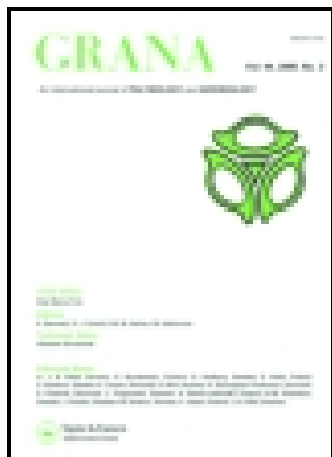




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Spatial and temporal variations of pollen concentrations in Islamabad (Pakistan): effect of meteorological parameters and impact on human health

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Abstract

This study focuses on the identification and quantification of airborne pollen grains from allergenic plant species and their relationship with meteorological factors, i.e. maximum and minimum daily temperature, relative humidity, rainfall and wind speed in the city of Islamabad, Pakistan. An aerobiological data set (2010–2012), collected using rotorod samplers in five different sectors of the city, was supplied by the Pakistan Meteorological Department. Pollen of eight allergenic species was identified amongst which *Broussonetia papyrifera* exceeded the highest pollen level and, therefore, likely played a key role in aggravating the symptoms of pollen allergy in the city. The mean weekly pollen counts were next correlated with the weekly number of allergic patients visiting hospitals during 2010–2011. Clinical data were acquired from the Pakistan Institute of Medical Sciences. The highest number of allergic patients visiting hospital was usually observed during weeks with high pollen level. These results suggest a close relationship between the pollen concentration in the air and the allergy symptoms. Spearman's rank correlation analysis was performed to establish the relationships between meteorological parameters and daily average pollen counts. A pollen calendar for the Islamabad city was also prepared to provide a guide for the timing and duration of season for all encountered pollen types.

Keywords: daily pollen count, *Broussonetia papyrifera*, meteorological parameters, pollen calendar

Pollen grains are one of the important factors involved in airborne allergies. Flowering of plants is the main factor establishing the time of pollen release and its amount in the air (Jäger et al. 1991). However, the abundance and the type of particular airborne pollen vary according to the time of the day, season and weather conditions, geographical location, type of vegetation dominating the area and proximity to pollen sources (Puc 2011; Grewling et al. 2012; Zielo et al. 2012). Moreover, each step of the aerobiological pathway (emission, dispersion and impact) is linked to different biological phenomena governed by various meteorological factors (Comtois & Sherknies 1991) that have an important

influence on airborne pollen and in turn acting as a causative agent of allergy (D'Amato et al. 2007).

Islamabad (33° 43' N; 73° 04' E) is the capital city of Pakistan, located at the foot of the Margalla Hills. During the 1960s, when the city was developed, a lot of exotic plant species were introduced to the area to make it green and beautiful. One of the important examples of these exotic plant species is *Parthenium hysterophorus* L., which was introduced in this newly developed city (Fatimah & Ahmad 2012). Apart from it, some plant species such as *Parthenium hysterophorus* and *Lantana camara* L. invaded the area and replaced the native plant species, which are becoming rare because of the fast spread of the invasive plant species.

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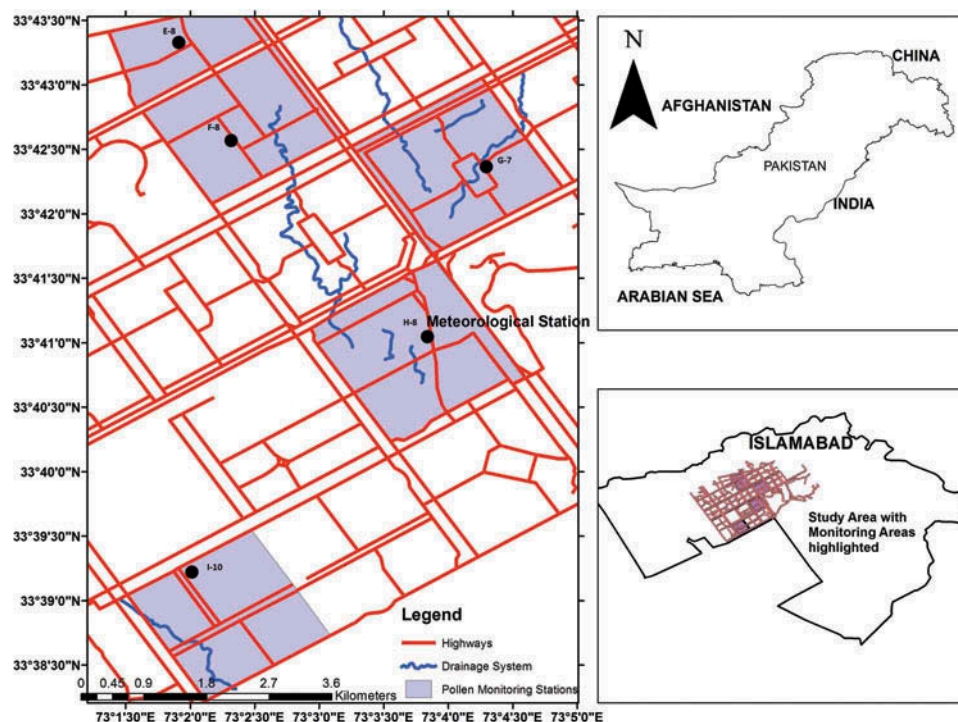


Figure 1. Geographical position of the pollen monitoring stations for sampling in Islamabad.

Apart from changes in biodiversity of the area, these invasive plants have resulted in a serious threat of pollen allergy to residents of the city (Shabbir & Bajwa 2006).

The highest concentrations of airborne pollen are observed in Islamabad in spring, which likely leads to the spread of pollen allergy related health problems in the city, particularly asthma, cough rhinitis and skin lesions (Haroon & Rasool 2008). According to the estimation by the Pakistan Ministry of Health, around 120 000 residents suffer from pollen allergy in Islamabad, but only 80–110 patients visit the hospital during the pollen season according to the Pakistan Institute of Medical Sciences (PIMS). Pollen calendars are helpful tools, which determine the start of the pollen season, its intensity, duration and the variation in daily pollen concentration. Such information helps in prevention of pollinosis (Emberlin et al. 1999; Chuine & Belmonte 2004; Garciamozo et al. 2009).

Keeping in view the importance of the issue, this study focused on the exploration of the spatio-temporal variations in atmospheric pollen concentrations in Islamabad during the years 2010–2012. In addition, based on the obtained results, the first pollen calendar for Islamabad has been prepared.

Material and methods

Study area and climate

Islamabad city is located at the northern edge of the Potohar Plateau (33° 42' N; 73° 10' E) with an

altitude of 500 to 600 m above sea level and the Margallah Hills in the northwest. The area is characterised by a subtropical climate with the coldest temperatures recorded in January. The average humidity level is 55% while the average rainfall recorded each year is around 1150 mm. Mean minimum and maximum daily temperatures in January are 2.6 °C and 17.7 °C, respectively. Wind blows predominantly from the north and the southeast (PCO 1999). The Islamabad flora is mainly composed of exotic trees and shrub species that include both native and non-native plants. Dominant species in the area are *Acacia modesta* Wall., *Acacia nilotica* (L.) Willd., *Adhatoda vasica* L., *Alternanthera pungens* Kunth., *Broussonetia papyrifera* (L.) Vent., *Cannabis sativa* L., *Cynodon dactylon* (L.) Pers., *Dalbergia sissoo* Roxb. ex. DC., *Eucalyptus globulus* Labill., grasses, *Lantana camara* L., *Morus alba* L., *Parthenium hysterophorus*, *Pinus longifolia* (Roxb.) and *Taraxacum officinale* (F.H.Wigg) (PCO 1999).

Data collection

Pollen data were collected using a Rotorod Sampler (Model 40) placed at roof level in five sectors of Islamabad (E-8, F-8, G-7, H-8 and I-10) supplied by the Pakistan Meteorological Department (PMD; Figure 1). The sectors are the residential and commercial units demarcated by the Islamabad Capital Territory (ICT). The pollen sampler consists of a retracting head with two plastic pollen collection

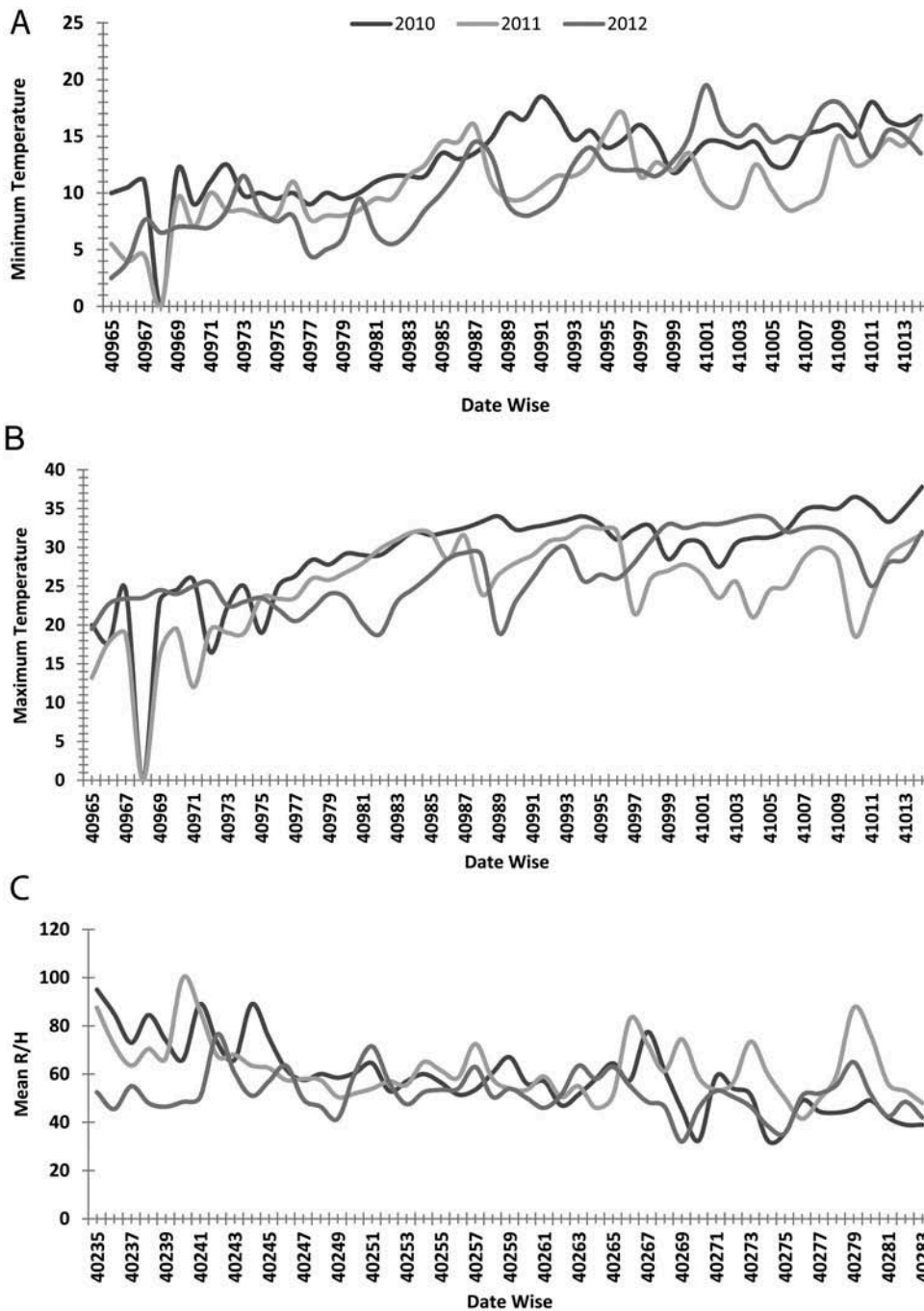


Figure 2. Minimum (A) and maximum (B) temperature as well as mean relative humidity (C) during the pollen seasons in the years 2010–2012.

rods. The rods were coated with silicone grease, which causes pollen to stick on to the rod when exposed to the air. Air was sampled for 24 hours and then the rods were removed and stained. Daily pollen data were analysed under a light microscope at a magnification of 400 $\times$ and expressed as pollen grains per cubic metre of air sampled (grains/m³). The methodology used for pollen collecting and counting was the same as reported by Haroon and Rasool (2008). The intensity of the season,

according to PMD, was assessed as the number of days in the month of March in which pollen counts exceed up to 40 000 grains/m³. Sampling was carried out from 26 February 2010 to 15 April 2012.

In order to evaluate the response of Islamabad inhabitants to pollen concentrations in the air, the relationship between weekly number of allergic patients and weekly mean pollen level was calculated. Clinical data, i.e. number of patients having rhinitis visiting hospitals during the pollen season ($N=366$ in

2010 and $N=282$ in 2011), were supplied by the statistical department of PIMS. Data were collected during 2010–2011.

Meteorological data were provided by the PMD. The following meteorological parameters were analysed: daily average minimum ($T_{\min}$) and maximum ($T_{\max}$) temperature, relative humidity (RH), wind speed (in m/s) and daily average rainfall (in millimetres). The meteorological station was located at $33^{\circ} 4' 00.94''$ N and $73^{\circ} 03' 50.24''$ E in the PMD. The statistical department of PIMS maintain the recent data of patients encountered with pollen allergies, which were acquired and compiled from the investigation reports of patients comprising of different age groups, who reported to the PIMS during the allergy season for treatment.

Statistical analysis

The relationship between daily average pollen concentrations and the daily meteorological data were examined using non-parametric Spearman rank correlation coefficients. A pollen calendar was prepared by using average values of weekly pollen counts. It shows the pollen concentration during nine weeks (from 26 February to 15 April). The pollen calendar provides a guide to the variation of pollen seasons of eight pollen taxa in Islamabad. All the statistical calculations were carried out using Microsoft Excel and Statistica 7 software packages.

Results

Variation in meteorological data during the study period

During the studied period, the mean $T_{\min}$ varied from 10°C to 16°C (in 2010), 5.5°C to 16.5°C (in 2011) and 2.5°C to 13.5°C (in 2012). Similarly, $T_{\max}$ observed for the study years (2010–2012) ranged between 20.0°C to 37.8°C , 13.2°C to 30.5°C and 19.5°C to 32.0°C , respectively (Figure 2A, B). The highest $T_{\min}$ values were observed in April (2012) and in March (2010 and 2011); likewise, the highest $T_{\max}$ values were usually recorded in March (in 2011) and in April (in 2010 and 2012). The mean RH for the years 2010–2012 ranged between 40–95%, 45–100% and 40–80%, respectively (Figure 2C). Generally, the highest RH was recorded in February and March. The maximum rainfall was recorded in February with a value of 6.3 mm in 2010. In 2011, the highest rainfall was observed in March and April (2.0 mm and 1.8 mm, respectively). A strong decrease in the rainfall data was observed during 2012 (Figures 3, 4).

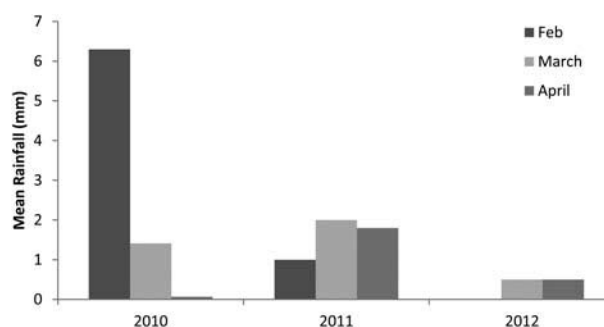


Figure 3. Mean rainfall during the pollen seasons in the years 2010–2012.

Spatio-temporal variation in pollen concentration and pollen calendar

In 2010, *Broussonetia papyrifera* was found to be the most abundant pollen grain type with the daily maximum pollen level varying from 7140 to 42 655 pollen grains/ m^3 (in sector I-10 and H-8, respectively) (Figure 4, Tables I–III). In the case of this species, the number of days with more than 500 pollen grains/ m^3 ranged from 16 to 35, depending on the city sector. The peak value of *Cannabis sativa*, grasses and *Pinus* sp. varied from 33 to 198 pollen grains/ m^3 (Tables I). Only few pollen grains of *Taraxacum officinale* and *Acacia* sp. were observed in 2010.

In 2011, out of eight plant species recorded, the highest pollen level was observed in *Broussonetia papyrifera* in sector H-8 (40 473 pollen grains/ m^3) (Table II). The maximum daily pollen concentrations of grasses in four city sectors reached 100 pollen grains/ m^3 , while the maximum pollen level of *Alternanthera pungens*, *Pinus* sp. and *Cannabis sativa* varied from 20 to 97 pollen grains/ m^3 , depending on the city sector. Usually, the highest pollen concentrations were recorded in sectors E-8, F-8 and H-8 (Table II).

In 2012, the daily pollen concentration of four species, i.e. *Acacia* sp., *Eucalyptus globulus*, *Cannabis sativa* and *Taraxacum officinale* rarely exceeded values of 25 pollen grains/ m^3 . The number of days with *Alternanthera pungens* pollen level between 25–500 pollen grains/ m^3 varied from 7 to 17 (depending on the sector). The highest pollen levels were usually recorded in the case of *Pinus* sp., grasses (> 100 pollen grains/ m^3) and *Broussonetia papyrifera* (> 2000 pollen grains/ m^3). The latter was the major pollen contributor with the maximum daily pollen value of 36 121 pollen grains/ m^3 in sector H-8 (Table III). Based on the results mentioned earlier, a pollen calendar for Islamabad was prepared to identify changes and fluctuations in atmospheric pollen levels in Islamabad (Figure 5).

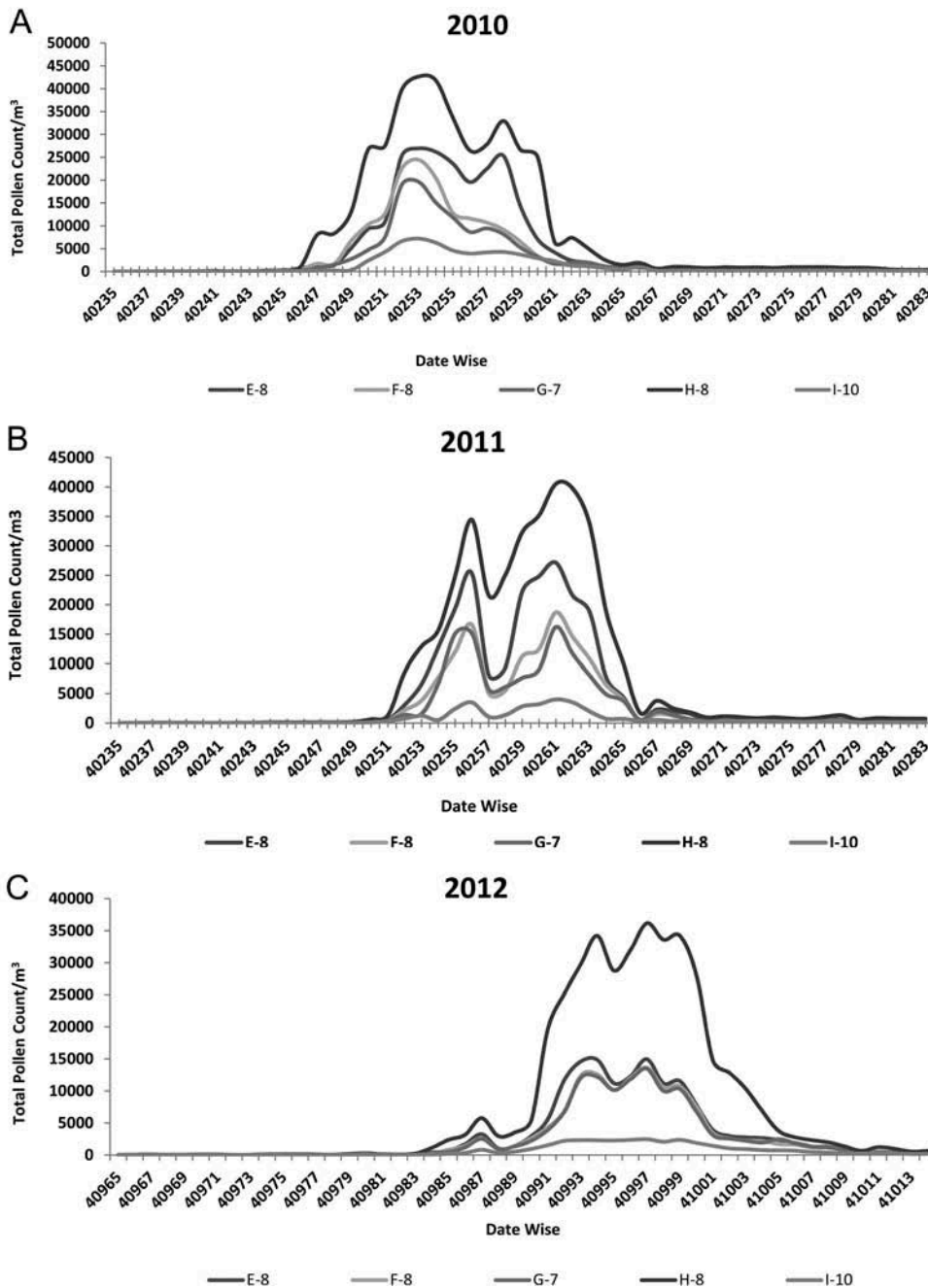


Figure 4. Total pollen count in respective sectors of Islamabad during the pollen season for the study years 2010–2012.

Correlations between aerobiological and meteorological data

A Spearman's rank correlation test was performed in order to identify the major variables likely to influence the dynamic of the pollen season. The statistical analysis revealed significant correlations at $p < 0.05$ between meteorological variables and mean daily pollen counts (Table IV).

Acacia sp. pollen counts for the studied years showed that the highest average pollen level was observed in sector F-8 (25 pollens grains/m³) in the

sixth week of the study (Figure 6A). Correlation analysis between pollen counts and meteorological parameters revealed a significant positive correlation between daily minimum and maximum temperatures and daily pollen counts for *Acacia* sp. in sectors E-8, F-8 and G-7, while it showed a negative correlation with RH in sectors E-8, F-8, G-7 and H-8. There was a negative correlation between rainfall and daily pollen counts of *Acacia* sp. in sector H-8 ($r = -0.46$, $p < 0.05$) while it showed a positive correlation in sector I-10 ($r = 0.28$, $p < 0.05$).

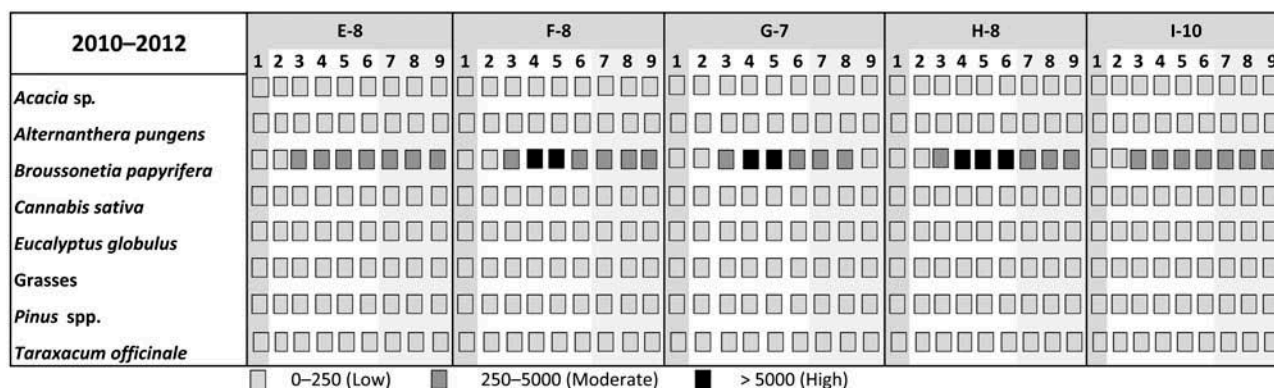


Figure 5. Week wise pollen calendar for Islamabad, Pakistan.

The highest average pollen concentrations of *Alternanthera pungens* (20 pollen grains/m³) were recorded in sector E-8 (fourth week of study) and in sector F-8 (second and seventh week) (Figure 6B). *Alternanthera pungens* showed a positive correlation with the minimum and maximum daily temperatures in sectors E-8, F-8, G-7 and H-8 while it showed a negative correlation with RH in sector I-10. The significant ($p < 0.05$) negative correlations with RH and rainfall were also observed in sector H-8 ($r = -0.27$ and $r = -0.25$, respectively).

Broussonetia papyrifera showed the highest average pollen count in sector H-8 with a value of 21 489 pollen/m³ followed by sector E-8 (12 442 pollen grains/m³) and F-8 (8128 pollen/m³). The lowest pollen count was recorded in sector I-10 with a value of 2353 pollen grains/m³ (Figure 6C). *Broussonetia papyrifera* showed a significant ($p < 0.05$) positive correlation between daily minimum and maximum temperatures and daily pollen count in all investigated city sectors. At the same time, the significant negative influence of rainfall and RH on daily pollen concentrations was observed in these sectors (except sector E-8 for RH). No significant correlations were recorded between daily pollen and wind speed data.

Cannabis sativa showed the highest average pollen count in sector G-7 during the sixth week of the study with a value of 28 pollen grains/m³ and in sector H-8 during the fourth week of the study (27 pollen grains/m³). In other sectors (F-8, I-10 and E-8), the peak value of average *Cannabis sativa* pollen level was lower and exceeded to 13 pollen grains/m³ (Figure 6D). The variation in daily pollen concentrations of *Cannabis sativa* showed a positive correlation with daily minimum and maximum temperatures in sectors F-8, H-8 and G-7 and with wind speed in sector E-8, F-8 and G-7. The positive influence of $T_{\min}$, $T_{\max}$ and wind speed on daily

pollen level was observed in sectors F-8 and H-8, respectively.

The highest average pollen count of *Eucalyptus globulus* was observed between the sixth and ninth week of the study, however, the pollen concentration was extremely low (around 3 pollen grains/m³) (Figure 6E). The correlation analysis revealed a positive influence between daily minimum and maximum temperatures and *Eucalyptus globulus* daily pollen count in all city sectors and a significant negative correlation with RH in sectors E-8, F-8, H-8 and I-10.

The maximum average grass pollen levels were recorded in all city sectors between the second and fourth week of study. The highest pollen values were observed in sector E-8 (58 pollen grains/m³), whereas the lowest in sector I-10 (32 pollen grains/m³) (Figure 6F). Grass pollen counts showed significant negative correlations with minimum and maximum daily temperatures and positive with RH in all sectors of the city. Rainfall negatively affected daily grass pollen concentration in sectors G-7 and H-8 ($r = -0.25$ and $r = -0.49$, respectively).

Pinus sp. showed the highest average pollen count in sectors E-8, G-7 and F-8 during the fourth and fifth week of study. In these sectors, the maximum pollen level exceeded 29, 25 and 25 pollen grains/m³, respectively. The peak value of average pollen count in sectors H-8 and I-10 were lower, i.e. 13 pollen grains/m³ (eighth week) and 9 pollen grains/m³ (sixth week), respectively (Figure 6G). The daily pollen concentration of *Pinus* sp. showed negative correlations ($r = -0.33$, $p < 0.05$) with rainfall in sectors E-8 and F-8 and positive correlation ($r = 0.25$, $p < 0.05$) with wind speed in sector H-8.

The daily average pollen levels of *Taraxacum officinale* in all city sectors were extremely low and rarely exceeded 1 pollen grain/m³ (Figure 6H). The

Table I. Characteristics of the mean pollen season (MPS) of species in different sectors of Islamabad (2010).

Pollen type	E-8	F-8	G-7	H-8	I-10
	26 February–15 April	26 February–15 April	26 February–15 April	26 February–15 April	26 February–15 April
<i>Acacia</i> sp.	49	49	49	49	49
Season length (days)	3 (13 April)	3 (4 April)	2 (2 days)	2 (2 days)	2 (12 April)
Daily maximum value (Date)	49	49	49	49	49
Number of days when pollen count 0–25	0	0	0	0	0
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
<i>Alternanthera pungens</i>	22 (27 March)	24 (2 days)	24 (27 March)	28 (27 March)	37 (30 March)
Daily maximum value (Date)	47	49	48	48	49
Number of days when pollen count 0–25	2	0	1	1	0
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
<i>Broussonetia papyrifera</i>	26 934 (16 March)	24 403 (16 March)	19 527 (16 March)	42 644 (16 March)	7140 (16 March)
Daily maximum value (Date)	9	9	9	8	11
Number of days when pollen count 0–25	18	20	18	6	22
Number of days when pollen count 25–500	22	20	22	35	16
Number of days when pollen count > 500	44 (9 March)	65 (10 March)	97 (3 April)	33 (27 March)	66 (March)
<i>Cannabis sativa</i>	43	45	33	44	45
Daily maximum value (Date)	6	5	16	5	4
Number of days when pollen count 0–25	0	0	0	0	0
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
<i>Eucalyptus globulus</i>	2 (30 March)	6 (31 March)	4 (15 April)	1 (2 days)	3 (4 April)
Daily maximum value (Date)	49	49	49	49	49
Number of days when pollen count 0–25	0	0	0	0	0
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
Grasses	54 (9 March)	50 (10 March)	58 (7 March)	59 (29 March)	196 (8 March)
Daily maximum value (Date)	46	46	43	44	45
Number of days when pollen count 0–25	3	3	6	5	4
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
<i>Pinus</i> sp.	58 (9 March)	42 (9 March)	70 (7 March)	65 (4 March)	43 (10 March)
Daily maximum value (Date)	48	47	42	48	45
Number of days when pollen count 0–25	1	2	7	1	4
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
<i>Taraxacum officinale</i>	1 (2 days)	1 (6 days)	9 (13 March)	1 (11 days)	2 (2 days)
Daily maximum value (Date)	49	49	49	49	49
Number of days when pollen count 0–25	0	0	0	0	0
Number of days when pollen count 25–500	0	0	0	0	0
Number of days when pollen count > 500	0	0	0	0	0
Total pollen count	26 953 (16 March)	24 433 (16 March)	7204 (16 March)	19 586 (16 March)	42 690 (16 March)
Daily maximum value (Date)	1	2	1	1	0
Number of days when pollen count 0–25	25	27	25	14	32
Number of days when pollen count 25–500	23	20	23	34	17
Number of days when pollen count > 500					

Table II. Characteristics of the mean pollen season (MPS) of species in different sectors of Islamabad (2011).

Pollen type	E-8	F-8	G-7	H-8	I-10
<i>Acacia</i> sp.	26 February–15 April 49 2 (15 April) 49 0 0 0 0 65 (30 March) 44 5 0 27 088 (24 March) 15 17 17 45 (28 March) 42 7 0 6 (14 April) 49 0 0 114 (15 March) 33 16 0 97 (10 March) 45 4 1 (6 April) 49 0 0 27 135 (24 March) 3 20 26	26 February–15 April 49 1 (8 April) 49 0 0 0 72 (30 March) 48 1 0 18 621 (24 March) 15 17 17 38 (28 March) 44 5 0 27 (12 April) 47 2 0 107 (14 March) 29 20 0 85 (10 March) 45 4 0 49 0 0 16 581 (19 March) 4 25 20	26 February–15 April 49 0 49 0 0 0 25 (18 March) 48 1 0 16 152 (24 March) 15 17 17 48 (13 March) 29 20 0 74 (11 March) 37 12 0 0 0 4005 (24 March) 3 26 20	26 February–15 April 49 1 (13–15 April) 49 0 0 0 59 (12 April) 43 6 0 40 473 (24 March) 14 2 33 42 (13 March) 43 6 0 3 (11 April) 49 0 0 130 (14 March) 32 17 0 55 (14 March) 45 4 0 1 (5 April) 49 0 0 15 124 (19 March) 3 12 34	26 February–15 April 49 1 (15 April) 49 0 0 0 31 (1 April) 47 2 0 3959 (24 March) 16 19 14 20 (13 March) 49 0 0 3 (9–12 April) 49 0 0 69 (28 March) 40 9 0 40 (28 March) 46 3 0 0 49 0 0 40 572 (24 March) 4 30 15
<i>Alternanthera pungens</i>					
<i>Broussonetia papyrifera</i>					
<i>Cannabis sativa</i>					
<i>Eucalyptus globulus</i>					
Grasses					
<i>Pinus</i> sp.					
<i>Taraxacum officinale</i>					
Total pollen count					

Table III. Characteristics of the mean pollen season (MPS) of species in different sectors of Islamabad (2012).

Pollen type	E-8	F-8	G-7	H-8	I-10
	26 February–15 April	26 February–15 April	26 February–15 April	26 February–15 April	26 February–15 April
<i>Acacia</i> sp.	Season length (days) 50 Daily maximum value (Date) 2 (11–12 April) Number of days when pollen count 0–25 50 Number of days when pollen count 25–500 0 Number of days when pollen count > 500 0	50 1 (3 days) 50 0 0	50 0 50 0 0	50 1 (13 April) 50 0 0	50 1 (11 April) 50 0 0
<i>Alternanthera pungens</i>	Number of days when pollen count > 500 0 Daily maximum value (Date) 30 (2 April) Number of days when pollen count 0–25 39 Number of days when pollen count 25–500 11 Number of days when pollen count > 500 0	33 (19 March) 39 11 0	30 (16 March) 43 7 0	43 (17 March) 33 17 0	30 (16 March) 42 8 0
<i>Broussonetia papyrifera</i>	Daily maximum value (Date) 14 882 (29 March) Number of days when pollen count 0–25 18 Number of days when pollen count 25–500 7 Number of days when pollen count > 500 25	13 580 (29 March) 18 7 25	13 426 (29 March) 18 8 24	36 121 (29 March) 18 1 31	2444 (29 March) 19 14 17
<i>Cannabis sativa</i>	Daily maximum value (Date) 20 (8 April) Number of days when pollen count 0–25 50 Number of days when pollen count 25–500 0 Number of days when pollen count > 500 0	23 (14 April) 50 0 0	27 (5 April) 48 2 0	18 (5 & 7 April) 50 0 0	14 (7 April) 50 0 0
<i>Eucalyptus globulus</i>	Number of days when pollen count > 500 1 (13 April) Daily maximum value (Date) 50 Number of days when pollen count 0–25 0 Number of days when pollen count 25–500 0 Number of days when pollen count > 500 0	4 (12 March) 50 0 0 0	0 50 0 0 0	1 (3 days) 50 0 0 0	1 (11 April) 50 0 0 0
Grasses	Number of days when pollen count 0–25 13 (11 April) Daily maximum value (Date) 50 Number of days when pollen count 0–25 50 Number of days when pollen count 25–500 0 Number of days when pollen count > 500 0	28 (11 April) 49 1 0 0	6 (12 April) 50 0 0 0	5 (12 April) 50 0 0 0	36 (11 April) 49 1 0 0
<i>Pinus</i> sp.	Number of days when pollen count > 500 0 Daily maximum value (Date) 154 (12 March) Number of days when pollen count 0–25 23 Number of days when pollen count 25–500 27 Number of days when pollen count > 500 0	147 (6 March) 27 23 0	107 (6 March) 21 29 0	153 (16 March) 30 20 0	67 (2 April) 39 11 0
<i>Taraxacum officinale</i>	Number of days when pollen count > 500 139 (12 March) Daily maximum value (Date) 32 Number of days when pollen count 0–25 18 Number of days when pollen count 25–500 0 Number of days when pollen count > 500 0	161 (2 April) 36 14 0	172 (2 April) 38 12 0	110 (2 April) 43 7 0	78 (2 April) 47 3 0
Total pollen count	Number of days when pollen count 0–25 0 Number of days when pollen count 25–500 23 Number of days when pollen count > 500 27	13 636 (29 March) 1 24 25	2474 (29 March) 0 26 24	13 472 (29 March) 0 19 31	36 164 (29 March) 1 29 20

Table IV. Spearman's correlation applied to daily pollen concentration and meteorological parameters during the study years 2010–2012.

2010-2012	E-8					F-8					G-7					H-8					I-10				
	$T_{\min}$	$T_{\max}$	RH	Wind speed	ppt	$T_{\min}$	$T_{\max}$	RH	Wind speed	ppt	$T_{\min}$	$T_{\max}$	RH	Wind speed	ppt	$T_{\min}$	$T_{\max}$	RH	Wind speed	ppt	$T_{\min}$	$T_{\max}$	RH	Wind speed	ppt
Pollen type																									
<i>Acacia</i> sp.	0.53	0.29	-0.37	—	—	0.43	0.32	-0.42	—	—	0.56	0.44	-0.41	—	—	—	0.30	-0.32	—	—	-0.46	0.35	—	—	0.28
<i>Alternanthera pungens</i>	0.34	0.54	—	—	—	0.28	0.34	—	—	—	0.30	0.33	—	—	—	0.47	0.58	—	—	—	—	0.40	-0.35	—	
<i>Broussonetia papyrifera</i>	0.36	0.60	—	—	-0.34	0.35	0.60	—	—	-0.34	0.46	0.62	-0.31	—	-0.29	0.40	0.56	-0.29	—	—	-0.30	0.45	0.60	-0.30	-0.31
<i>Cannabis sativa</i>	—	—	—	—	—	0.28	0.39	—	0.46	—	—	—	—	—	—	—	0.35	—	—	—	—	—	—	—	—
<i>Teraxacum officinale</i>	—	—	—	—	—	—	—	—	—	—	-0.29	-0.29	—	—	—	-0.39	-0.46	0.37	—	—	—	—	—	—	—
<i>Eucalyptus globulus</i>	0.58	0.37	-0.43	—	—	0.62	0.42	-0.43	—	—	0.57	0.40	—	—	—	0.59	0.37	-0.29	—	—	—	0.58	0.48	-0.44	—
Grasses	-0.56	—	—	—	—	-0.53	-0.28	0.34	—	—	-0.48	-0.31	0.28	—	—	-0.62	-0.55	0.40	—	—	-0.49	-0.41	0.34	—	—
<i>Pinus</i> sp.	—	—	—	—	-0.33	—	—	—	—	-0.33	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Where $p > 0.05$.

correlation analysis revealed that *Taraxacum officinale* pollen counts were negatively affected by daily minimum and maximum temperatures (sectors G-7 and H-8) and positively by RH (sector H-8).

Resident's response to pollen count during pollen season

Allergenic patients visiting hospital were compared with weekly mean pollen counts during 2010 and 2011. In 2010, the highest number of patients ($n = 113$) was recorded in the fourth week of the study, when the mean pollen count was also at its peak with 18 731 pollen grains/m³. The lowest number of patients was reported in the ninth week of the study ($n = 21$). During that week, the pollen season was at its end and the mean weekly pollen level did not exceed 4000 pollen grains/m³ (Figure 7A).

In 2011, the highest number of patients ($n = 77$) was again recorded during the fourth week and corresponded well with a sudden increase in the mean weekly pollen level (from less than 39.71 pollen grains/m³ in week 3 to almost 10 000 pollen grains/m³ in week 4). Surprisingly few patients ($n = 53$) were recorded in the fifth week of the study when the highest mean weekly pollen counts were observed (around 14 000 pollen grains/m³; Figure 7B).

Our results showed that the number of patients visiting hospital decreased in 2011 as compared to 2010. It is worth noticing that the pollen content in the air in Islamabad also decreased in the same year (Tables I, II). In addition, the numbers of allergic patients visiting hospital were usually high during weeks with high pollen level with the exception of a few weeks (i.e. week 5) during 2011. These results suggest a close relationship between the pollen concentration in the air and the allergy symptoms.

Discussion

During the studied period, the following allergenic pollen types have been identified in Islamabad city: *Acacia* sp., *Alternanthera pungens*, *Broussonetia papyrifera*, *Cannabis sativa*, *Eucalyptus globulus*, grasses, *Pinus* sp. and *Taraxacum officinale*. Their pollen concentrations varied distinctly depending on year and city sector. In general, our results show that *Broussonetia papyrifera* was the most abundant pollen type in the city, *Acacia* spp. (25 pollen grains/m³) showed a moderate concentration of pollen while other pollen types have comparatively low pollen content.

In 2010, the peak value of the pollen count was recorded on 16 March in all analysed sectors. In sector H-8, the pollen level exceeded 28 pollen grains/m³ while in sector G-7 the observed pollen

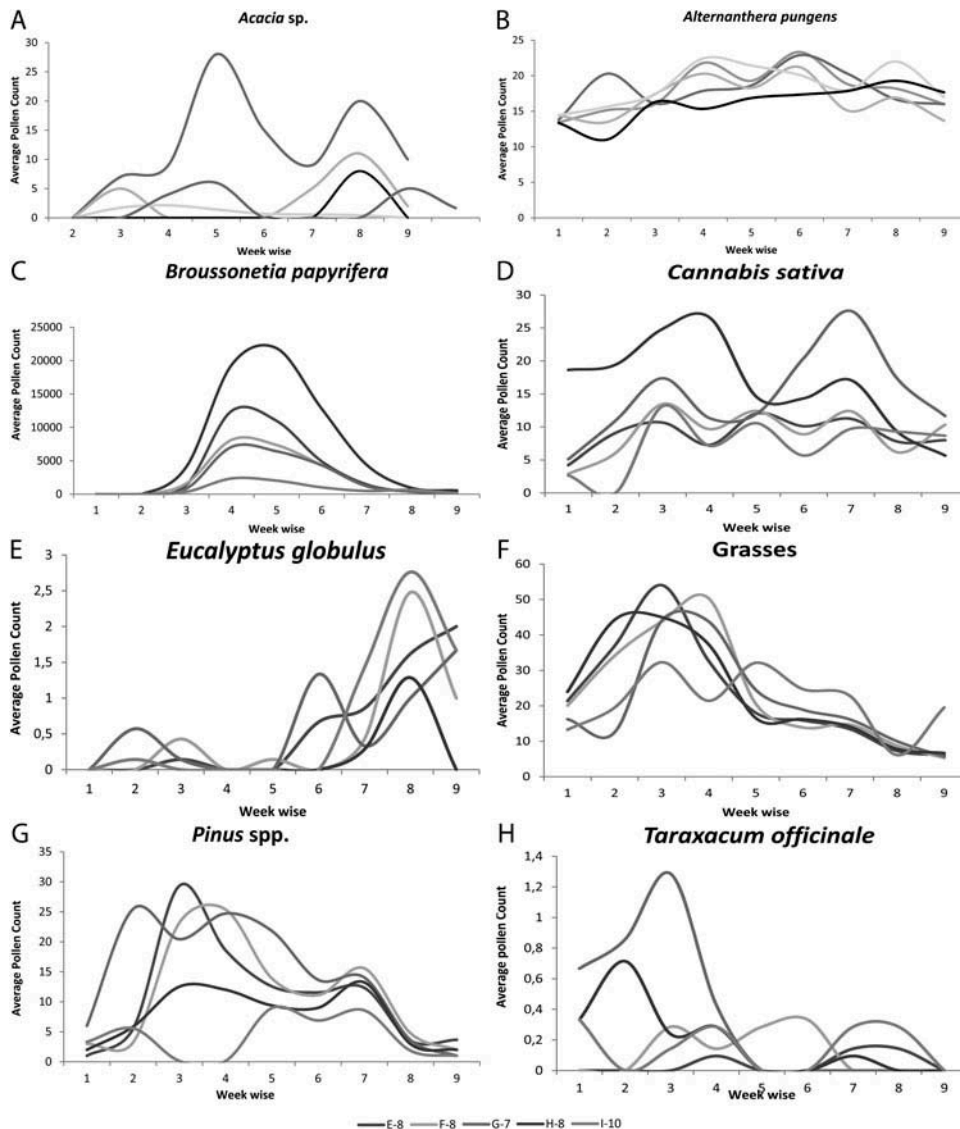


Figure 6. Average pollen count observed for eight pollen types in different sectors of Islamabad for the years 2010–2012; started from 26 February to 15 April.

level amounted to 11 pollen grains/m³. In later years, a gradual shift in the start dates of the pollen season was observed. The distinct delay in the timing of the pollen season in 2012 was mainly attributed to a low amount of rainfall recorded during that year (Figure 3). It has been previously announced that meteorological factors, particularly mean temperature, RH, rainfall and wind speed, directly influence the release of pollen from anthers and its dispersal throughout the atmosphere (Davies & Smith 1973). As Munshi (2000) showed, the prevalence and distribution of airborne pollen varies with weather conditions, vegetation type and flowering period.

The highest annual mean pollen count was recorded for *Broussonetia papyrifera* (> 3000 pollen grains/m³), which contributed over 98% of all collected pollen grains. It belongs to the Moraceae and is considered to be among the world's worst alien

invasive species and has already invaded different parts of the Islamabad city deteriorating its natural and agricultural landscapes (Florence & Coladilla 2006). It spreads by means of its 1.5–2.0 cm long fruits, which are spread to significant distances by local wildlife (Morgan & William 2000).

We have identified four pollen types belonging to tree species, i.e. *Broussonetia papyrifera*, *Acacia* sp., *Eucalyptus globulus* and *Pinus* spp. In many regions, trees are considered to be the main pollen producers because of their common occurrence and the high rate of pollen production per anther, inflorescence or individual tree (Molina et al. 1996). The high pollen concentrations observed in the air is mostly due to the large number of flowers produced by particular species (Ladeau & Clark 2006; Ziska et al. 2008). As mentioned earlier, *Broussonetia papyrifera* was found to be the most prevalent pollen tree in Islamabad and is

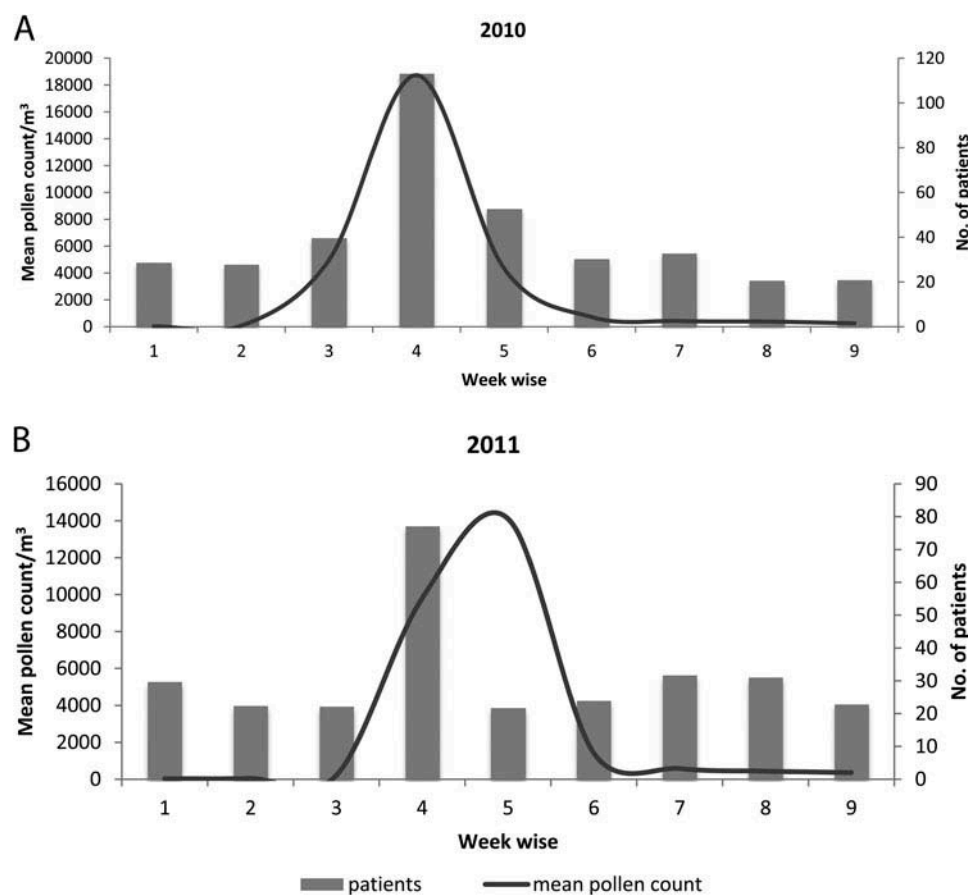


Figure 7. Weekly recorded allergic patients and mean pollen count during pollen season for the years 2010–2011.

thriving along streams and drains where the maximum moisture is available for its growth (Malik & Husain 2007). It was introduced about 40 years ago and exhibited aggressive growth and has a shallow root system that makes the trees susceptible to blow over during high winds. The World Conservation Union listed this species as one of the worst plant invaders in Pakistan (Morgan & Overholt 2004). The high pollen concentrations in sector H-8 was likely related to the large area occupied by vegetation, especially *Broussonetia papyrifera*, while in sector G-7, there is less green areas due to heavy infrastructure. Although the *Broussonetia papyrifera* pollen exceeded very high pollen level through the whole analysed period (2010–2012), in 2012, a further decrease in pollen level has been observed (Tables I–III). It is likely because the Capital Development Authority (CDA) started a campaign for the removal of *Broussonetia papyrifera* due to the potential increase in the risk of pollen allergies. Alternatively, unfavourable weather conditions, i.e. low rainfall in 2012 (Figure 3) may have reduced pollen production.

It is well known that climate and meteorological conditions affect plant responses in terms of pollen quantity and seasonality (Ziska et al. 2008). In 2010, the peak of pollen in Islamabad was noticed in the

middle of March. In later years, the gradual shift in the start dates of the pollen season was observed. The distinct delay in the timing of pollen season in 2012 was mainly attributed to a low amount of rainfall as well as lower daily temperature recorded that year. Temperature is considered as a main factor affecting plant phenology (Sparks et al. 2000). Generally, high temperature in the period preceding flowering accelerates the start of the pollen season (Van Vliet et al. 2002; García-Mozo et al. 2010).

The results of the correlation analysis between aerobiological and meteorological data showed that generally the week increase in pollen levels was positively related to air temperature and negatively to rainfall and RH. Thus, in general, our results agree with observations made by Hyde (1950) who concluded that the release of pollen grains from different species varies depending on both the variations in meteorological parameters as well as the total number of plants in the area (Hyde 1950). Among the weather data, it has been shown that daily maximum, minimum and average temperatures as well as RH, rainfall and wind speed strongly affect the daily variation in pollen concentrations. It varies because different plants have different physiologies, flowering times, dispersal biology, etc. (Galán et al. 2000;

Chmielewska et al. 2005; Stefanic et al. 2005). Typically, even a slight rainfall removes a lot of pollen from the air by washout. Humidity has a negative effect on pollen release from the anthers because they do not open when environmental humidity is high (Palacios et al. 2007). However, it should be stressed that results of correlation analysis sometimes could be biased, e.g. when the pollen levels are very low. In our studies, such phenomenon could occur in the case of *Taraxacum officinale* and *Acacia* sp., for which maximum daily pollen counts rarely exceeded a few pollen grains/m³. Therefore, these results should be examined and interpreted carefully.

From the allergenic point of view, grass pollen is considered as a very important source of allergic symptoms (Suphioglu 2000). Patients could experience allergy reactions during days with daily pollen level varying from several pollen grains to around 50 pollen grains/m³ (De Weger et al. 2013). In our study, the grass pollen level usually exceeded moderate levels, however, during particular days, the daily maximum pollen concentration reached almost 200 pollen grains/m³. In 2011 and 2012, the daily grass pollen level, which could induce allergic reactions (25–500 pollen grains/m³), was observed through week 2–4 (depending on the city sector). Therefore, these pollen taxa, together with *Broussonetia papyrifera*, may be considered as a cause of allergic reactions in Islamabad. The daily variation in grass pollen level was highly dependent on meteorological parameters. These results support previous studies showing that the flowering, pollination and dispersion of grass pollen are all closely related to variations in meteorological parameters, especially rainfall and temperature (Green et al. 2004; Jato et al. 2009). In addition, many studies have also reported that warmer weather in the pre-season months of the year would encourage grass growth, with earlier maturation of vegetative and reproductive structures (Emberlin et al. 1994; Penuelas et al. 2002). Our study showed clear relationships between the weekly number of pollen in the air and the number of patients visiting hospital during the particular weeks. Associations between allergenic airborne pollen, hay fever and asthma were already linked in relation to several species of weeds, grasses, trees and field crops (Murray et al. 2006; D'Amato et al. 2007; Taylor et al. 2007).

The comparison of daily pollen counts with allergic patient's data revealed that most peaks coincided with increase in pollen level suggesting that pollen plays an important role in the development of allergic diseases. Similarly, some other studies have described the relationship between allergic symptoms and atmospheric pollen concentrations

(Florido et al. 1999; Carinanos et al. 2002; Mandal et al. 2008; Karatzas et al. 2014). Therefore, it is essential to know the daily, weekly, monthly and annual variations in pollen concentrations, what could be used by allergists and patients in allergy prophylaxis and treatment (Docampo et al. 2007).

Conclusions

Our study revealed seasonal variations in atmospheric pollen concentrations in Islamabad. Eight different pollen types were identified with the highest pollen values recorded for *Broussonetia papyrifera*, grasses and *Pinus* sp. High concentrations of pollen were recorded in March for all study years when the climate conditions are favourable for a large pollen release. Meteorological conditions such as daily maximum and minimum temperatures showed a significant positive effect on daily pollen counts, whereas RH and precipitation showed a negative correlation with pollen data. In addition, the analysis of weekly pollen counts in relation to weekly numbers of allergic patients attending hospitals revealed distinct positive relationship between these two variables suggesting that allergy symptoms are strongly associated with the magnitude of pollen concentration in the air, especially that of *Broussonetia papyrifera*. In the view of these results, capital authorities and forest departments should be conscious regarding the selection of ornamental species for plantation. Some of them, such as *Broussonetia papyrifera*, could be invasive causing health and economic problems. It is worth noticing that the high number of people suffering from pollen allergies in Islamabad drew the attention of the CDA towards the replacement of *Broussonetia papyrifera* by indigenous species. Based on the results obtained from this study, we suggest that pollen monitoring should be expanded in all big cities of Pakistan. This will allow evaluating the risk of pollen allergy in other regions. Prepared pollen calendars and pollen forecasts should be distributed through print, electronic and social media.

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