parmotrema reticulatum																		7.6	21.6	
Parmotrema tinctorum									4.5			6.7		1.8					2.8	7.5
Phaeophyscia hispidula var. *hispidula*	12.4		25.3	67.7		61.6	25.6	26.9		16.3		7.3	25.3	8.8	43.3				7.4	
Phaeophyscia pyrrhophora																			3.0	
Phyllopsora corallina																				33.2
Physcia abuensis																				7.7
Physcia aipolia												3.7					13.3			
Physcia crispa		35.1									45.3									
Physcia dubia	20.0								12.7				69.6	2.2	13.4		11.6		1.5	6.2
Physcia integrata																		1.6	15.9	
Physcia sorediosa	52.8	35.6	35.7	25.2	106.02	37.7	14.8	42.1	43.2	66.3	22.6	75.7	32.5	47.7	39.6	50.8	12.5		14.5	9.4
Polymeridium submuriforme														37.9						
Pyrenula astroidea																				8.1
Pyrenula submastophora																		4.1		
Pyxine reticulata							9.7								7.5		8.3			
Pyxine subcinerea			37.4			11.7										18.0			6.1	
Remototrachyna awasthii																9.1				5.5
Remototrachyna flexilis																		1.0		

Discussion

Lichen species found in Kathmandu valley

This study revealed that a total of 97 species of corticolous lichens are found in Kathmandu valley (Table 1). Previously, Baniya *et al.* (2001) enumerated 99 species of lichens from Shivapuri (clean forest area), Kathmandu and Sikles, Pokhara. But in this case, 97 species of bark-inhabiting lichens were reported only from Kathmandu valley. This number is quite high in comparison to the previous study from Kathmandu valley alone, which may be due to the variation in topography and heterogeneity in a climate with diverse vegetation in the study areas which provides good habitat for the luxuriant growth of lichens. The rich lichen flora in a particular region was dependent upon their growth, development, diversity and a wide range of interrelated environmental factors (Brunialt & Giordani, 2003; Sequiera & Muktesh, 2008). Similarly, Chonbang *et al.*, (2018) observed that the distribution of lichen community was significantly affected by elevation gradient, different land use types and variations in canopy openness in the Kanchenjunga Conservation area, eastern Nepal. In recent years, many Nepalese lichenologists have enumerated and studied the distribution pattern of lichen flora in different parts of the country. In this contest, Baniya & Gupta (2002) reported 77 species from Thodimai of Annapurna Conservation Areas and 78 species from the buffer zone of Makalu-Barun National Park. Similarly, Devkota (2008) enumerated 32 species of lichens from Phulchowki Hill, Lalitpur. In the same way, Baral (2015) reported 68 species from Sagarmatha National Park and 13 species from Manaslu Conservation Area. Among the species recorded from Kathmandu Valley, 18 lichen species of Graphidaceae are new records for Nepal (Karmacharya *et al.*, 2018). Similarly, Rai *et al.* (2016) added 28 species of lichens from Dadeldhura, Mahakali Zone, as new to Nepal. These findings indicate the occurrence of rich lichen flora in the country and many areas are still unexplored lichenologically.

Among the 21 families reported in this study, Parmeliaceae and Graphidaceae, which exhibited the same number of species were the largest families in the Kathmandu valley. Globally these two families are the largest with 2,765 lichen species under Parmeliaceae and 2,161 species under Graphidaceae (Lucking *et al.*, 2016). Similarly, the finding of Singh & Sinha (1997) also supported our study as they reported Parmeliaceae (199 species) is the largest family in India. This study recorded the corticolous lichens with the green algae as a photobiont in most of the study areas whereas cyanophycean lichens with blue-green algae as photobiont showed poor diversity representing only two species of a single-family Collymataceae. Cyanophycean lichens are shade-adopted and moisture-dependent. Hence these two cyanolichens were found in shade and moisture conditions. Many numbers of shade-loving and moisture-tolerant cyanophycean lichens including Collemataceae were observed in the Bolampatti II forest range, in Tamil Nadu, India (Balaji and Hariharan, 2013). Among the growth form studied, crustose lichens dominate the study areas followed by foliose lichens. Contrary to this, Chongbang *et al.* (2018) observed a higher number of foliose lichens compared to other growth forms in the Kanchenjunga Conservation area of eastern Nepal. This difference in growth forms might be due to the variation in habitat as Kathmandu valley is a polluted urban area whereas Kanchejunga is a comparatively clean area. They also observed that the area was dominated by corticolous lichens and showed poor diversity of cyanophycean lichens supporting this study. In the study, fruticose lichens were reported only from higher altitudes. This finding is comparable to Pinokiyo *et al.* (2008), who observed a higher abundance of crustose lichens than other growth forms and an absence of fruticose lichens at lower altitudes of Arunachal Pradesh in northeast India. Fruticose lichens prefer areas having good air quality with appropriate light conditions (Wolseley and Pryor, 1999).

Lichen diversity

The study of importance value (table 2) investigated the effect of different areas of pollution gradients on the distribution and diversity of corticolous lichens. The distribution

and species richness of corticolous lichens were not uniform and were found different in different study areas of Kathmandu valley. Undisturbed (clean) areas have rich lichen diversity and supported more species compared to sampling sites of disturbed (polluted) areas (industrial, heavy traffic and residential areas) (Table 2). Similar results have been obtained by various researchers (Das *et al.*, 2013; Agnan*et al.*, 2017; Khastini *et al.*, 2019). Pinokiyo *et al.* (2008), also observed a higher number of corticolous lichen species in the dense forest of the undisturbed central zone than in areas along the roadsides located towards the periphery of the Sanctuary in northeast India. Distribution and diversity of epiphytic lichen flora are influenced by changes in microclimate, air quality, local sources of disturbance, alteration in environmental pollution and habitat fragmentation (Brunialti & Giordani, 2003; Moen & Jonsson, 2003; Jayalal *et al.*, 2015; Das *et al.*, 2013; Khastini *et al.*, 2019). In the present study, the occurrence of a higher number of lichen species in undisturbed areas could be due to the presence of forest patches with dense vegetation, suitable environmental conditions, sufficient moisture, unpolluted air and undisturbed stratum (Purvis, 2000; Nayaka, 2014; Jayalal *et al.*, 2015). On the contrary, the decrease of lichen species in disturbed (polluted) areas may be the cause of industrial activities, the density of road traffic and anthropogenic activities which influence the epiphytic vegetation to decline (Gombert, *et al.* 2004; Seaward, 2008; Llop *et al.*, 2012; Das *et al.*, 2013; Sett & Kundu, 2016; Khastini *et al.*, 2019). Weerakon *et al.*, (2020) observed that the diversity and community composition of corticolous lichens were strongly influenced by the richness of tree species, vegetation type and disturbance in the study area.

The present study revealed that the most common and dominant group of lichens species in Kathmandu valley were *Candelaria concolor* (Dicks.) Arnold, *Dirinaria aegialita* (Afzel. ex Ach.) B.J. Moore*, Lepraria* sp.*,* (Afzel. ex Ach.) B.J. Moore, *Phaeophyscia hispidula var. hispidula* (Ach.) Essl. and *Physcia sorediosa* (Vain.) Lynge. These species were reported from all the study areas of different degrees of pollution levels (Industrial, heavy traffic, residential and clean areas) and have comparatively high importance values in disturbed areas (Table 2). *Candelaria concolor* and *Lepraria* sp. are nitrophilous species and are able to thrive in both polluted and clean areas (Fibrous *et al.*, 2017). Similarly, *Dirinaria aegialita* and members of lichen belonging to physciaceae (*Phaeophyscia hispidula* var. *hispidula* and *Physcia sorediosa*) are pollution-tolerant species and able to exist in areas with high anthropogenic activity (Shukla & Upreti, 2011; Nag *et al.*, 2020; Díaz *et al.*, 2021). Among these species, *Candelaria concolor* and *Physcia sorediosa* exhibited the highest importance value in polluted areas indicating more tolerant species than other species. Hence, the high IV value of these species can be used as suitable indicators for monitoring air quality.

Epiphytic lichens are good indicators to monitor air quality as they are very sensitive to changing environments (Das *et al.*, 2013; Jayalal *et al.*, 2015; Varela *et al.*, 2018; Loppi, 2019). The species like *Bacidia incongruens, Remototrachyna flexilis, Hypotrachyna cirrhata* and *Leptogium burnetiae* which showed their occurrence in undisturbed (clean) areas having no industries, less traffic and minimum anthropogenic activities can be considered sensitive species. Similarly, the lichen species having high importance value and mostly growing in more or less polluted sites with industrial, heavy traffic and anthropogenic activities (disturbed areas) can be considered pollution-tolerant species (Mishra *et al.*, 2016). In this way, the distribution and diversity of tolerant and sensitive lichens species help to distinguish the high and less polluted localities in the study areas.

Conclusion

The study showed that a total of 97 species of corticolous lichens are found in Kathmandu valley indicating the lichen species richness of study areas. The areas with rich lichen diversity indicate a low level of environmental pollution whereas the areas with poor lichen diversity indicates a high level of pollution. The most dominant species of the valley are *Candelaria concolor, Dirinaria aegialita, Lepraria* sp.*, Phaeophyscia hispidula var. hispidula* and *Physcia sorediosa*, which

can be considered pollution-tolerant species whereas the species like *Bacidia incongruens, Remototrachyna flexilis, Hypotrachyna cirrhata* and *Leptogium burnetiae*are are rare species that can be considered pollution-sensitive species. In this way, the present study helps us to learn about tolerant and sensitive species of the valley. The findings of this research provide a suitable platform for monitoring the air quality of Kathmandu Valley using these species for future purposes.

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