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Sensitivity of Lichens to Air Pollution around the Industrial Area of Bhadravathi Town, India

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ABSTRACT

Ambient air quality monitoring was carried out for two consecutive years (2006-2008) to assess the concentration of suspended particular matter (SPM), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) at an industrial area of Bhadravathi town and at Kuvempu University campus (15 km away from Bhadravthi town). Epiphytic lichens were monitored according to EU guidelines. The concentration of SPM (232.30-236.56 µg/m^3) was highest of the three analyzed air pollutants, although all three were well within the threshold limit at both sites. Lichen species belonging to 9 genera were identified on the tree barks of *Mangifera indica* and *Pongamia pinnata* in the control area while sensitive lichen species were absent in the industrial area. The varied response of lichen species may be directly attributed to air pollution in Bhadravathi town.

Keywords: air quality, air pollutants, epiphytic lichen, lichens diversity value, *Ramalina*, *Teloschistes*

INTRODUCTION

Ambient air quality monitoring was carried out for two consecutive years (2006-2008) to assess the concentration of suspended particular matter (SPM), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) at an industrial area of Bhadravathi town and at Kuvempu University campus (15 km away from Bhadravthi town). Epiphytic lichens were monitored according to EU guidelines. The concentration of SPM (232.30-236.56 µg/m^3) was highest of the three analyzed air pollutants, although all three were well within the threshold limit at both sites. Lichen species belonging to 9 genera were identified on the tree barks of *Mangifera indica* and *Pongamia pinnata* in the control area while sensitive lichen species were absent in the industrial area. The varied response of lichen species may be directly attributed to air pollution in Bhadravathi town.

MATERIALS AND METHODS

Description of study area

Bhadravathi is an industrial town situated at 13°49′46″ N to 75°42′22″ E in the Shimoga District of Karnataka state, India. It is situated at a distance of about 255 km from the state capital Bangalore. The study area is notorious for its emissions from two large-scale industries (Visweswaraya Iron and Steel Plant and Mysore Paper Mills Ltd.) in addition to numerous small-scale industries of the town. Air quality and lichen diversity of Bhadravathi town were compared with that of a control area (Kuvempu University campus). Secondary additive factors could not have affected the morphology of the identified lichen species, such as soil type and weather of neighbouring areas since both sampling sites (Bhadravathi and University campus) are very similar.

Ambient air quality monitoring to determine air quality

Ambient air quality monitoring followed standard methods of the National Ambient Air Quality Monitoring (NAAQM). Air sampling was carried out using APM-410 and APM-411 high volume air samplers. The sampling frequency was 24 h, twice a week at uniform intervals and for a period of 2 consecutive years (July 2006 to June 2008). The specifications of the high volume air sampler used for air monitoring are: Flow rate, 0.9-1.2 m^3/min; Recommended filter, Whatman filter paper No. 41 (25 cm diameter); Sampling time, normally 8 h, 24 h (max); Power requirement, 220 V, single phase, 50 Hz, A.C. built in voltage stabilizer with automatic shut off.

Determination of suspended particulate matter

1. Filter inspection

The light table surface was cleaned with a methanol-soaked wiper and allowed to dry. The filter was handed with sterile gloves to prevent contamination. Before placing each filter in the filter chamber of the instrument it was examined for damage.

Suspended particulate matter (SPM) was measured (w/v) as was the mass/quantity of SPM. In each case it was determined by weighing the filter paper before and after sampling with proper equilibrium each time. The monthly mean of SPM for each of the sampling sites was obtained separately using the values of all the samplings of the respective month.

SPM in ambient air (IS 5182-Part IV) was calculated as:

$$\text{SPM} = \frac{\left(W_r - W_i \times 10^6\right)}{V}$$

where, SPM = in µg/m^3, W_r = final weight of the filter in g, W_i = initial weight of the filter in g, V = volume of air sampled in m^3, 10^6 = conversion of g to µg.

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Research Note

Determination of sulphur dioxide

A modified West and Gaeke (1956) method was used. The ambient air was bubbled through the aqueous solution of potassium tetrachloromercurate (TCM) and the SO_2 in air forms a dichlorosulphitomercurate complex, which resists oxidation by the oxygen in the air. This complex is stable to strong oxidants such as ozone and nitrogen oxides (NO_x) and therefore, the absorber solution is stored for a couple of hours prior to analysis. This complex was made to react with pararosanilline and formaldehyde to form the intensely colored pararosaniline methylsulphonic acid. The absorbance of the solution was measured by means of a spectrophotometer (Systronics 367). The concentration of SO_2 in the sample was expressed in $\mu g/m^3$ and was calculated as follows:

$$C\,(SO_2\ \mu g/m^3) = \frac{(A - A_0) \times 1000\,(B)\,V_s}{V_a \times V_t}$$

where A = sample absorbance, A_0 = reagent blank absorbance, B = calibration factor (μg/absorbance), V_a = volume of air sampled (l), V_s = final volume of sampling solution, V_t = aliquot taken for analysis, 1000 = conversion factor from l to m^3.

Determination of nitrogen oxides

The gas was collected in the absorber of the air sampler and the mixture was analyzed with the sodium arsenite method (Jacob and Hochheiser 1958).

Ambient NO_x was collected by bubbling air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion (NO^-_2) produced during sampling was determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide and *N*-(1-naphthyl)-ethylenediamine di-hydrochloride (NEDA) and measuring the absorbance of highly colored azo-dye at 540 nm using a spectrophotometer (Systronics 367). The concentration of the NO_x in the sample was expressed in $\mu g/m^3$ and was calculated as follows:

$$C\,(NO_x\ \mu g/m^3) = \frac{(S\,NO_2) \times V_s}{V_a \times 0.82 \times V_t}$$

where S NO_2 = NO_2 concentration in analyzed sample, 0.82 = sampling efficiency, V_a = volume of air sampled (l), V_s = final volume of sampling solution, V_t = aliquot taken for analysis.

Epiphytic lichen diversity monitoring

European guidelines (Asta 2002) were adopted. These are based on the on the fact that epiphytic lichen diversity is impaired by air pollution and environmental stress. The frequency of occurrence of lichen species on a defined portion of tree bark can be used as an estimate of diversity and as a parameter to estimate the degree of air pollution. Sampling Design: Each sampling unit was selected to represent a certain portion of the survey area and it received equal attention.

The size of sampling units depends on the grid size and hence on the geographical scale of the study. With sampling units of 0.25 × 0.25 km, 0.25 km is the maximum grid density. For the same reason, a 1 × 1 unit can be sampled every 1, 2, 3, ...*n* km according to the survey requirements. Sampling units larger than 1 × 1 are not recommended, as they can cause a number of practical problems. Hence, in the present study, the 0.25 × 0.25 km grid density was selected. Identification of distinct perturbation occurrences at point sources were given attention while in control areas, general investigations were adopted. The number of trees per sampling unit was dependent on its dominance.

Selection of tree species

Tree species must be selected, after reconnaissance of the study area, in order to verify the frequency/distribution of suitable trees. Free-standing trees were selected, i.e. those whose trunks received direct solar radiation for at least part of the day. However, the use of both free-standing trees and of those in closed-canopied stands must be avoided in a single survey. After reconnaissance of the study area, on the basis of dominance, two tree species were selected namely, *Mangifera indica* and *Pongamia pinnata*. Sample trees were selected to ensure that they were free standing and also received direct solar radiation at least part of the day.

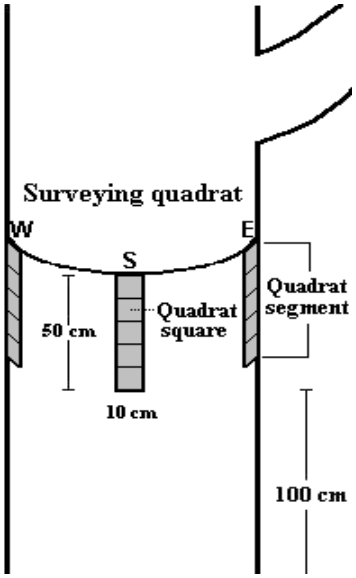

Fig. 1 Recording quadrate composed of four quadrate segments each with five squares.

A monitoring quadrate consisting of four independent quadrat segments of five 10 × 10 cm^2 each (**Fig. 1**) was attached vertically to the tree trunk in such a manner that the lower edge of each segment was 1 m above the ground. This was adopted as in urban centers where lichen cover is often restricted at the base of trees (Asta 2002).

All lichen species present within each quadrat segment were recorded using a form and the frequency of occurrence of each species in the 5 squares of each quadrat segment noted. The list of species with their frequency values in one segment constitutes a relevé of lichen vegetation.

All species were suitable for the calculation of lichen diversity value (LDV). However, a few small crustose lichens were particularly difficult to identify and were thus overlooked (Wolseley 2002).

The four segments of the sampling quadrate were placed to correspond with the four geographic coordinates (NSEW) of the tree trunk with > 2 segments on the trees surveyed. Lichens were identified according to the methods described in the published literature and using European Guidelines (Asta 2002). LDVs were calculated.

Statistical analysis of the obtained data was done using SPSS software v. 12.0.

RESULTS

The concentration of air pollutants was within the threshold limit prescribed by the Central Pollution Control Board (CPCB 2000), but in comparison with control sites, air pollution was very high in the study area. Among air pollutants,

Table 1 Annual concentrations of SPM, SO_2 and NO_x ($\mu g/m^3$) showing significant differences among the industrial area and control site.

	SPM			
Sites	**Control**	**Around industrial area**	***F*-value**	***P*-value**
2006-07	20.08 ± 11.91	236.56 ± 83.22	122.16	0.0001
2007-08	20.15 ± 16.14	232.30 ± 81.63	115.85	0.0001
SO_2				
2006-07	0.07 ± 0.09	13.23 ± 4.75	134.56	0.0001
2007-08	0.033 ± 0.06	13.62 ± 6.09	133.87	0.0001
NO_x				
2006-07	0.35 ± 0.36	19.69 ± 7.88	136.21	0.0001
2007-08	0.28 ± 0.31	19.15 ± 6.88	126.01	0.0001

All values ± standard deviation

Table 2 Variation in lichen diversity (mean ± SD) at control site.

Lichen	*Mangifera indica*				*Pongamia pinnata*			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Pyxine	16 ± 4.96	04 ± 0.81	04 ± 0.81	05 ± 0.81	04 ± 0.00	12 ± 1.41	02 ± 0.00	02 ± 0.00
Chrysothrix	03 ± 0.00	04 ± 0.00	02 ± 0.81	--	01 ± 0.00	05 ± 0.00	02 ± 0.00	08 ± 1.63
Parmotrema	03 ± 0.00	--	--	02 ± 0.81	06 ± 0.81	03 ± 0.00	04 ± 0.00	--
Teloschistes	02 ± 0.81	--	--	07 ± 2.12	02 ± 0.00	02 ± 0.00	--	01 ± 0.00
Dirinaria	04 ±0.00	02 ± 1.63	06 ± 0.81	--	03 ± 0.00	09 ± 0.00	03 ± 1.41	06 ± 0.00
Graphis	03 ± 0.00	06 ± 0.00	--	04 ± 1.63	--	02 ± 0.00	04 ± 0.00	04 ± 1.63
Ramalina	08 ± 1.63	--	04 ± 0.81	--	05 ± 0.81	07 ± 0.00	01 ± 0.00	--
Lecanora	03 ± 0.81	--	01 ± 0.00	05 ± 0.81	06 ± 1.63	06 ± 0.81	06 ± 0.95	01 ± 0.81
Heterodermia	03 ± 0.00	09 ± 2.16	06 ± 0.81	02 ± 00	02 ± 0.00	07 ± 0.00	01 ± 1.41	05 ± 0.81
Sum of frequencies	43 ± 4.55	25 ± 3.19	23 ± 2.45	25 ± 2.63	29 ± 2.15	53± 3.22	23 ± 1.96	27 ± 2.84

Table 3 Variation in lichen diversity (mean ± SD) at industrial area.

Lichen	*Mangifera indica*				*Pongamia pinnata*			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Pyxine	08 ± 0.81	10 ± 1.41	02 ± 0.00	01 ± 0.81	01 ± 0.81	02 ± 0.00	08 ± 1.41	04 ± 3.55
Chrysothrix	02 ± 0.81	03 ± 0.81	--	--	01 ± 0.00	--	--	--
Parmotrema	--	01 ± 0.81	--	--	03 ± 0.00	02 ± .00	01 ± 0.81	04 ± 1.41
Teloschistes	--	--	--	--	--	--	--	--
Dirinaria	01 ± 0.81	01 ± 0.81	--	--	--	01 ± 0.81	02 ± 0.81	--
Graphis	01 ± 0.00	05 ± 0.81	01 ± 0.81	02 ± 0.81	01 ± 0.00	01 ± 2.15	01 ± 0.81	06 ± 0.81
Ramalina	--	--	--	--	--	--	--	--
Lecanora	01 ± 0.81	02 ± 0.81	--	--	01 ± 0.81	--	02 ± 0.81	--
Heterodermia	01 ± 0.81	--	--	--	--	--	--	--
Sum of frequencies	14 ± 2.45	22 ± 3.21	3 ± 0.71	3 ± 1.12	7 ± 0.98	6 ± 1.51	14 ± 2.52	14 ± 2.56

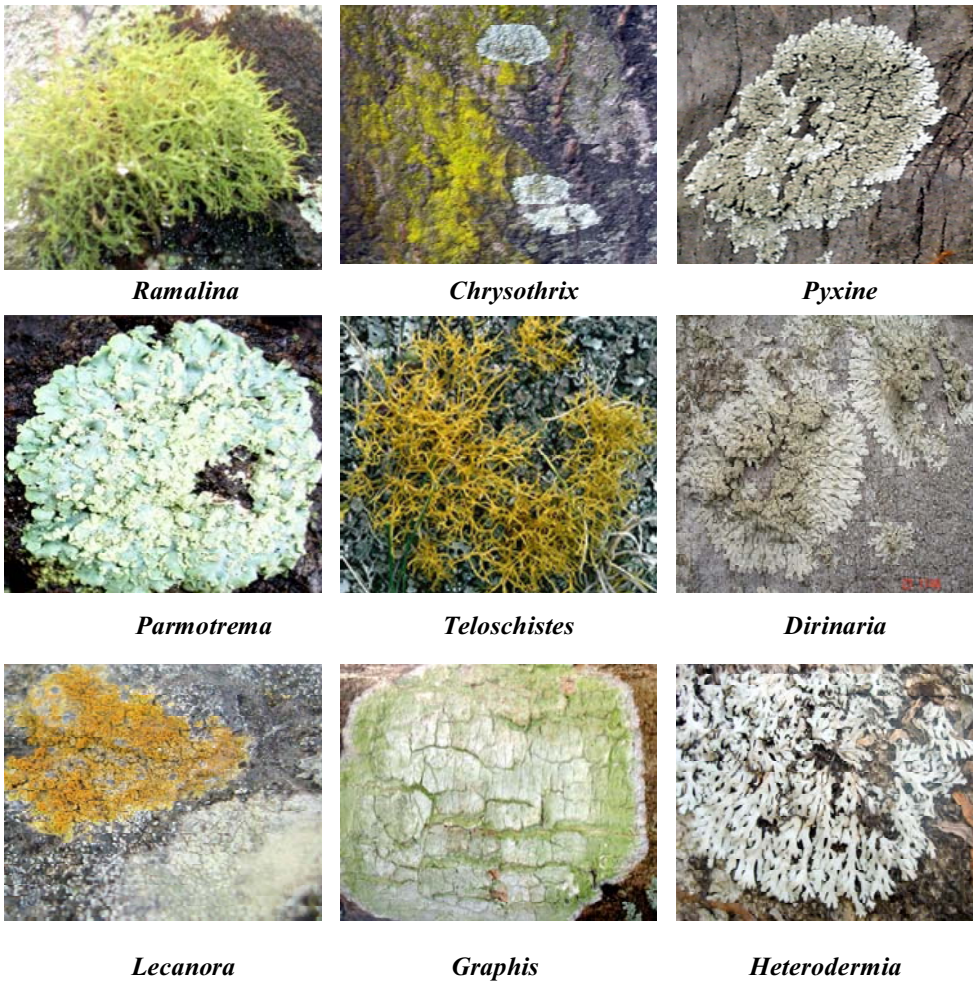

Fig. 2 Lichen genera identified during the study period in Bhadravathi town.

SPM concentration was comparatively higher than the concentrations of NO_x and SO_2 (**Table 1**).

In all, a total of 9 genera of epiphytic lichens were identified: *Pyxine*, *Chrysothrix*, *Parmotrema*, *Teloschistes*, *Dirinaria*, *Graphis*, *Ramalina*, *Lecanora*, and *Heterodermia* (**Fig. 2**). Their occurrence is listed in **Tables 2** and **3**.

In comparison, all 9 genera of epiphytic lichens were present in the control site, but lichens belonging to the genera *Ramalina* and *Teloschistes* were absent on *M. indica* in the industrial area. Species of genera *Teloschistes*, *Rama-*

lina and *Heterodermia* were absent on the bark of *P. pinnata* while only six genera were found. These results suggest that the control site had high diversity of lichens with frequencies of 118 ± 7.23 and 132 ± 5.12 on the barks of *M. indica* and *P. pinnata*, respectively. The genus *Pyxine* (29 ± 5.8) dominated while *Parmotrema* (5 ± 0) showed the least diversity on *M. indica*. *Dirinaria* sp. (21 ± 2.8) was dominant on *P. pinnata*.

At the industrial site *Pyxine* sp. (21 ± 4.4) was most common on the bark of *M. indica*. The total sum of frequencies of lichen genera was 42 ± 3.5, indicating lichen diversity. *Pyxine* sp. (15 ± 3.1) dominated on *P. pinnata*. The industrial area had and LDV of 41.7, about three times less than the control site (122).

All values of air pollutants were expressed as the mean of 96 trials for each year and lichen species were expressed as the mean of 12 trials for each year. Data pertaining to the air pollutants were subjected to one-way multifactorial analysis of variance (ANOVA) in order to determine significant differences between means ($P < 0.001$).

DISCUSSION

From the present study it is evident that the diversity of lichens differed between the industrial area and the control site. The variation in response could be directly attributed to the emissions from two large industries and from a number of small-scale industries in the study area. This observation supports what was noted in earlier studies on lichens at Pauri City, Uttaranchal, India by Vertica Shukla and Upreti (2007). A qualitative survey of the epiphytic lichens in the surroundings of Ulan Bator in October 2007 also showed similar trends (Hauck 2008). Gombert *et al*. (2006) found lichens and tobacco plants as complementary biomonitors of air pollution in the Grenoble area (Isere, southeast France).

Findings

The present work on the use of lichens as a litmus for air pollution reveals that air pollution is the main factor affecting lichen distribution in the study area. Lichen communities change as air quality and environmental conditions change. So, by examining the types of lichens on trees in a neighborhood and the amount of bark that they cover, one can obtain a relative measure of local air quality (EnviroZine 2004) and lichens, therefore, are excellent bioindicators and biomonitors. Some species appear to have different tolerance in different geographical regions and so scales of tolerance must be determined in the area to be surveyed. A scale drawn up in one region can not consequently be reliably applied to another without prior study. Karunarathna (2008) noticed lichens as biomonitors of SO_2 and NO_2 pollution in Colombo and suburbs, further the lowest lichen diversity (0.8374) was recorded from the site located in Colombo Fort. He identified 47 genera of lichens, out of them 10 were sensitive to air pollutants. Dolney *et al*. (2009) found more than 20 lichen species among all sample plots with the two (*A. palmulata* and *P. squarrosa*) in southwestern Pennsylvania, USA being sensitive to air pollution. These results suggest that urban and rural regions show contrasting communities of epiphytic lichen corresponding to air pollution and habitat alteration.

Since the LDV varies from site to site it is clear that air pollution has not equally spread throughout the study area. Nayaka *et al*. (2003) reported a similar correlation between air pollution and lichen diversity in Bangalore.

CONCLUSION

In most studies crustaceous lichens are most tolerant, foliose lichens less tolerant, and fruticose lichens least tolerant. It does not follow that all crustaceous lichens are more tolerant than all foliose and fruticose species: In the present study, sensitivity had the following order: *Pyxine* (foliose) < *Graphis* (crustose) < *Parmotrema* (foliose) < *Dirinaria* (foliose) < *Chrysothrix* (crustose) < *Lecanora* (crustose) < *Heterodermia* (foliose) < *Teloschistes* (fruticose) < *Ramalina* (fruticose).

The present investigation gives strong evidence that lichen growth in the study area was affected by air pollution. Moreover, a relationship existed been between the lichen community existing at sampling sites and the degree of air pollution. The absence of naturally appearing lichens in severely polluted areas limits the spatial differences of polluted areas. Zones based on epiphytic lichen vegetation provide a better indication of air pollution intensity than distribution maps of particular species. Hence, documentation of the lichen species at the study area will be of greater importance in the future.

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