Assessment of the health impact of paper mulberry (*Broussonetia papyrifera L.*), an invasive plant species in Islamabad, Pakistan

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Abstract

This study focuses on the risk of pollen allergy due to paper mulberry (*Broussonetia papyrifera L.*), an Asian invasive plant species now common in large parts of the world. Pollen plays a key role in the pathogenesis of respiratory allergic diseases, particularly rhinitis and asthma, and Islamabad, a major metropolitan city, is severely affected by allergy owing to *B. papyrifera* pollen. Due to its seasonality and other relationships with climatic variables, we used remote sensing to monitor the trend of pollen count. We also mapped the localisation of patients affected by pollen allergy using geographic information systems. The maximum likelihood algorithm was applied to SPOT-5 satellite imagery for land use/land cover classification. Temporal analysis of remotely sensed data revealed an increasing trend of paper mulberry density towards the southern and south-western part of Islamabad. Although not evident during rainfall, a clear positive correlation was found between patient count and pollen count. Field survey data and hotspot spatial analysis of allergy patients revealed that residents of Shakerperiyan and Lok Virsa areas (Sectors H-8, I-8, I-9, G-8, G-7 and G-6 in Islamabad) had more pronounced symptoms compared to residents of other sectors. The methodology adopted used in this study can be used to map the distribution of similar invasive species in other parts of the country.

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Acknowledgments: the authors would like to show their gratitude to the National Institute of Health (NIH) and Pakistan Institute of Medical Sciences (PIMS) for sharing the data of allergic patients with us which made this research possible.

Key words: Paper mulberry; Invasive species; Pollen allergy; Remote sensing; Spatial analysis; Pakistan.

Contributions: the authors contributed equally.

Conflict of interest: the authors declare no potential conflict of interest.

Funding: the research was funded by National University of Sciences and Technology, Pakistan.

Received for publication: 25 July 2018.
Revision received: 27 October 2019.
Accepted for publication: 28 October 2019.

Geospatial Health 2019; 14:727
doi:10.4081/gh.2019.727

Introduction

Pollen released from different plants is a key aeroallergen in the pathogenesis of respiratory allergic diseases, *i.e.* rhinitis (Bousquet *et al.*, 2003) and asthma (Wu *et al.*, 2011). The male plant of paper mulberry (*Broussonetia papyrifera L.*) produces an inflorescence called *toot* or *catkin* and its pollen is regarded one of the most clinically relevant aeroallergens investigated (Micheal *et al.*, 2013). The pollen situation is aggravated by the rapid growth and invasive nature of alien species triggered by the homogenisation of the world's flora and fauna (Mooney and Hobbs, 2000). As invasive plants have a tendency to replace native vegetation (Stohlgren *et al.*, 2001; Pauchard and Alaback, 2004), they represents a threat for forests and agricultural lands globally. Paper mulberry is identified as an invasive species in twenty-eight states of the United States and reported as a weed in over a dozen countries around the world (Malik and Husain, 2006). It is a native plant of China, Japan, Korea, Taiwan, Cambodia, Laos, Myanmar, Thailand, Vietnam, and Malaysia (Csurhes, 2012) and (Malik and Husain, 2007) have documented invasion by this plant in the Himalayan foothills of Pakistan during the three latest decades.

The cultivation of alien species of trees, shrubs and herbs, imported from distant regions of the world, is an essential component of urban vegetation (Honu *et al.*, 2009). In the federal capital Islamabad, a strategy called the *Greenway concept* started as early as in the 1960s to revamp the roads by plantations in an effort to improve landscape quality (Ali and Malik, 2010). However, this practice affected the diversity of the indigenous vegetation negatively, and paper mulberry is now the sixth worst plant-invader among the many non-native plant species introduced into Pakistan, (Khatoon and Ali, 1999, *Alien invasive species in Pakistan*, University of Karachi, Pakistan. Personal Communication) recognised as a critical factor in the transformation of the vegetation composition of the area (Ashraf *et al.*, 2012). *B. papyrifera* tolerates a wide range of climates, including humid tropical (monsoon), humid and sub-humid subtropical as well as warm temperate situations. It tends to be most abundant on soils that are generally moist; however, it is also capable of occupying drier sites (Malik and Husain, 2007) as it can survive a 3-4 months dry season (Whistler and Elevitch, 2006). Conventionally, invasive plant species removal is carried out, using the method described by Flory and Clay (2009), *i.e.* weeding by hand, spraying with both post-emergent and pre-emergent herbicides.

Each *B. papyrifera* catkins yield approximately 150-200 inflorescences, each capable of releasing 3 to 6 million pollen grains into the atmosphere during the spring season (Galán *et al.*, 1991). In the period February-April, proximity to this plant contributes to severe pollen allergy in many parts of Pakistan (Ali and Malik, 2010). Pollen counts during this period reaches approx. 40,000/m^3 (Haroon and Rasul, 2008) in some places causing severe asthma-related problems in the local population. Pollen allergy occurs in Islamabad and most parts of North Western Punjab, Hazara, Lahore, Karachi and Central Pakistan (Sadiq and Qureshi, 2010). The World Allergy Organization once stated that 41.9% of allergy patients in Islamabad are suffering from pollen allergy due to paper mulberry pollen (Abbas *et al.*, 2009) and this situation has not improved. In Islamabad, the *B. papyrifera* pollen count can be very high, some days reaching above 30,000/m^3. Most of the residential area of Islamabad is under the threat of this pollen allergy. What is alarming is that its severity level is gradually increasing. This is obvious from the fact that the increasing number of patients with serious respiratory conditions, including asthma that can lead to death due to congestion of the airways.

Remote sensing has many attributes beneficial for detecting, mapping and monitoring the invasive plants (Joshi *et al.*, 2004; Huang and Asner, 2009). A few attempts made with SPOT-XS data have been carried out (Malik and Husain, 2008), but satellite data have not been utilised fully for mapping different plant species in Pakistan. The potential of satellite data for estimating species richness is likely to be due to the near-infrared bands, rather than the visible bands, which share highly redundant information (Nagendra and Rocchini, 2008; Hofmann *et al.*, 2017).

This study focuses on: i) mapping and monitoring the presence of *B. papyrifera L.* by means of remote sensing; ii) monitoring pollen count trends and association with climate variables; and iii) mapping the localisation of patients affected by pollen allergy using geographic information systems. The overall aim was to confirm the association between areas where pollen is produced in the spring and allergy.

Materials and Methods

Study area

Part of Islamabad, the capital of Pakistan situated around coordinates 33.7167°N, 73.0667°E was selected as study area (Figure 1). During summer, daytime air temperature ranges from 21°C to 49°C; whereas from it varies 5°C to 27°C in winter, sometimes falling below zero at night. Autumn is generally limited to October and November with light showers of rain. The average annual rainfall in the area is about 400 mm. The monsoon months are June, July and August. The spring season is pronounced but of short duration (end of February till April), while the summer season is long and hot extending from April to September (Malik and Husain, 2007).

Paper mulberry survey

A total of 100 sampling points of paper mulberry and 50 sampling points of other plant species were recorded with a handheld Garmin eTrex Vista HCx global positioning system. The control points found were further divided into two equal subgroups with half of them used as training samples for supervised classification and the other half used for validation of a land use/land cover map. The maximum likelihood classifier was used for imagery classification.

Patient data

The relationship between the pollen count and the number of patients was analysed. Data regarding patients affected by pollen allergy were collected from the Institute of Medical Sciences (PIMS) hospital and at the National Institute of Health (NIH) in Islamabad. Due to lack of spatial location information of the data provided by hospitals, a field survey was conducted from 10 to 15 December 2013 mapping all residencies of interest. Random allergy patient data were recorded in different sectors of Islamabad to get first-hand information regarding pollen allergy severity and prevalence of this type of allergy in Islamabad City. The flowchart of the methodology of the study is depicted in Figure 2. In order to find the severity level of pollen allergy among the patients, four categories were defined, *i.e.* i) no symptoms, ii) mild symptoms (sneezing accompanied with clogged or runny nose), iii) severe symptoms (fever and inflammation of the membrane that line the eyelids causing red-rimmed eyes), iv) asthma. The patient data were also categorised by age to study the impact of pollen with reference to the age of the patients. For this purpose, five age classes were defined: 0-18, 19-30, 31-50, 51-60 and >60 years old. The total number of patients sampled were 145, out of whom 76 were females and 69 males.

Pollen data

The pollen count data used in the study was obtained from the Pakistan Meteorological Department (PMD) along with the other meteorological data such as rainfall, humidity, wind speed and wind direction.

Satellite data

Remotely sensed data from Landsat 7 (https://landsat.

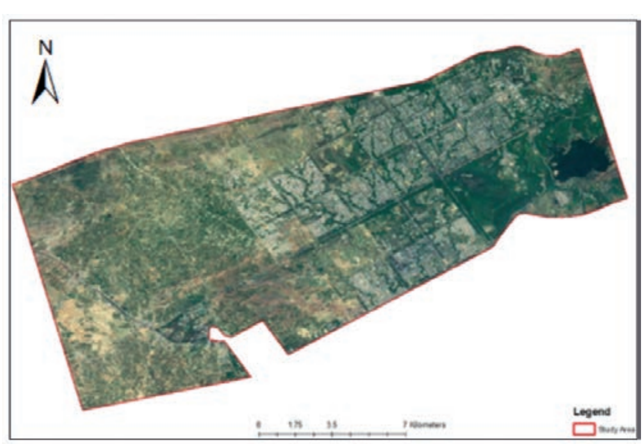

Figure 1. True colour composite image (SPOT-5) of the study area showing various sectors of Islamabad.

gsfc.nasa.gov/landsat-7/) and SPOT-5 (https:// www.satimaging-corp.com/satellite-sensors/other-satellite-sensors/spot-5/) and for the March-April period of the years 2006, 2008, 2010 and 2012 were downloaded to compare the sensor capabilities for mapping paper mulberry presence. Landsat 7, equipped with the Enhanced Thematic Mapper Plus (ETM+), delivers data with a 30-m spatial resolution in 7 spectral bands, while SPOT-5 has a 2.5m spatial resolution in 4 spectral bands. However, already at this stage, it became clear that the Landsat 7 classification was not completely satisfactory. Although the ETM+ had a better spectral resolution than SPOT-5, its spatial resolution (30m) was not effective for discrimination of the different plant species in the area. Therefore, SPOT-5 was used to generate the spectral signature of the paper mulberry plant. Moreover, SPOT-5 satellite imageries were further used to generate maps of land use and land cover from 2006 to 2012.

Statistics

Kappa coefficient, discrete multi-variate statistics that is used to assess agreement between two categorical items, was incorporated to evaluating the accuracy of the land use maps (Thompson and Walter, 1988; Foody, 2002; Du *et al.*, 2014). It takes into account all the observations of an error matrix for determining accuracy. If the value of kappa is 1, it shows perfect agreement between ground samples and result (Gong *et al*., 1992). The overall accuracy was determined by the widely used and simplest descriptive accuracy assessment statistics, *i.e.* the diagonal values (correctly classified values) in the error matrix were summed up and divided by the total number of samples (Lunetta and Lyon, 2004). Kernel Density, a non-parametric statistic was used to estimate density probability of random variables. It computes the density of the features in the region based on their spatial occurrence (Anderson, 2009; ArcGIS Desktop: Release 10; ESRI, Redlands, CA, USA) and fits a curved surface over the line whose value diminishes with the increase in distance from the line (Silverman, 2018).

Results and Discussion

Spatial distribution of paper mulberry

Different types of plant species present on the ground resulted in a mixed spectral response. The spatial resolution of SPOT-5 turned out to be useful for the present study, as it gave 70-75% overall accuracy (Figure 3A and B) in the identification/discrimination of paper mulberry presence. Adam *et al.* (2017) claim a 70% accuracy in mapping the *Acacia podalyriifolia*, *Chromolaena odorata*, and *Litsea glutinosa* within the eThekwini Municipality, KwaZulu-Natal, South Africa by World View 2 imagery, while Asner *et al.* (2008) used the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) (https://aviris.jpl.nasa.gov/) to discriminate the canopy of 37 distinct species, which included 7 native and 24 invasive tree species. They reported that a combination of leaf/canopy water content and nutrient concentration of leaves associated with spectral reflectance range of 125-2,500 nm was best for discriminating the native tree species from the invasive ones. However, they concluded that no single spectral range could effectively discriminate between the species.

SPOT-5 spectral reflectance plot of mean digital numbers (DN) values for paper mulberry reference signature was generated by using the location of cluster of samples collected from the fields and then plotting their mean DN values (Figure 4). Figure 5A-D shows the classification results generated from the four SPOT-5

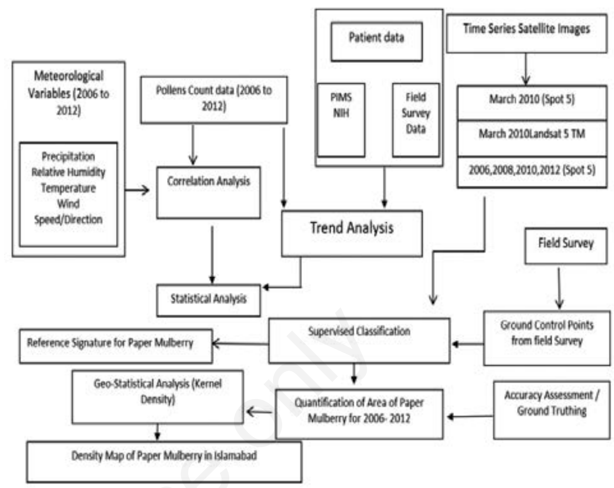

Figure 2. Methodological flowchart used for the study.

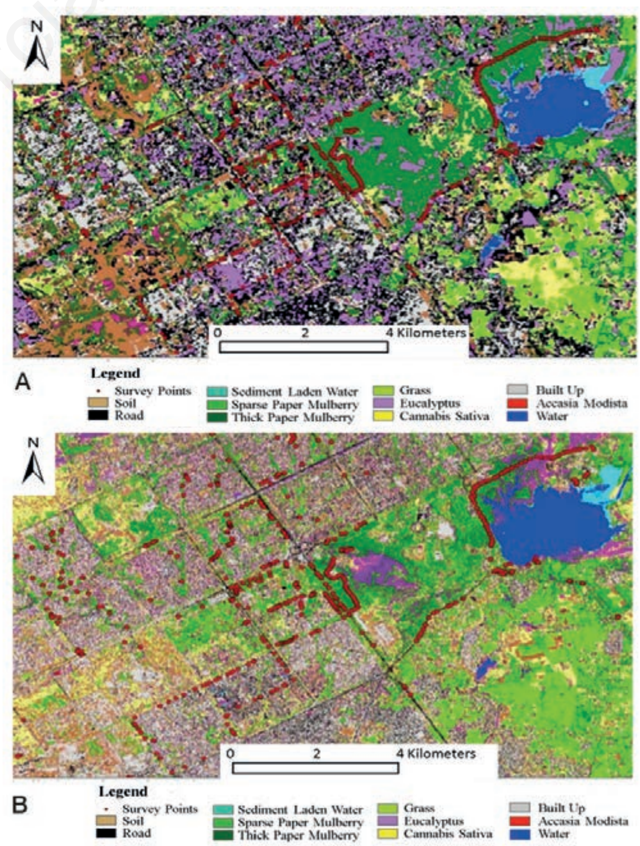

Figure 3. Comparison of (A) Landsat 7 (Mar 2010) and (B) SPOT-5 (Mar 2010) imagery for classification of land cover with paper mulberry field survey points.

images depicting the paper mulberry's temporal-spatial distribution in 2006, 2008, 2010 and 2012. The maps highlight the temporal change in plant density across the study area. For example, in 2006, paper mulberry covered 20% of the total study area which decreased to 14% in 2008, it started increasing again and covered 21% in 2010 and 26% in 2012. The lower density of paper mulberry recorded in 2008 occurred because of the Capital Development Authority (CDA) campaign of cutting the male paper mulberry during the year 2007. However, from 2008 onward, since CDA did not take any action for the eradication of paper mulberry; so its density again increased again reaching 26% in 2012.

Production of the paper mulberry density maps by kernel density analysis was done to generate a detailed analysis of spatial distribution of paper mulberry across the study area (Figure 6A-D). As can be seen, the growth of paper mulberry varied over the time studied. The tendency observed was a spread from the North and East of the city to the north-western direction with only sparse paper mulberry identified in the Southwest. The decrease seen in 2010 (Figure 6C) can be explained by land being cleared for housing at that time in the western part of the city (sectors E-10 and E-11), while the paper mulberry density prevailed in the North and East. In 2012 (Figure 6D), however, the density map revealed that paper mulberry was again common all over Islamabad in Capital Territory, except for a small area where some of the plants were taken out in 2011 for construction of new roads. *i.e.* Margalla Avenue and an extension of Peer Sohawa. Figure 6A-D indicates continued shrinkage of the paper mulberry areas in Northeast. However, generally, the spread of paper mulberry plant was more towards western and south-western directions of the study area. As shown in Figure 7 and Table 1, the reason behind this spread was the wind direction prevailing in that area, which caused the spread of pollens in these directions.

Table 2 shows spatial extent of the land-cover according to supervised classification. It was observed that in 2008, the area covered by paper mulberry was reduced to 14%; the reason being CDA's campaign for the eradication of male *B. papyrifera* plants during 2007, after which it increased again in further years. The overall significant change observed was that the built-up area increased about 11%, while paper mulberry increased about 7% and coverage by other vegetation area decreased by 17%, whereas no significant change occurred in water bodies and soil classes. The decrease in vegetation and increase in paper mulberry proved

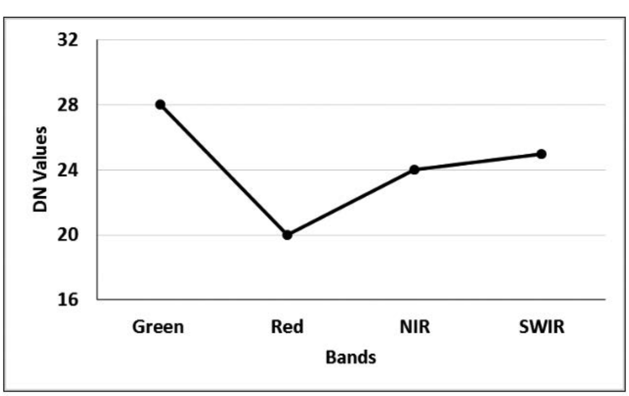

Figure 4. Digital number (DN) spectral profile of paper mulberry canopy. NIR, near-infrared; SWIR, short-wave infrared.

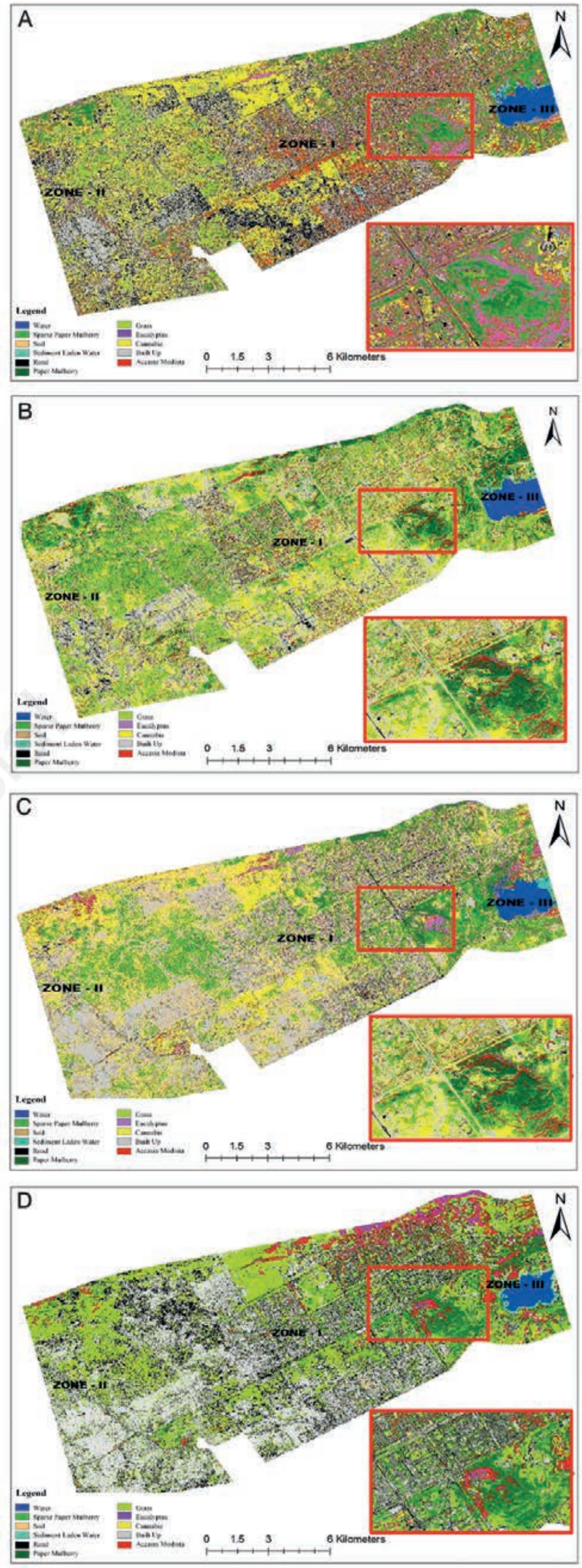

Figure 5. Land cover classification by SPOT-5 with satellite images for (A) 2006; (B) 2008; (C) 2010; and (D) 2012.

Table 1. Average and maximum.

2012	Average Wind Direction	Maximum Wind Direction	Average Wind Speed	Maximum Wind Speed	Temperature Minimum	Temperature Maximum	Relative Humidity
26-Feb-12	0	NW	0	2	2.5	19.5	53
27-Feb-12	SW	SW	1	6	4.0	22.7	46
28-Feb-12	NW	SW	1	4	7.6	23.4	55
29-Feb-12	NW	NW	2	18	6.5	23.5	58
1-Mar-12	0	S	0	2	7.0	24.5	48
2-Mar-12	SW	W	1	4	7.0	24.0	47
3-Mar-12	SW	SW	1	4	7.0	25.0	49
4-Mar-12	0	N	0	4	8.5	25.5	51
5-Mar-12	NE	NE	1	6	11.5	22.5	77
6-Mar-12	N	N	1	4	8.5	23.0	61
7-Mar-12	SW	SW	1	8	7.5	23.5	51
8-Mar-12	SE	SE	2	6	8.0	22.0	57
9-Mar-12	SW	SW	2	15	4.5	20.5	64
10-Mar-12	0	SE	0	2	5.0	22.0	50
11-Mar-12	0	SW	0	2	6.0	24.0	47
12-Mar-12	0	0	0	0	9.5	23.5	42
13-Mar-12	NW	NW	2	8	6.4	20.2	61
14-Mar-12	SW	SW	1	2	5.5	18.8	72
15-Mar-12	SW	SW	1	6	6.5	23.0	57
16-Mar-12	NW	NW	1	4	8.5	24.7	48
17-Mar-12	0	SW	0	2	10.0	26.5	53
18-Mar-12	0	S	0	2	12.0	28.5	54
19-Mar-12	0	SE	0	4	14.5	29.3	54
20-Mar-12	SE	SE	4	25	13.3	29.0	63
21-Mar-12	SW	SW	2	6	9.0	19.0	51
22-Mar-12	NW	NW	1	4	8.0	23.0	54
23-Mar-12	SW	SW	1	6	8.5	26.0	50
24-Mar-12	SW	SW	1	4	9.7	29.0	46
25-Mar-12	NW	NW	2	6	12.6	30.0	52
26-Mar-12	SW	W	4	60	14.0	25.7	64
27-Mar-12	SW	SW	1	6	12.3	26.5	58
28-Mar-12	0	SW	0	9	12.0	26.0	63
29-Mar-12	SW	SW	1	4	12.0	28.0	55
30-Mar-12	NW	W	2	8	11.5	30.8	49
31-Mar-12	SW	SW	1	6	12.8	33.0	47
1-Apr-12	NW	NW	2	25	15.0	32.5	32
2-Apr-12	0	NW	0	2	19.5	33.0	46
3-Apr-12	SW	SW	1	8	16.0	33.0	53
4-Apr-12	0	SW	0	4	15.0	33.5	51
5-Apr-12	SW	SW	1	4	16.0	34.0	47
6-Apr-12	W	W	1	6	14.5	33.8	39
7-Apr-12	0	S	0	4	15.0	32.0	36
8-Apr-12	0	SW	0	4	15.0	32.5	51
9-Apr-12	SW	SW	1	4	17.5	32.6	52
10-Apr-12	SW	SW	1	2	18.0	32.0	56
11-Apr-12	SW	SE	2	8	16.2	29.8	65
12-Apr-12	NE	N	1	6	13.2	25.0	52
13-Apr-12	NE	NE	1	4	15.5	28.0	43
14-Apr-12	NE	NE	1	18	15.0	28.5	49
15-Apr-12	NE	NE	2	4	13.5	32.0	42

SW, south-west; NW, north-west; NE, north east; N, north; SE, south-east; S, south.

that this invasive plant invaded the land and suppressed the growth of other plants. This is in accordance with the results reported by Malik and Husain (2007) who analysed that invasion by *B. papyrifera* in the Himalayan foothills finding an association mainly with the soil physiochemical properties along with high soil moisture.

Validation of land use classification

Accuracy assessment was carried out for all the land use maps. The accuracy was determined by using overall and Kappa statistics. Ground sample data was also used to assess the accuracy of classification results. Overall accuracy for 2006 was 78.73% with a Kappa coefficient of 0.7471, whereas classification of the year 2008 resulted in an overall accuracy of 70.13% with kappa values of 0.6372. In the map showing the situation in 2010, the results had a 74.46% overall accuracy with a 0.7021 kappa coefficient value; while in 2012 map showed 70.90% overall accuracy with 0.6623 kappa values.

Location of pollen allergy patients in Islamabad

The variation of allergy severity of the patients among patients is shown in Figure 8, while the geographic distribution of the patients in the study area was found to be well spread out with random levels of severity (Figure 9A-D). These figures show the severity level of patients from 2006 to 2012 overlaid on the paper mulberry density maps.

There was no gender difference with respect to symptoms. However, regarding patient age, those most affected belonged to

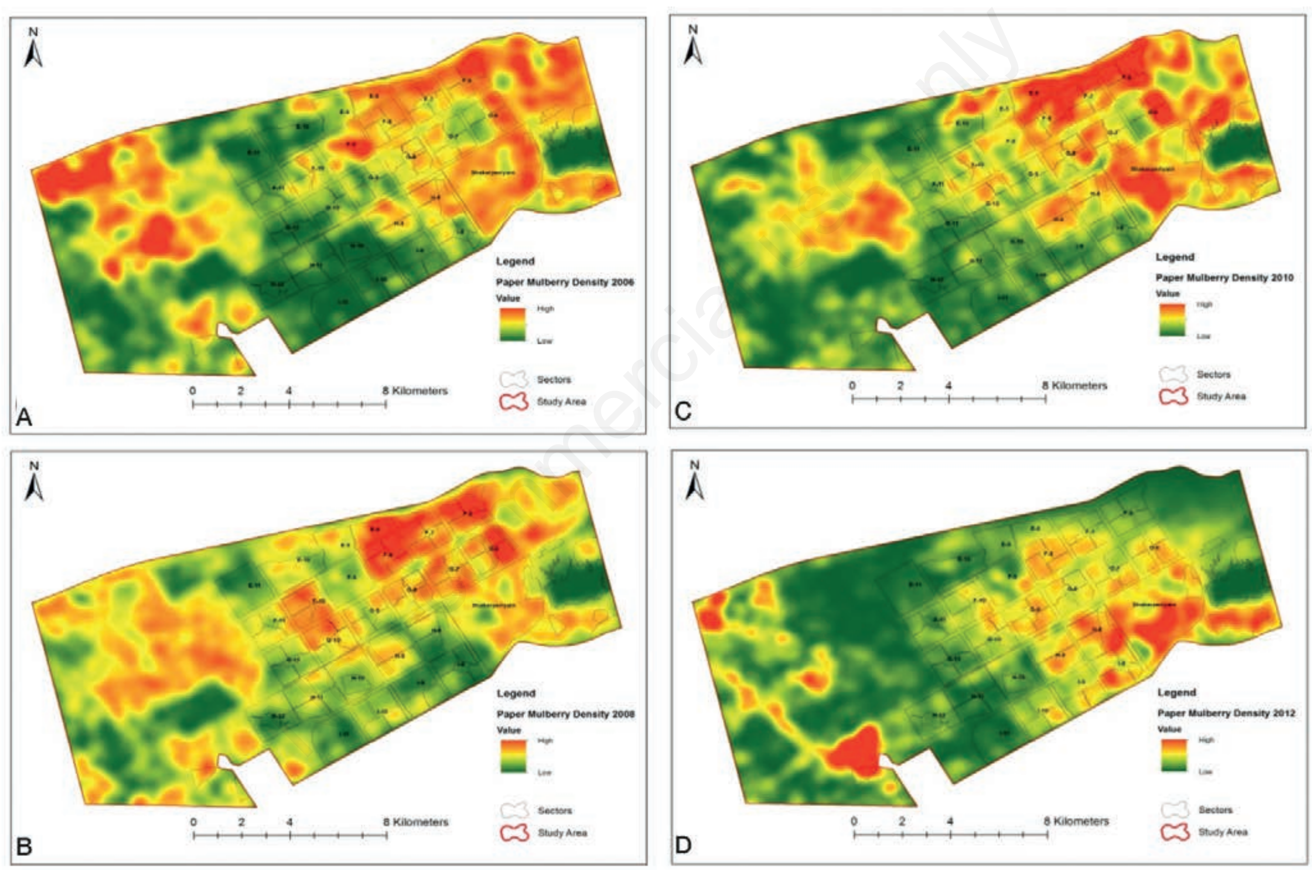

Figure 6. Paper mulberry density maps for year (A) 2006; (B) 2008; (C) 2010; (D) 2012.

Table 2. Percentage of land cover by year and overall change from 2006 to 2012.

Land cover class	Distribution of areas (%)				
	2006	2008	2010	2012	2006-2012
Built area	32	33	41	43	11 (Increase)
Paper mulberry	20	14	21	26	6 (Increase)
Soil	7	7	9	7	0 (No significant change)
Water	2	2	2	2	0 (No significant change)
Other vegetation	39	43	28	22	17 (Decrease)

the 31-50 age group and the least affected those older than 60. The most possible reason for this was that most of those in the affected age group (31-50) had greater exposure time outside the home compared to the other age groups. The geospatial analysis showed that the residents living near Shakerperiyan and Lok Virsa, (sectors H-8, I-8, I-9, G-8, G-7 and G-6) registered more severity level for pollen allergy compared to residents of other sectors. The apparent reason determined from overlay analysis showed that these sectors were located near the identified hotspot areas of paper mulberry clusters in Islamabad (Figure 10A-C).

The results of the analysis carried out for the study years 2006-2012 are shown in Table 3. A linear relationship was found between pollen count and both the number of patients treated at PIMS and at the NIH during pollen season the parameters. In 2006, it was observed that 400-450 patients on average reported daily during the peak pollen days of the season when the pollen count was in the range of 44,774-44,808 ppm. Similarly, in 2008, when the peak pollen count was 44,761-44,828 ppm, the number of patients was 410-450 per day. The scenario in 2010 was not different from the previous years as the peak pollen count was up to 42,690 ppm, and the patients who reported in PIMS and NIH were 400-420 per day. In 2012, when the total pollen count came down

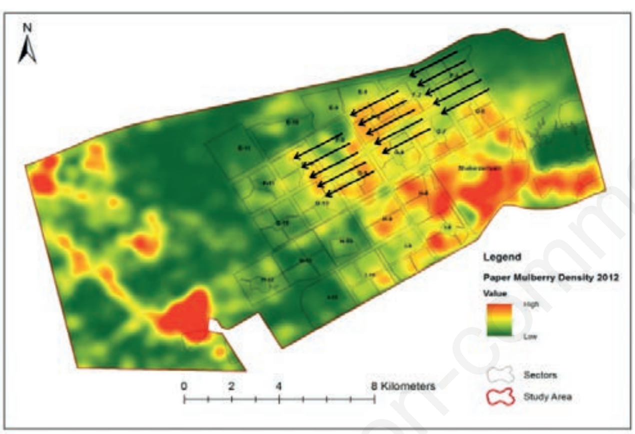

Figure 7. Impact of wind direction onthe spread of paper mulberry.

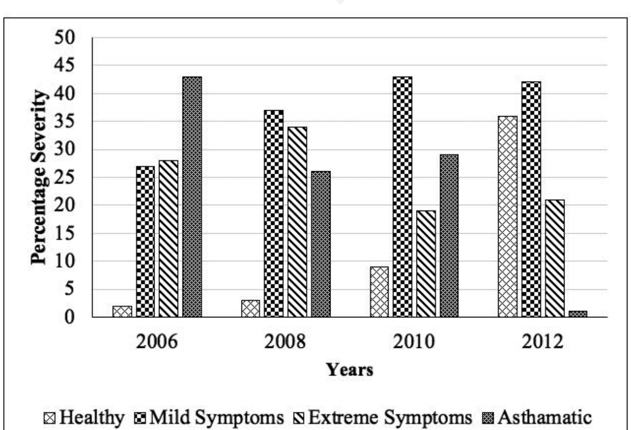

Figure 8. Percentage allergy severity levels among patients (2006-2012).

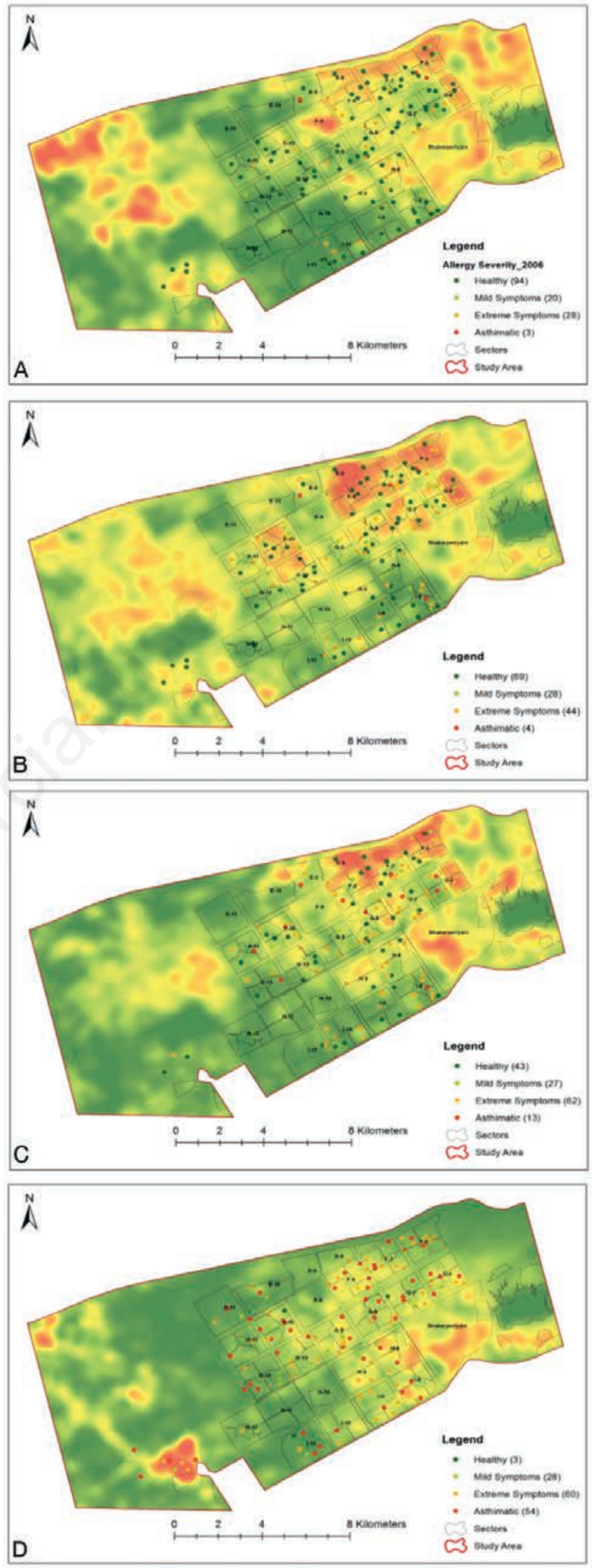

Figure 9. Allergy severity among patients living in different sectors of Islamabad in year (A) 2006; (B) 2008; (C) 2010; (D) 2012.

to 36,164 ppm, the number of patients also declined to 350-400 per day. The decrease in the number of patients during 2012 was due to frequent rainfall events that provided relief to them, as the pollen count values did not hit the highest scales during this year.

Relationship between pollen count and meteorological variables

Figure 11 shows the relationship between pollen count data for the period March and April of the years 2006, 2008, 2010 and 2012 and meteorological parameters (relative humidity, maximum temperature, precipitation and wind speed). It was observed that no other meteorological factor, except rainfall, affected the pollen count. Rainfall washed away pollen resulting in lower values of air-borne pollen concentration count. There were far fewer cases of pollen allergy reported if there was rainfall during the spring season in Islamabad. However, the possibility of frequent/high exposures to such high levels of pollen count in less sensitive individuals can make them more susceptible and they may become sensitised if the strength of the immune system abates. Nyenhuis and Mathur (2013) and De Martinis *et al.* (2017) report that the immune system weakens with age, which may have such an effect.

An analysis of the trend of the pollen count for the study period of 2006-2012 showed that the pollen count for paper mulberry alone crosses the limit of >1,500 ppm. It was found that the peak value of pollen count in the year 2006 was 44,808 ppm. In 2008, there was a nominal increase, and it went up to 44,828 ppm, while it slightly came down to 42,690 ppm in 2010. Thus from 2006 to 2010, it remained around 43,000 ppm. However, in the year 2012, it drastically came down to 36,164 ppm. This was due to more frequent rain showers observed during the spring season of 2012 (Table 4), which proves that rain showers clean the atmosphere from pollen (Haroon and Rasul, 2008). However, rain has an inverse relationship with the pollen count as it also promotes plant growth and increase in plant density (Smart *et al.*, 1979; Barnes *et al.*, 2001; Abbas *et al.*, 2009). The trend of spring rainfall during the study period (2006-2012) in relation to pollen count is shown in the Figure 11. This increase must be judged as part of the reason for the increased density of the plant over the study period noted by our research as shown earlier in Figure 6.

The recorded data also showed that during the first 15 days of March 2006, maximum pollen count was observed. However, the remaining spring season of 2006 showed that the pollen count remained in the ranges of 0-100 ppm because there was rainfall after 15th March in that year. Similarly, in 2008 the peak pollen count was observed from 10th-25th March, which ranged from 44,761-44,828 ppm. Then rainfall events were observed from 31st March onward and reached up to 40-44 mm till the end of the spring season, which reduced the pollen count considerably. In 2010, the rainfall events were observed at the beginning of the season from the end of February till 10th March with an average of 16-22 mm which brought down the pollen count. After this, the pollen count increased and touched its peak (41,342-42,690 ppm) from March 13th till 25th March. Then again rainfall events were observed in the first week of April, thus resulting in lowering the pollen count values. In 2012 an apparent shift in the season was observed. Three/four rain events starting from 5th March to 15th

Figure 10. (A) Allergy patients' distribution in study area; (B) Age distribution of patients; (C) Gender wise distribution of patients.

Table 3. History of severity levels of patients surveyed.

Severity level	Distribution of symptoms between patients surveyed (%) 2006	2008	2010	2012
Healthy	2	3	9	36
Mild symptoms	27	37	43	42
Extreme symptoms	28	34	19	21
Asthmatic	43	26	29	1

March were recorded. The rainfall for each event was 2.5-5 mm which reduced the pollen count considerably. Later, the pollen count had its peak (30,154-36,164 ppm) from March 23rd till 6th April as there was no rainfall. Moreover, throughout the season, 4-5 more rainfall events were observed which resulted in low pollen count recorded during that particular season.

The images of paper mulberry distribution (Figure 6), its relative land cover (Table 2) and the pollen count (Figure 11) over the years covered by this study indicates a strong correlation. In 2006, the total area covered by the paper mulberry plant in the study area was 44.7 km^2 while peak pollen count recorded in this year was 44,808 ppm, whereas in the year 2008 area calculated was 33.2 km^2 and pollen count values were 44,828 ppm. In 2010, the area turned out to be 46.6 km^{2,} and pollen count values were 42,690 ppm. There was an increasing trend observed in the area occupied by the fast-growing invasive plant paper mulberry throughout these four years. The correlation analysis showed that there was a linear relationship between an increase in the area of the plant and the pollen count values. However, in 2012 although the area increased up to 59.5 km^2 yet, the pollen count came down to 36,164 ppm. This increase in area and decrease in pollen values in 2012 were merely due to heavy rainfall in spring season during that year. As already discussed above, the correlation analysis of pollen count with rainfall showed that there was a negative correlation between the two parameters. The graphical analysis between pollen count and rainfall shows that the pollen count values increase with the decrease in rainfall intensity. The observed inverse relationship showed that on the day when the pollen count was the highest (44,774-44,808) ppm, there was no rainfall at all according to the record of PMD, which is responsible for providing

Table 4. Table showing peak pollen count and rainfall events relation.

Year	Peak Pollen Count (ppm)	Rainfall Events during season	Average rainfall (mm)	Max Rainfall (mm)	Total Rainfall (mm)
2006	44808	8	11.2	22.6	89.7
2008	44828	9	11.9	42.0	107.1
2010	42690	8	7.15	15.9	57.2
2012	36164	12	2.6	5.2	23.1

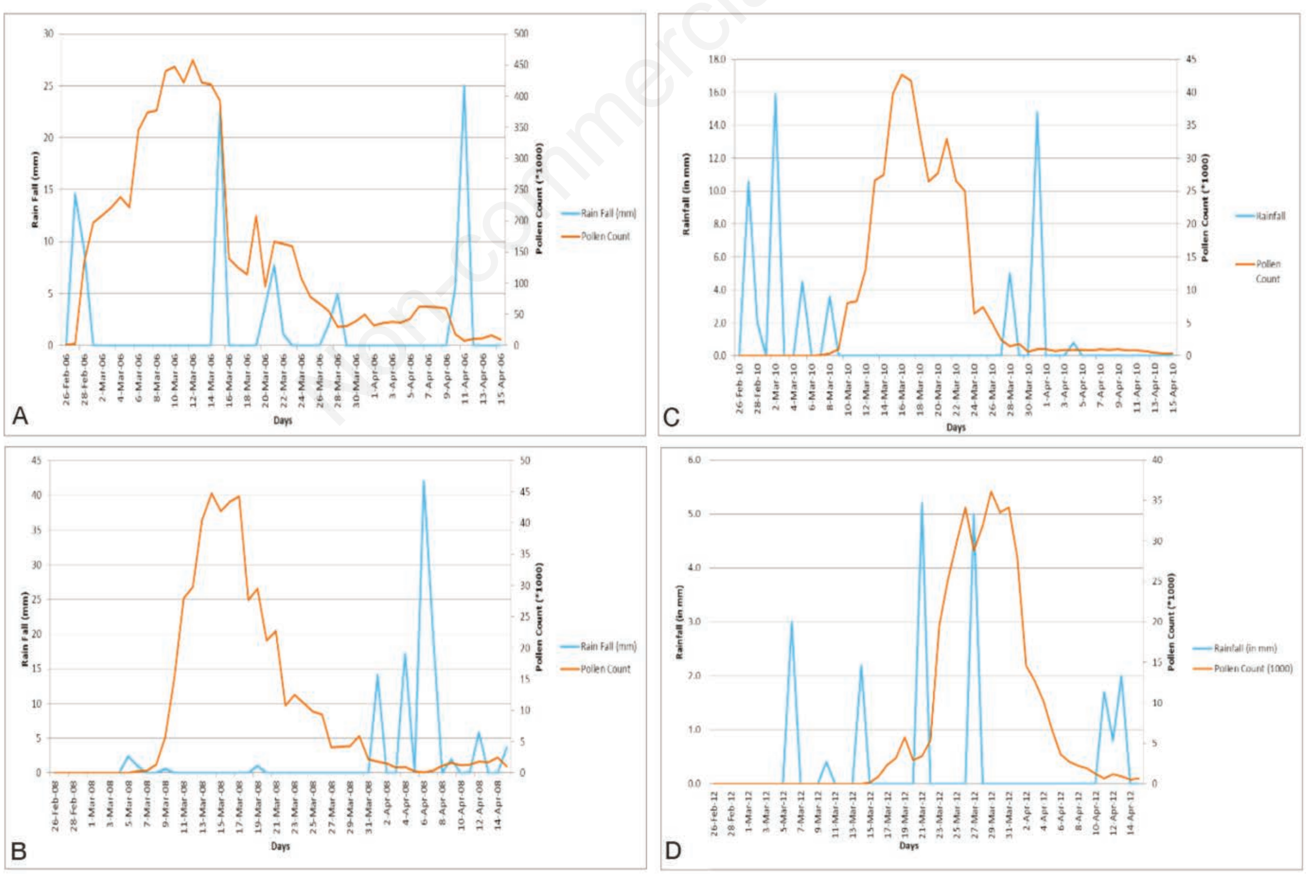

Figure 11. Relationship of pollen count with rainfall during year (A) 2006; (B) 2008; (C) 2010; (D) 2012.

meteorological service throughout Pakistan and provide data for projects and activities. On the contrary, during the spring season of 2006, when the rainfall was at a peak value (25mm) on 11th April, the recorded pollen count came down to 0-25ppm (almost *nil*).

Some limitations to current study were noted. Identification and mapping of alien/invasive species through remote sensing present several challenges since the spectral profiles of invasive species are similar to those of the native plant species. In addition, some of the alien plants are obscure in the background of the native vegetation, which presents another challenge in their identification/mapping through remote sensing. These challenges can be overcome to some extent if high-resolution spatial data collected at the right time (the phenological stage) and used in conjunction with ground truth data of large patches of invasive species. Alternatively, a wider spectral range would help, such as that now available from Landsat 8 thanks to its Operational Land Imager (OLI), but this sensor was not available at the time of this study. The improved signal-to-noise ratio of OLI compared to past Landsat instruments might even offset the lower spatial resolution compared SPOT-5. Indeed, it is highly recommended to use high spatial, temporal and spectral data to monitor this plant species over time. Light Detection and Ranging and handheld spectroradiometers may be used to generate a more accurate spectral profile of the paper mulberry plant. In addition, hospitals should be asked to acquire patient addresses in digital form in order to perform spatial analysis, and more pollen-monitoring stations must be installed at different spots throughout the city. Proper biological treatment should be used to destroy the roots of the plants, as simple chopping off the trunk will not solve the problem and should be replaced with the native plant species.

Conclusions

This study, based on land-use/land-cover classification using SPOT-5 imagery from the years 2006 to 2012, verified and confirmed that the density of the highly pollen-producing plant paper mulberry has increased at a very rapid rate. The geospatial analysis shows that the residents living near Shakerperiyan and Lok Virsa (sectors H-8, I-8, I-9, G-8, G-7 and G-6) registered more severe levels of pollen allergy compared to residents in other sectors. The results of this study can be used by the stakeholders in decision making and for preparing an action plan for the eradication of paper mulberry, which is essential for saving the precious lives of the residents of Islamabad, Pakistan. Eradication of this highly dangerous plant from the city can save the lives of many people who would otherwise die due to choking during extreme attacks of allergy to this kind of pollen in the spring season. It is highly recommended that more pollen collection observatories be installed at various points in Islamabad by PMD to record the exact pollen count levels for all sectors of capital city. Moreover, invasive plants should be replaced by native vegetation through forestation plans.

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