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RESEARCH ARTICLE

Correlation of atmospheric purity index to the diversity of lichens in the Horton Plains National Park, Sri Lanka

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Abstract: Horton Plains National Park (HPNP) has been declared as a world heritage site, because of its unique biodiversity. Die-back of certain areas of this park is widely believed to be due to acidic precursor depositions carried over from other parts of the country and also from neighboring countries. Air pollution data for the two pollutants, NO_2 and SO_2 were obtained from the passive air sampling method. The data revealed that the concentrations of ambient NO_2 and SO_2 were very low in the HPNP. The variations of ambient NO_2 and SO_2 concentrations during the study period showed insignificant positive correlation ($p \geq 0.05$) with the rainfall data. Considering the variations of these two pollutants with Relative Humidity and the number of vehicles visiting HPNP, both pollutants had insignificant positive correlation. The Index of Atmospheric Purity (IAP) value obtained for the whole area of the HPNP was 54.22. This value belongs to the quality level 5 which represents the 'very low' pollution level. The results including lichen distribution and air quality data could confirm that the ambient air quality at HPNP is very high. The high diversity of lichens and the minimum levels of air pollutants suggested that the forest health of HPNP is at a favorable level. Therefore, it is essential to maintain at least the current air pollution level of HPNP in order to conserve the forest and its biodiversity.

Keywords: Lichen Diversity; Horton Plains; Air Pollution; Sri Lanka.

INTRODUCTION

Horton Plains National Park of Sri Lanka, a cloud forest, recently designated as a World Heritage Site by UNESCO. Because of the unique climatic and physiographic features, it ranks high among the biodiversity super hotspots within the Western Ghats and Sri Lanka harboring a large number of endemic flora and fauna within its range (World Heritage Report, 2010). HPNP is located about 24 km south of Nuwara Eliya between latitude 6° 47'- 6° 50' N and longitudes 80° 46'- 80° 51' E at an elevation ranging from 1500 m to 2524 m Above Sea Level (ASL) with a plateau starting from about 2,100 m ASL. This is the only montane plain in Sri Lanka with a natural history dating back to pre-historical times (Green, 1990). The unique characteristics of this ecosystem highlight the importance of its conservation. However, the forest die back at HPNP in recent times has initiated a debate regarding air pollution issues at the park.

In one of the rare studies related to the atmospheric pollution at the HPNP, Gunawardena *et al.* (1998) reported the possibility of acid deposition in the fog which arrives predominantly from the Indian continent and from the western parts of the country where more than 50 % of the vehicle population and the major industries are located. Further, they reported that atmospheric pollution levels in the HPNP may increase due to the trans-boundary pollution from the Indian Sub-continent during the North-East monsoon.

Although chemical analysis to determine the atmospheric purity is important and would derive baseline information, biomonitoring attempts to evaluate the presence of air pollutants are not reported from HPNP. Biomonitoring is a collective term for the techniques where living organisms are used to provide information about both abiotic and biotic components of an

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environment. Biological monitoring of air pollutants can be passive or active. Passive methods involve observing plants growing naturally within the area of interest. Active methods detect the presence of air pollutants by introducing test plants of known genotypes and its response within the study area (Mulgrew and Williams, 2000).

Traditionally, lichens flora have been used for monitoring air pollution from the 1860s (Nylander, 1866; James, 1973; Seaward *et al.,* 1981; Garty and Hagemeyer, 1988; Brown, 1984; Sawidis *et al.,* 1995; Nimis *et al*., 2002; Stamenkovic *et al*., 2010; Jayalal *et al*., 2015). Because of the lack of a cuticle and an epidermis, lichens accumulate air borne metals (Olmez *et al.*, 1985), actively uptake anions and adsorb cations and ion exchange ions such as Na^{+} and Ca^{2+} passively (Nieboer and Richardson, 1981).

The diversity of HPNP lichen flora can use as a tool for biomointoring air pollutant levels at the HPNP (Jayalal *et al*., 2006). The most recent check list of flowering plants within the HPNP prepared by Wijesundara (2007) indicated 653 species belong to 102 families and 461 genera. However, no extensive collection of lichens have been recorded in the past in HPNP other than Santesson and Moberg who visited Sri Lanka in 1975 and collected about 10 specimens of Thelotremataceae, mostly from the Horton Plains area (Hale, 1981). More recently,many lichen species have been recorded from HPNP (Jayalal *et al*., 2012; Wijesundara & Karunaratne, 2015).

According to the past literature and some recent investigations on lichens carried out in Sri Lanka, the numbers of lichen species already recorded from Sri Lanka may exceed 1,000 species (Jayalal *et al*., 2008). Importantly several new species have been added to the Sri Lankan lichen flora (Orange *et al*., 2001; Jayalal *et al*., 2012; Weerakoon *et al*., 2012). The rich chemical substances and their biological/pharmaceutical activities have made lichens important organisms (Karunaratne *et al*., 2005; Kathirgamanathar *et al*., 2006; Thadhani *et al*., 2012). Finally, in terms of the soil ecology, phenolic lichen metabolites are known to play siderophore type iron chelating ability (Karunaratne *et al*., 1992; Jayasinghe *et al*., 2015), thus affecting soil microbial dynamics.

The objective of this study was firstly to determine the quality of ambient air chemically, by measuring the concentrations of SO_2 and NO_2, over a period of 12 months, and secondly to correlate the data to biomonitoring of lichens through determining their diversity at HPNP using the Index of Atmospheric Purity (IAP) modeling.

METHODOLOGY

Climatic parameters

Climatic parameters such as rainfall, maximum and minimum daily temperature, wind direction and relative humidity during the research period were obtained on a daily basis from the Seetha Eliya Meteorological Station which is located about 10 km from the sampling sites.

Preparation of air samplers and sampler stands

Reagents were prepared, using high purity chemicals from Sigma-Aldrich, in small vials immediately prior to the use. Samplers were in house assembled using 25 mm diameter Teflon rods and were prepared using the method followed by Ileperuma and Abeyratne (2001). The sampler stands were also manufactured in-house using PVC tubes and plastic plates. Prior to use, all sampler components and glass vials were soaked in a detergent solution to remove contaminants, rinsed thoroughly, dried in an oven and stored in a clean environment.

The coating solution for NO_2 was prepared by dissolving 0.44 g of NaOH and 3.95 g of NaI in 10 ml of water and diluting to 50 ml with methanol. For SO_2 determination, the coating solution was prepared by dissolving 0.5 g of NaOH in the minimum of water followed by dilution to 50 ml with methanol.

Table 1: Location characteristics **(**latitude, longitude and elevation) of the five air sampling points in HPNP.

Sampling Site	Latitude	Longitude	Elevation (m)
Pattipola Road	06^{O} 50' 30.4" N	80^{O} 48' 45.7" E	2,172
Ohiya Road	06^{O} 48' 45.7" N	80^{O} 90' 11.0" E	2,161
Worlds' End	06^{O} 47' 08.1" N	80^{O} 47' 59.8" E	2,080
Middle (Car Park area of HPNP)	06^{O} 48' 10.0" N	80^{O} 48' 26.4" E	2,190
Kirigalpotta	06^{O} 47' 55.0" N	80^{O} 47' 46.3" E	2,145

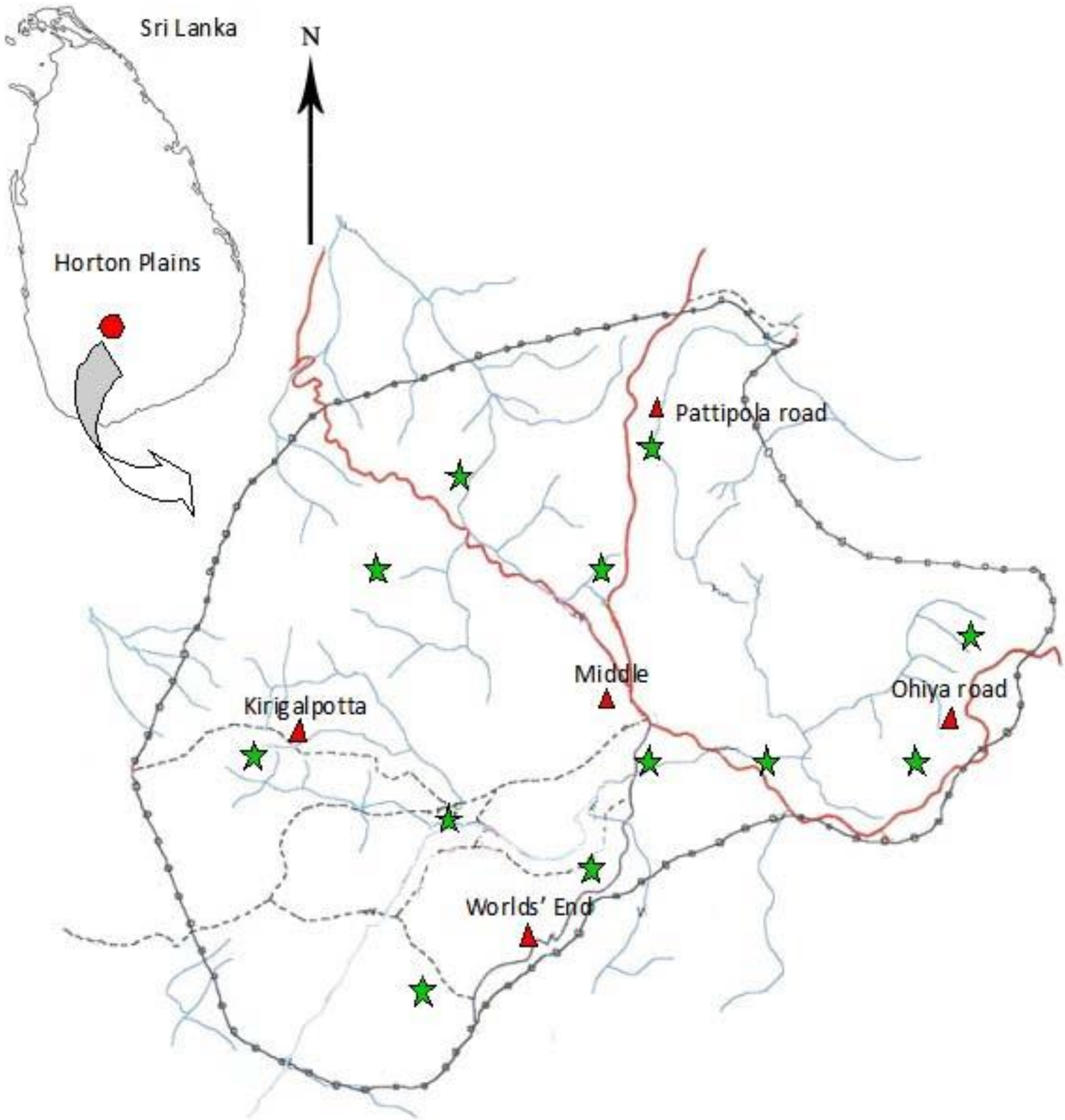

Figure 1: Map of Horton Plains National Park showing air sampling sites (red triangles) and lichen sampling sites (green stars).

Sampling sites

Air sampling sites (5) and lichen sampling sites (12) were selected using a map of HPNP (Figure 1). Lichen sampling sites were situated in both continuous forest (6) and forest islands (6). All the air sampling sites were situated facing the north-west or south-east wind directions. The longitude, latitude and altitude of all the sampling sites are given in the Table 1.

Air sample storage

After exposure, the samplers (in duplicate) were removed and sealed and taken to the laboratory for further analysis. In the laboratory, the sorbent filter was removed and sealed in a small polythene bag. These were then marked with an identifying code indicating the pollutant, site and sample number and stored at 4 ^{0}C for three days until analyses. At the same time, a set of samplers was prepared in an identical manner and kept unexposed at each sampling site to be used as controls for each pollutant type.

Analysis of NO_2

Before the analysis, filters with trapped pollutants were transferred into clean glass vials (20 ml) using Teflon covered tweezers. Pollutants were then extracted into deionized water (5 ml) by sonicating for 10 minutes in a shaker. The same procedure was carried out to the blank. The solution was then analyzed for nitrite using a colourimetric technique (Saltzman, 1954). For the preparation of the colour reagent, phosphoric acid (25 ml of 85 %) and 2.5 g of sulfanilamide were added to 200 ml of deionized water in a 250 ml volumetric flask. After dissolving sulfanilamide completely, 0.25 g of *N*-(1-napthyl)-ethylenediamine dihydrochloride was added and mixed to provide a clear solution. It was then diluted to 250 ml with water. Then the colour reagent (0.2 ml) was added to 5 ml of the sample while mixing the solution. After 10 minutes, the absorbance was measured using a colourimeter (Janway-6050) at a wavelength of 540 nm against a blank, which was treated with the same quantities of the reagents employed for colour development. Finally, a calibration curve was obtained for solutions in the concentration ranged from 1-10 ppm.

Analysis of SO_2

A buffer solution [3 g of $MgCl_2$. 6 H_2O, 0.5 g of CH_3COONa. $3H_2O$, 0.1 g of KNO_3 and 2 ml of acetic acid (99%)] was made in 50 ml of distilled water and it was made up to 100 ml. To prepare the standard sulphate solution, 0.0148 g anhydrous Na_2SO_4 was dissolved in deionized water and was diluted to 100 ml in a volumetric flask. For the measurement of turbidity, the sample (20 ml) was filtered and placed in a 25 ml conical flask. The buffer solution (4 ml) was added and mixed using a magnetic stirrer. To this solution, 1 g of $BaCl_2$ crystals was added at once and stirred for 1 min. The solution was poured into the cell of the turbidity meter (DRT-15CE) and the absorbance reading was taken after 5 minutes. Finally, a calibration curve was obtained for solutions in the concentration ranged from 0.5-5.0 ppm.

Concentrations of absorbed pollutants

The concentration of each pollutant was calculated in nM M^{-3} as follows:

$$\text{Pollutant}(g) = \frac{L \times E_v \times [X]}{T \times D_c},$$

where, L = Total air resistant (41.2 m^{-1})
E_v = Extraction volume (ml)
T = Sampling time (s)
D_C = Diffusion coefficient (m^2 sec^{-1})
D_C for $NO_2 = 1.54 \times 10^{-5}$ m^2 sec^{-1}
D_C for $SO_2 = 1.32 \times 10^{-5}$ m^2 sec^{-1}
$[X]$ = Pollutant anion concentration (µM)

The resulting value from the above equation was converted to parts per billion by volume (ppbv) using the following formula.

$$p = \frac{n \times R \times T}{V},$$

where, n = Number of moles (in a m^3)
R = Gas constant (0.082061 atm mol^{-1} K^{-1})
T = Temperature during sampling (K)
V = Air volume (1000 L)

Table 2: Correlation analysis results (Pearson Correlation Coefficient and p values) amongst the meteorological parameters.

Meteorological parameter	Temperature	Rainfall	Relative Humidity
Rainfall	0.046 0.876^{ns}		
Relative Humidity	0.743 0.002^{**}	-0.052 0.860^{ns}	
Wind Velocity	0.040 0.892^{ns}	-0.091 0.757^{ns}	0.004 0.989^{ns}

Lichen collection and Identification

Lichen distribution on one third of the trees (GBH ≥ 10 cm) present in each plot (50 × 20 m^2) was studied. Lichen diversity and their distribution pattern were studied by recording the presence or absence of lichens on each tree up to 2 m height from the ground level, using a 20 × 20 cm^2 grid. The lichen specimens collected were observed under the dissecting microscope for morphological characters. A cross-section of the thallus and ascomata were taken using a sharp blade prior to observe under the compound stereomicroscope. At each stage, illustrations were made as much as possible. Characters were noted according to the lichen data sheet. Finally, all the lichens were identified up to genus level according to lichen determination keys and previous literature.

Index of Atmospheric Purity (IAP)

The IAP was calculated using the occurrence and frequency of lichens at the study sites and an ecological index for each species using the formulae;

$$IAP = \sum_{i}^{n} \frac{Q \times f}{10}$$

where, n is the number of lichen species found at a given station, Q is the ecological index of a species or the average species richness and f is the number of sampled trees on which this lichen species was found at the site;

The value for $Q \times f$ is divided by 10 to give a more manageable number (Johnsen and Søchting, 1973).

RESULTS

Variation of meteorological data in HPNP

The highest maximum temperature has been observed during March to April and the lowest was recorded in July. The average highest rainfall occurred during October to December and the lowest rainfall in February (Data not given). According to the correlation analysis, the mean temperature and the relative humidity were significantly correlated (Table 2).

Variation of ambient NO_2 concentrations

Data used in this study for passive sampling was the average values of 15-30 days. The obtained values were further averaged in to 24 hours. As there are no standards available for the period of 15-30 days, 24 h values were compared with 24 h standards (WHO, 2000; 2006).

Variation of ambient SO_2 concentrations

The average concentrations of SO_2 during the study period (August, 2005 to September, 2006) at each sampling point showed considerable variations (Figure 2). The variation pattern of SO_2 concentrations among five sampling points was also showed almost a similar trend throughout the study period. World's End showed comparatively low concentration of SO_2 throughout the study period. Comparatively higher concentrations were observed during the whole period at Pattipola road and at the middle point.

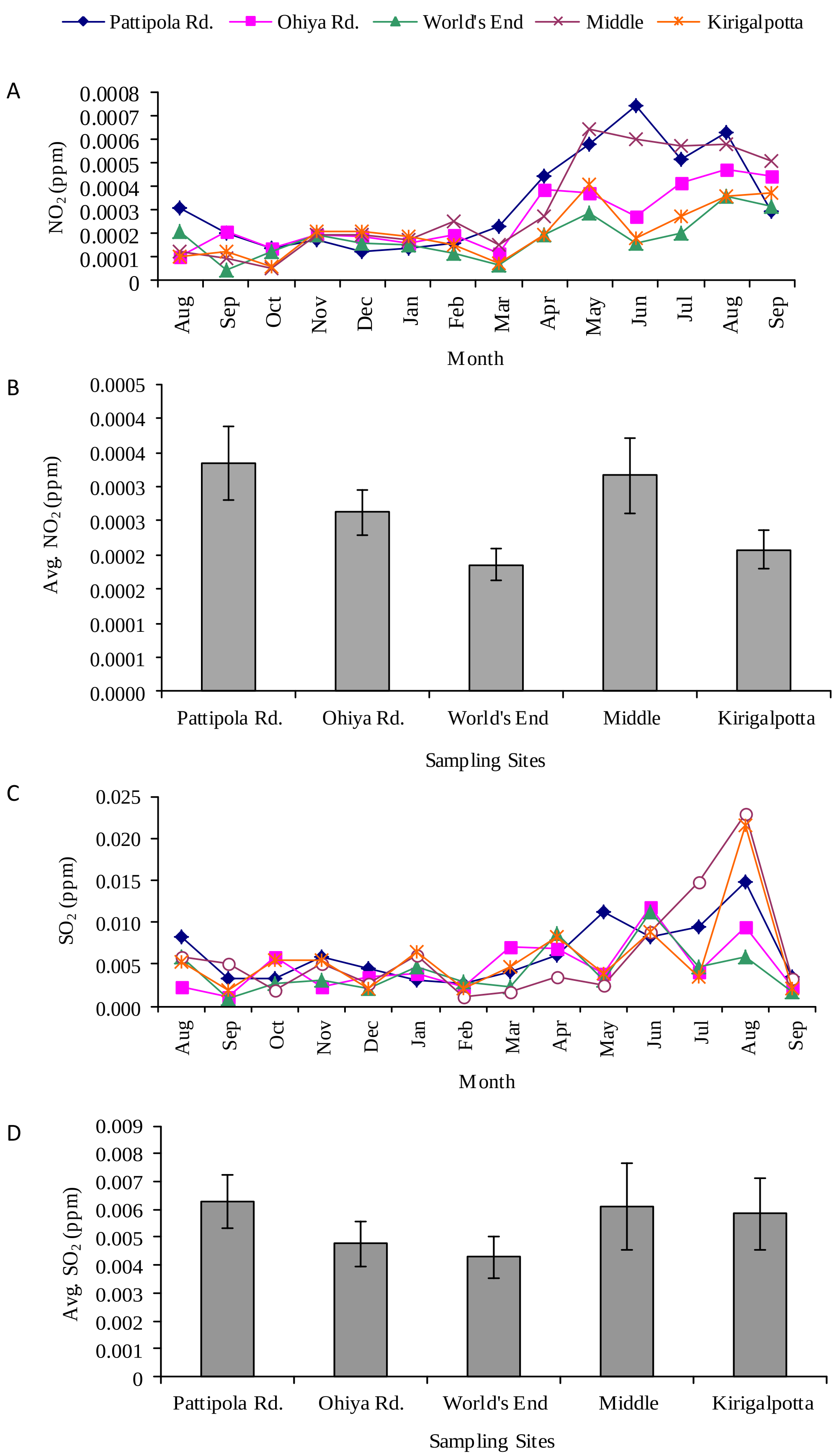

Figure 2: Variation of 24 h average ambient concentrations of NO_2 (A) and SO_2 (C) over the period of 12 months and average concentrations of NO_2 (B) and SO_2 (D) in each sampling point.

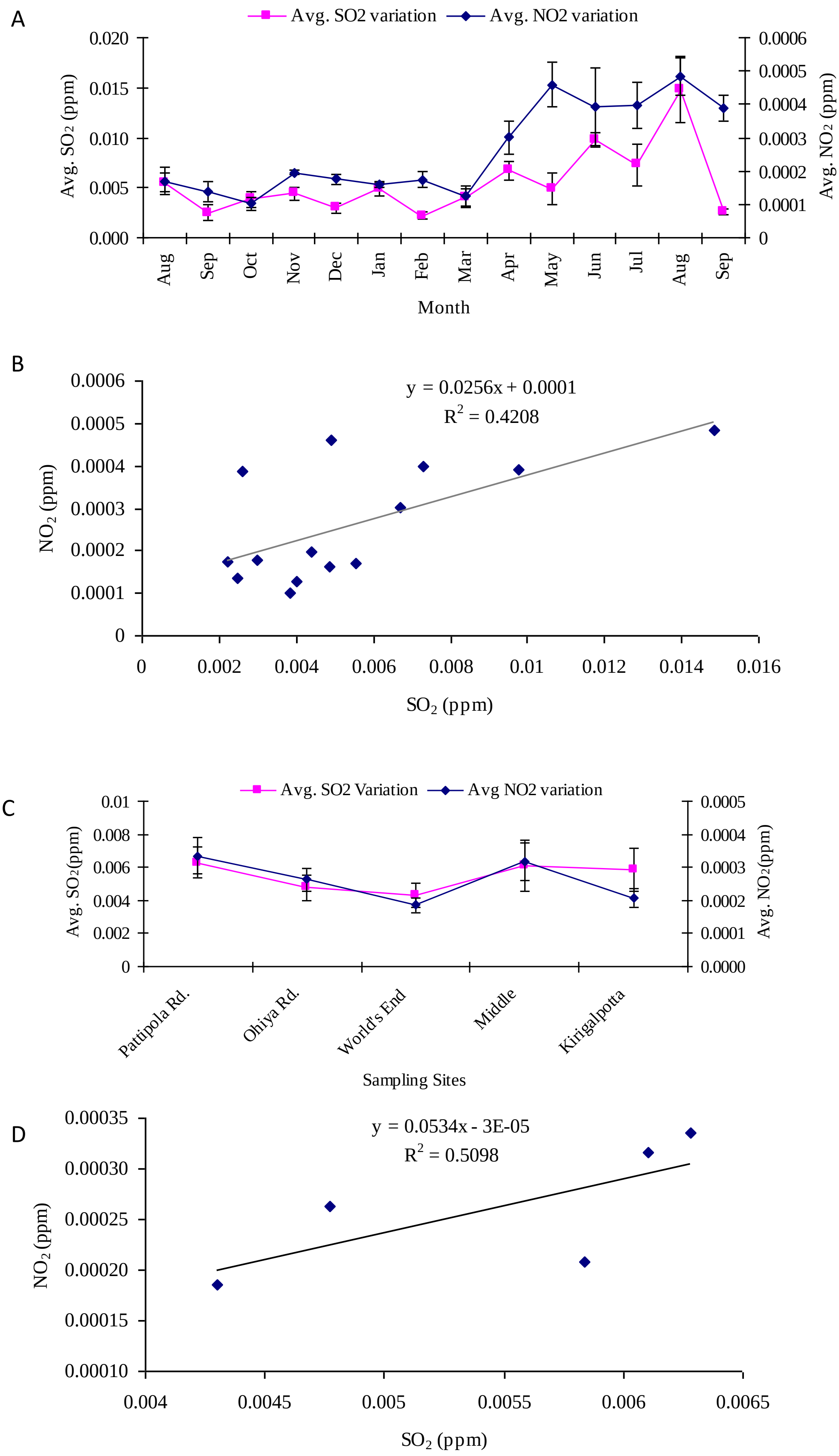

Figure 3: Monthly variations of average ambient SO_2 and NO_2 concentration at HPNP (A), their correlations (B), at each observed point (C) and their correlations (D).

The average concentration of SO_2 was comparatively low between September 2005 to March 2006 and began to increase after March 2006 till September 2006. The lowest average SO_2 concentration (0.002 ppm) was observed in February 2006 and the highest average concentration (0.014 ppm) was in August 2006 (Figure 3). The highest concentration of SO_2 (0.0063 ppm) was observed at the Pattipola sampling point and the second highest value (0.0061 ppm) was observed at the Middle sampling point which was situated close to the vehicle park in HPNP. The lowest concentration of SO_2 (0.0042 ppm) was observed at the World's end.

The variations of the average NO_2 and SO_2 concentrations in each month were almost similar throughout the study period with a significant positive correlation at $p \leq 0.05$ (Figure 2). Similarly, the average concentrations of the two pollutants in each sampling site showed similar variations (Figure 3), but with an insignificant positive correlation at $p \leq 0.05$.

Relative Humidity (RH) at HPNP showed values >70 % throughout the year. Lower RH was recorded during February to March (<70 %). The highest wind velocity was observed during June to July and the lowest was observed in April (Data not given). RH and wind velocity correlated positively but was insignificant (Table 2).

Variation of ambient NO_2 concentration with environmental and vehicular factors

temperature, relative humidity, bright sunshine and the total number of vehicles visiting the HPNP are given in Figure 4. The variation of ambient NO_2 concentration during the study period showed insignificant positive correlation ($p \geq 0.05$) with the rainfall pattern (Table 3). Similar insignificant relationship was observed between wind velocity and RH, hours of bright sunshine and the number of vehicles visiting to HPNP. However, a positive significant correlation ($p \leq 0.05$) was observed between the ambient NO_2 concentration and temperature (Table 3).

Variation of ambient SO_2 concentration with environmental and vehicular factors

Variation of the ambient SO_2 concentration with respect to rainfall, wind velocity, average temperature, relative humidity, bright sunshine and the number of vehicles visiting HPNP were comparable to those of the ambient NO_2 concentration. However, the correlations of variations of the ambient SO_2 concentration with meteorological parameters were different to those for NO_2 concentrations. The ambient SO_2 concentration showed a positive correlation with rainfall, wind velocity, ambient temperature, RH and the number of vehicles visiting HPNP during the study period. The positive correlation was higher with wind velocity and the number of vehicles visiting, while the correlation was less with rainfall, ambient temperature and RH. However, all these correlations were insignificant at $p \leq 0.05$ (Table 3). Further, ambient SO_2 concentration was inversely varied with the precipitation in many months of the study period (Figure 5A). A negative but insignificant correlation was observed between the ambient SO_2 concentration and bright sunshine (Table 3).

Table 3: Correlation coefficients and their p values between the pollutants and climatic and other parameters (bright sunshine, temperature, wind velocity, rainfall and number of vehicles).

Variables	SO_2 (ppm)	Rainfall (mm)	Wind Velocity (km/h)	Temperature (^oC)	Relative Humidity (%)	Bright Sunshine (h)	No. of Vehicles
NO_2 (ppm)	0.641 0.013*	0.158 0.590^{ns}	0.100 0.734^{ns}	0.566 0.035*	0.425 0.129^{ns}	0.192 0.511^{ns}	0.181 0.537^{ns}
SO_2 (ppm)	-	0.122 0.677^{ns}	0.382 0.178^{ns}	0.169 0.564^{ns}	0.056 0.849^{ns}	-0.149 0.611^{ns}	0.448 0.108^{ns}

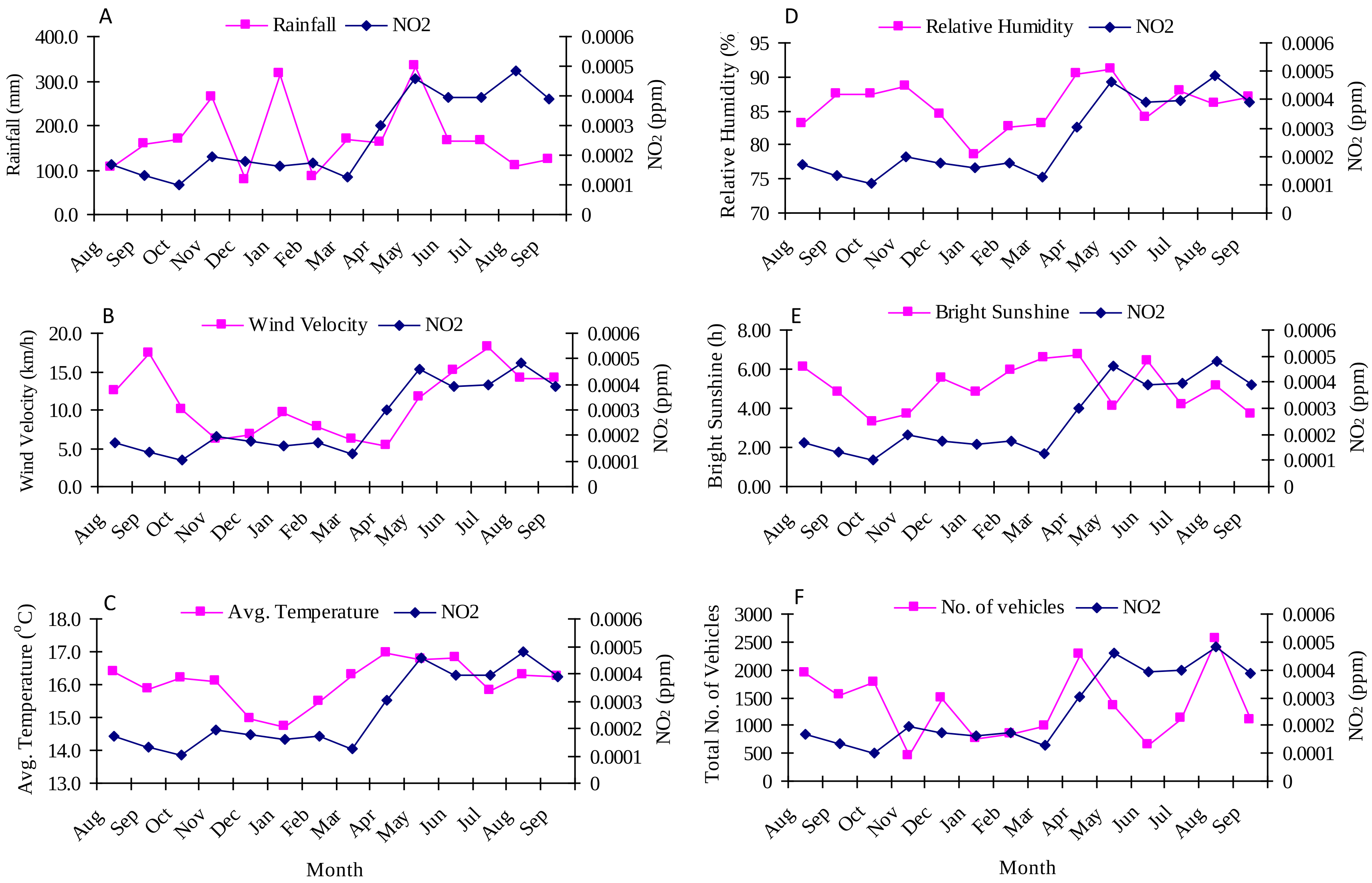

Figure 4 : Variation of NO_2 with rainfall (A), wind velocity (B), average temperature (C), relative humidity (D), bright sunshine (E) and total number of visited vehicles (F) in HPNP.

Table 4: Number of genera and taxa included in each lichen families recorded in HPNP

Family	Genera	Species/Taxa
Bacidiaceae	02	09
Chrysothricaceae	01	01
Cladoniaceae	01	05
Coccocarpiaceae	01	03
Collemataceae	02	16
Gyalectaceae	01	03
Lecanoraceae	03	14
Lobariaceae	03	48
Megalosporaceae	01	02
Nephromataceae	01	01
Pannariaceae	05	12
Parmeliaceae	16	67
Pertusariaceae	02	18
Physiaceae	04	31
Placynthiaceae	01	01
Pyrenulaceae	05	29
Ramalinaceae	01	01
Sphaerophoraceae	01	04
Stereocaulaceae	02	03
Teloschistaceae	02	02
Thelotremataceae	09	71
Porinaceae	03	08
Unknown	-	30

Lichen taxa in the HPNP

A total of 379 lichen taxa belonging to 67 genera and 23 families were identified during the survey (Table 4).

Number of lichen species in each plot

The distribution of lichens from the 12 plots is shown in the Figure 6. The highest number of taxa (107) was recorded from B1 closely followed by B9 (106 taxa) and B7 (101 taxa). All these sampling sites are located in forest islands in HPNP. Considering the continuous forest of the HPNP, the highest number of lichens (89 taxa) were recorded from the plot A4, while the least (50 taxa) was recorded in A8. Some lichen species were recorded exclusively from a single sampling location. A total of 219 lichen species were confined to 10 sampling plots. The maximum number of exclusive species was recorded from B9 (34 species) followed by A4 (31 species). The lowest number was recorded from A8 (7 species).

Index of Atmospheric Purity (IAP) in HPNP

The IAP value obtained for the whole area of the HPNP was 54.22. This value was calculated using 379 lichen species spread in 12 quadrats in forest islands and continuous forest of HPNP. The IAP value for each site is given in Table 5. The IAP varied between 21.7 and 63.7. Almost all the sites present in forest islands had relatively higher IAP values indicating that those areas have low level of SO_2.

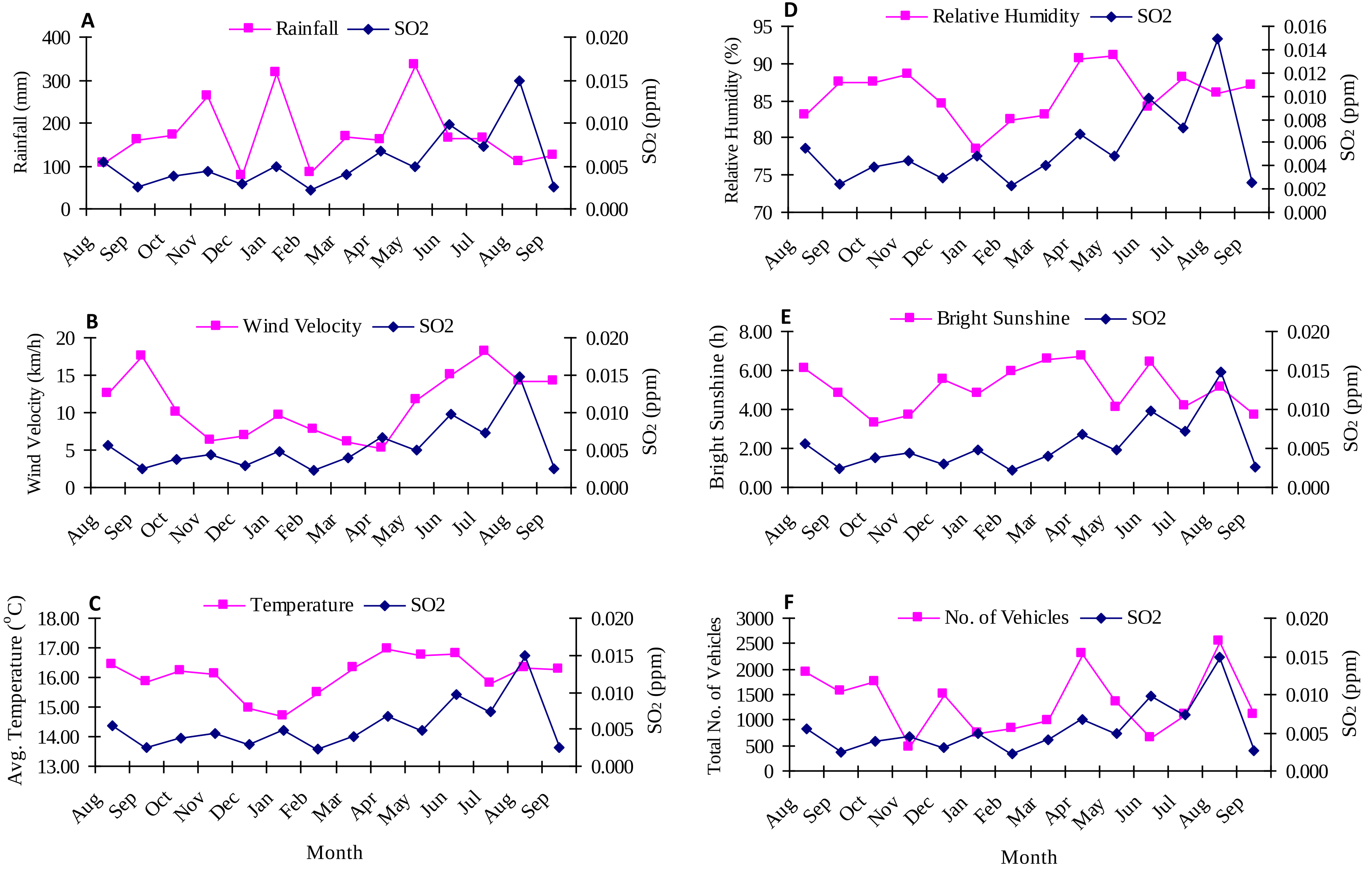

Figure 5. Variation of SO_2 with rainfall (A), wind velocity (B), average temperature (C), relative humidity (D), bright sunshine (E) and total number of vehicles (F) in HPNP.

Table 5: IAP values for each site in HPNP.

Site	IAP Value	SO_2 Level	Site	IAP Value	SO_2 Level
A2	28.3	Moderate	B1	58.0	Very low
A3	58.2	Very low	B6	40.7	Low
A4	45.4	Low	B7	57.0	Very low
A5	39.3	Low	B8	50.4	Very low
A7	32.2	Moderate	B9	63.7	Very low
A8	21.7	High	B10	50.5	Very low

DISCUSSION

Owing to the adverse effects caused by air pollution, studies on air quality parameters are becoming important in atmospheric and environmental research today (Ghazali *et al*., 2009). These adverse effects have direct and indirect consequences on ecosystems and the environment. Such effects can include visible injury on vegetation and adverse impact on growth, changes in productivity, nutritive quality and community structure and biological diversity, with or without symptoms of injury to the plant foliage (Legge, 2009).

At HPNP, the average concentration of both NO_2 and SO_2 were comparatively low in months during September, 2005 to March, 2006 and then began to increase until September, 2006. These variations are highly correlated with the wind velocities at HPNP. Different wind velocities are due to seasonal wind patterns in Sri Lanka. Since Sri Lanka is situated close to the equator within an altitude of 6^o to 10^o N, it experiences a tropical climate which is somewhat modified by the seasonal wind reversal of the Asiatic monsoons. According to Domroes (1974) and Suppiah (1984) Sri Lanka and the other South Asian countries experience four climatic monsoons, namely, Southwest monsoon (May-September), the first inter-monsoon (October-November), Northeast monsoon (November-February), and the second inter-monsoon (March- May).

The lower concentrations of NO_2 and SO_2 were observed during the intermediate and north-east monsoonal period compared to the period during the southwest monsoonal. This could be due to relatively low wind speed experienced during inter-monsoons and north-east monsoons. During a given year, south-west winds towards the island are regular and as a result the central part of the country could also be affected due to the air pollutants coming from the more industrialized Western province. Air pollution in main cities such as Colombo and Kandy is mainly caused by increasing traffic congestions (Ileperuma, 2000). Romero *et al*., (1999) reported that the wind decreases pollution in some areas at Santiago in Chile. In contrast to present findings, Abeyratne (2005) reported the highest concentrations of ambient NO_2 and SO_2 in Kandy and Anuradhapura during north-east monsoonal period in 2001. The higher concentrations of ambient NO_2 and SO_2 recorded after March 2006 correlate with the number of vehicles visiting the HPNP. Festival seasons and school vacations overlap with this period and as a result a higher number of visitors and vehicles arrive at HPNP. The highest number of vehicles visiting HPNP recorded in August 2006 with the probability of increasing vehicular emissions. Similarly, Abeyratne (2005) observed sudden increases in NO_2 and SO_2 in Kandy during festival seasons such as Christmas, Sinhalese and Tamil New Year and Kandy Esala Perahera while reporting relatively low levels during school vacations, when the vehicular traffic was the least. Shankar (2002) in India stated that the possible reasons for increase in the levels of NO_2 are due to tremendous increase in the number vehicles in the Mumbai city.

The recommended 24 h Sri Lankan air quality standards for SO_2 and NO_2 are 0.03 and 0.05, respectively. Both SO_2 and NO_2 concentrations in HPNP were much lower than the standard air quality levels in Sri Lanka. A similar study carried out by Aberathne (2005), revealed that NO_2 and SO_2 analyzed in Kandy exceeded the recommended Sri Lankan standard by about 14 % and 41 % of the sampling occasions respectively. Another study carried out at Galaha junction in Peradeniya revealed that both pollutants exceeded the Sri Lankan standard on 60 % of the twenty sampling occasions (Ileperuma and Dissanayake, 2004). In comparison, the average concentrations of NO_2 and SO_2 observed for the period of 14 months indicates that the air quality in HPNP is very high. However, there were no records available for the same study carried out in any national park in Sri Lanka.

Since HPNP is a remote, undisturbed forest reserve, the pollution levels could be low. However, the very low concentrations of ambient NO_2 and SO_2 reported in HPNP may perhaps due to the conversion of ambient NO_2 and SO_2 into nitric and sulfuric acid in presence of moisture, respectively (U.S. EPA report, 1998 and Martin, 1989). These acids may be deposited on the earth's surface in dry form as gases or aerosols or in wet form as acid rain. Wet deposition is determined by the amount, duration, and location of precipitation and changes in the total acid levels, which are in turn determined by atmospheric chemistry and precipitation patterns. Gunawardena and Nandasena (1998) reported that that the pH of rain water varied from 5.37 to 7.47 with sulphate and nitrate concentrations ranging from 0-3.39 mg/l and 0-3.54 mg/l, respectively. In the same study (Gunawardena and Nandasena, 1998), the fog had shown much higher acidities with pH values as low as 3.88 recorded during the dry season of April to May. All the air samples in the current study were collected inside the forest of HPNP. Hence, considerable amount of ambient NO_2 and SO_2 might have been taken up by the foliage of plants. Lendzian (1984) found foliar uptake of SO_2 *via* stomata although the cuticle is impermeable to the gas. According to Rondon and Granat (1994), NO_2 also enters via the cuticle of leaves without internal resistance. The lower NO_2 concentrations at the HPNP might also be due to the conversion process, in which ambient NO_2 converts into O_3 in the presence of sunlight (Ghazali *et al*., 2009). In addition to individual effects, a combination of above factors may also have contributed to the low levels of NO_2 and SO_2 at HPNP.

The average concentrations of NO_2 and SO_2 between sampling points showed considerable variations in the present study. The highest ambient concentrations of both NO_2 and SO_2 at Pattipola, which is situated in a hilly terrain close to a main road. The main entrance of the HPNP is situated along the Pattipola road with more than 90 % of vehicles arriving in HPNP. Moreover, this area directly faces Nuwara Eliya and Pattipola, where large-scale livestock farms are situated. Livestock farms generate large amount of organic waste and through anaerobic decomposition it generates ammonia and hydrogen sulphide (H_2S) (Ileperuma, 2000). H_2S oxidizes to form SO_2 rapidly under atmospheric conditions (Finlayson-Pitts and Pitts, 1986; Jacobson, 1999). This could have contributed to high levels of SO_2 at Pattipola. The middle sampling point which was situated very close to the vehicle park at HPNP showed the highest concentrations of pollutants. Abeyratne (2005) also mentioned that the sampling sites closer to city centers recorded higher pollutant levels.

The lowest ambient NO_2 and SO_2 were recorded at the World's End sampling point, which faces directly towards the windward direction. High speed winds are able to carry pollutants away and perhaps account for the low pollutant concentrations in the present study. Çelik and Kadi (2007) showed that pollutants can accumulate due to slow wind speeds at high hills and mountains in a study carried out in Turkey. Furthermore, Ileperuma (2000) reported that calm weather conditions in valleys make the air quality very poor. At Kirigalpotta, where the sampling point was situated at the base of the mountain, showed higher concentrations of ambient NO_2 and SO_2 than in the World's End but lower than Pattipola and Middle point concentrations. The medium pollutant concentrations at Kirigalpotta site may be due to wind break effect of the Kirigalpotta Mountain. Penner *et al*. (1989) and Robinson (1989) have shown that the atmospheric chemical reactions were influenced by local weather patterns such as temperature, precipitation, clouds, atmospheric water vapor, wind speed, and wind direction. The variations of ambient NO_2 and SO_2 concentrations during the study period showed insignificant positive correlation with the rainfall pattern. Abeyratne (2005) observed a lower concentration of NO_2 and SO_2 during high rainfall periods, perhaps due to dissolving the gases in rainwater. A positive significant correlation was observed between the ambient NO_2 concentration and temperature, but not with SO_2 concentration. In contrast, Salem *et al*. (2009) have found an insignificant positive correlation between temperature and NO_2 concentrations and a significant positive effect with SO_2 concentration. Çelik and Kadi (2007) also reported that SO_2 concentration increased with temperature at Karabük City in Turkey. Abeyratne (2005) found a negative relationship between NO_2 concentration and ambient temperature only.

Considering the variations of the pollutants with relative humidity and number of vehicles visiting HPNP, both pollutants had insignificant positive correlation. According to Sánchez-Ccoyllo and Andrade (2002), high values of pollution concentrations prevail due to weak ventilation, low relative humidity and an absence of precipitation. However, bright sunshine hours were positively and significantly correlated with t ambient NO_2 concentrations and negatively with SO_2 concentrations. Although the ambient NO_2 and hours of bright sunshine were positively correlated with each other in the current study, Logan *et al*., (1981); Thompson (1992) and Ghazali *et al*., (2009) have shown that a considerable amount of NO_2 is converted to O_3 through photochemical reactions in the presence of sunlight. Similarly, the same correlation was observed by Trebs *et al*. in 2009.

The diversity and abundance of lichens are considered as indicators of environmental quality, where high values correspond to good air quality (Asta *et al.*, 2002a, 2002b). In addition to the air quality, a combination of bark pH, light, humidity, tree diameter, tree height and distribution is important in determining the richness of lichens (Kotelko *et al*, 2008). The results of the present study showed that forest islands are highly diverse compared to the continuous forest. However, evenness values were lower in forest islands than that of continuous forests.

The IAP value obtained for the whole area of the HPNP was 54.22. This value belonged to the quality level 5 indicating a 'very low' level of SO_2. This value was calculated using 379 lichen species spread in 12 quadrats situated in forest islands and continuous forests at HPNP. However, IAP values calculated were different in each quadrat in HPNP. Relatively low IAP values were obtained from quadrats placed in continuous forests than that in forest islands, indicating relatively higher levels of SO_2 in continuous forests (Pattipola and Middle points) than that of forest islands (Ohiya road and Kirigalpotta points). IAP values have provides a quantitative measure of the differences in richness and diversity of lichen communities influenced by activities such as habitat disturbances and urbanization (DeSloover and Leblanc, 1968; Kricke and Loppi, 2002). According to Ruoss and Vonarburg (1995) and van Dobben and ter Braak (1998) many lichen species respond negatively to high SO_2 concentrations while the direct effects of O_3 and NO_2 on lichen communities are not well understood. However, Fuentes and Rowe (1998) observed no consistent relationship between IAP and SO_2 concentration, but a reliable relationship with SO_2. However, van Dobben *et al*., (2001) stated that, atmospheric SO_2 and NO_2 concentrations are the most important factors in determining the lichen biodiversity

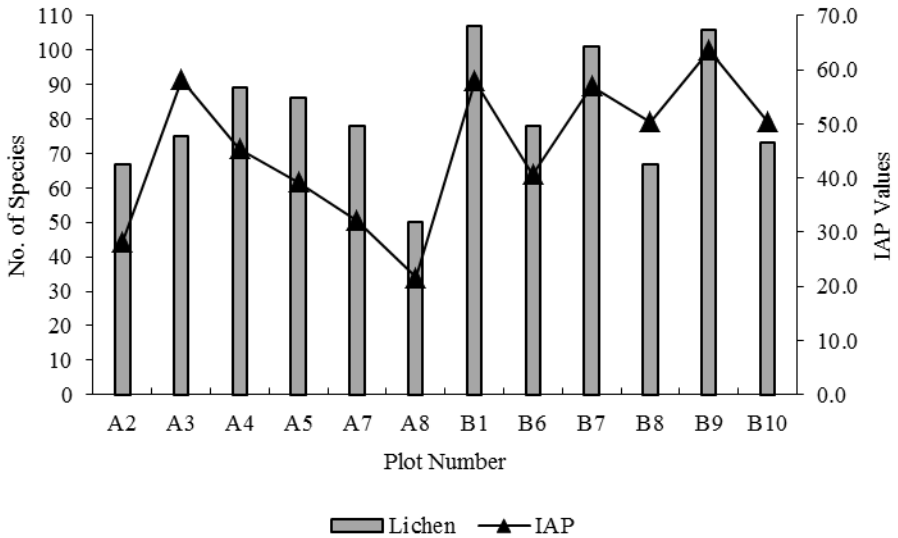

Figure 6: Number of lichen species recorded in each plots and their correspondent IAP values at the HPNP.

CONCLUSION

Though several studies have been carried to evaluate air quality using passive gas sampling technique in Sri Lanka, this was the first study to correlate the air quality and the lichen diversity in a National Park. In the present study, a total of 379 lichen taxa were recorded and they were used to calculate IAP. The resulting higher IAP value significantly correlated with the very low level of SO_2 concentration of the ambient air quality of the HPNP. These results were further confirmed by the data of passive gas sampling, in which very low levels of the ambient SO_2 and NO_2 concentrations were recorded. .

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