

Journal Pre-proof

Influence of meteorological parameters and air pollutants on the airborne pollen of city Chandigarh, India

Khaiwal Ravindra, Akshi Goyal, Suman Mor



PII: S0048-9697(21)06905-9

DOI: <https://doi.org/10.1016/j.scitotenv.2021.151829>

Reference: STOTEN 151829

To appear in: *Science of the Total Environment*

Received date: 19 September 2021

Revised date: 13 November 2021

Accepted date: 16 November 2021

Please cite this article as: K. Ravindra, A. Goyal and S. Mor, Influence of meteorological parameters and air pollutants on the airborne pollen of city Chandigarh, India, *Science of the Total Environment* (2021), <https://doi.org/10.1016/j.scitotenv.2021.151829>

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2021 Published by Elsevier B.V.

**Influence of meteorological parameters and air pollutants on the airborne pollen
of city Chandigarh, India**

Khaiwal Ravindra^{a*}, Akshi Goyal^b and Suman Mor^b

^{a*}Department of Community Medicine and School of Public Health, Post Graduate Institute
of Medical Education and Research (PGIMER), Chandigarh, 160012, India

^bDepartment of Environment Studies, Panjab University, Chandigarh, 160014, India

***Corresponding author:** Department of Community Medicine and School of Public Health,
Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, India
160012. E-mail: khaiwal@yahoo.com and khaiwal.ravindra@pgIMER.edu.in

Abstract

Pollen, climatic variables and air pollutants coexist in nature with the potential to interact with one another and play a crucial role in increasing allergic diseases. The current study evaluates the influence of meteorological parameters and air pollutants on the airborne pollen in an urban city, Chandigarh, situated in the Indo-Gangetic Plains. Airborne pollen monitoring was done following Spanish Aerobiological Network guidelines and dynamics of daily total pollen and six most abundant taxa were studied from June 2018 to June 2020. Among meteorological parameters, temperature and wind were the most correlated and influential parameters to airborne pollen concentration. Annual Pollen Integral (APIn) of *Cannabis sativa* ($r=0.52$), *Parthenium hysterophorus* ($r=0.27$), Poaceae ($r=0.32$) and total pollen concentration ($r=0.30$) showed a statistically significant positive correlation with temperature. In contrast, precipitation and relative humidity negatively correlated with APIn of total pollen concentration, *Eucalyptus* sp. and Poaceae except for *Parthenium hysterophorus* and *Celtis occidentalis*. Similar results were found with Seasonal Pollen Integral (SPIn) of total pollen concentration, six major taxa and meteorological variables. Spearman correlation performed for NO_x showed a significant positive correlation among APIn and SPIn of *Celtis occidentalis* and insignificant among APIn and SPIn of *Eucalyptus* sp. and *Morus alba*. In contrast, except for *Eucalyptus* sp., PM₁₀ and PM_{2.5} were negatively correlated among APIn and SPIn of total pollen concentration and other major taxa. Spearman's correlation of APIn and SPIn for each pollen taxon, meteorological parameters and air pollutants suggests that each taxon has a different pattern in response to all parameters. The study findings suggest that pollen response must be examined at the taxon level, not the assemblage level, having long time-series data. This will help to compute future scenarios of changing environmental factors and comprehend the relationships and trends among meteorology, air pollutants and aerobiology.

Keywords: climatic variables; airborne pollen concentration; Annual Pollen Integral (APIn); Seasonal Pollen Integral (SPIn); Indo-Gangetic Plain

1. Introduction

Pollen are the most abundant primary biological airborne particles (PBAPs) among different atmospheric bioaerosols (Fröhlich-Nowoisky et al., 2016). These bioaerosols are considered as the most common outdoor allergen responsible for exacerbating respiratory illnesses, majorly asthma and chronic obstructive pulmonary diseases (COPD) and significantly impact the 'patient's quality of life (QOL) (Poole et al., 2019). Apart from this, pollen are also accountable for causing allergic rhinitis in around 20-30% of the population worldwide (Pawankar et al., 2013; Cecchi et al., 2010; Ravindra et al., 2021a). Further, the changing climate also worsened the pollen trends from the past two decades (Anderegg et al., 2021). Enhanced pollen production, change in pollen morphology, longer pollen seasons and altered distribution are reported to be directly influenced by climate change (Beggs, 2004; Poole et al., 2019).

The airborne pollen concentration is primarily influenced by geographical location, plant reproductive biology, phenology, and pollinators (Damialis et al., 2020). Pollen release and dispersal depend on weather conditions, i.e., temperature, precipitation, relative humidity, wind speed and direction, etc. (Beggs, 2004; Bisnan et al., 2020) and also on the topography that exists within the particular area (Fang et al., 2018; Li et al., 2018). Moreover, changes in the temperature, relative humidity and precipitation are known to interfere with the amount of pollen production, daily pollen concentration, length and time of pollen season, pollen distribution and allergen content, pollen fertility and pollen viability (Beggs et al., 2015; Majeed et al., 2018). In addition, regional and long-range transportation of pollen with the movement of air masses from one place to another also exposes the susceptible individuals to new and novel allergens (Clot, 2003). This strong association between meteorological parameters and airborne pollen became more apparent when long-term data sets were examined. Therefore, extensive assessments of changing environmental conditions on diverse species can be considered over time to understand the pollen dynamics (Bruffaerts et al., 2018; Majeed et al., 2018).

As the air pollution is increasing, the pollen (biological particles) and air pollutants (non-biological particles and gases, for example, particulate matter (PM), ozone (O₃), nitrogen oxide (NO₂), etc.) coexist in nature with more potential to interact with one another and exacerbate their adverse effects on human health. Acute and chronic exposure to various pollutants, for example, nitrogen dioxide, ozone and particulate matter, intensify airway

responsiveness to pollen in atopic individuals (Sousa et al., 2012; Zhao et al., 2016). Atmospheric pollutants not only affect the pollen morphology like thinning in exine layer, exine rupture, shrinkage in grain size, etc. (Motta et al., 2006, Suárez-Cervera et al., 2008) but is also engaged in changing its allergenic content (Beck et al., 2013). They can modify the exine structure and promote the release of sub-pollen particles (SPPs) that contain allergens, which will increase the availability of airborne allergens (Singer et al., 2005; Azzazy, 2016). Therefore, this is possible that individuals in polluted areas are more likely to suffer from pollen-allergies than non-polluted areas (Chehregani et al., 2004; Sénéchal et al., 2015). Many evidence indicates metropolitan regions have higher rates of respiratory allergies than rural areas due to interactions among pollen grains and various air pollutants (Ziska et al., 2000; Wan et al., 2002; D'amato et al., 2007). Chiarì et al. (2012) also reported that the rapid urbanization with high vehicular emissions is linked with rising incidences of pollen-induced respiratory allergies. Further studies suggest that air pollution is attributed to growing incidences of pollen-induced allergies in heavily polluted metropolitan regions (Ghiani et al., 2012; Makra et al., 2015; Sedghy et al., 2018).

Currently, most aerobiological research focuses on the strong association between climatic conditions and airborne pollen spectrum (Fernández-Rodríguez et al., 2014; Fang et al., 2018; Majeed et al., 2018; Bishan et al., 2020). Also, there are few studies, which discuss and evaluate the relationship between airborne pollen, meteorology and air pollutants (Cariñanos et al., 2021; Rahman et al., 2019; Oduber et al., 2019), but these are majorly reported in developed and high-income countries. In India, the importance of pollen causing "Pollinosis" is widely understood and well-documented (Singh and Kumar, 2003; Basak et al., 2019; Chaurasia, 2021), but aerobiological studies are confined to only some parts of India (Boral and Bhattacharya, 2000; Boral et al., 2004; Mandal et al., 2008; Ghosal et al., 2015; Ravindra et al., 2021d). Therefore, considering the significant impact of airborne pollen on human health, the main objective of the current study is to investigate the linkages/relationships of meteorological parameters and air pollutants (PM₁₀, PM_{2.5} and NO_x) to the airborne pollen in low and middle-income regions, India. This would be the first study focusing on air pollutants and meteorological variables and their association with the airborne pollen in the Indo-Gangetic Plain (IGP), a global air pollution hotspot. The current study's findings could help to improve the understanding of complex interactions between airborne pollen, air pollutants, and climatic variables to aid in formulating suitable mitigation policies and minimizing the burden of pollinosis in the IGP region.

2. Data and Methodology

2.1 Site description

Chandigarh is the first planned city, located in the northern Himalayas (30°75'N 76°76'E) at the foothills of Shivalik range of northwest part of India (Figure 1). There are different climatic zones in India, based on the Köppen classification system -Alpine E (ET_h), Humid subtropical C (Cwa), Tropical wet-dry A (Aw), Tropical wet A (Am), Semi-arid B (BSh), Arid B (BWh). And the climate of Chandigarh is categorized under 'Cwg' category with four major seasons are: Pre-Monsoon (March, April and May); Monsoon (June, July, August and September); Post-monsoon (October and November) and Winter (December, January and February) (Ravindra et al., 2020). Its geographical location falls in the presence of a distinct subtropical climate with hot summers and cold winters (average annual temperature 38 °C - 43 °C in summers, 2 °C–10 °C in winters, and 910 mm of average annual precipitation) (Ravindra et al., 2021d). In the city's master plan, ample area has been set up for parks, green belts and green spaces. Municipal Corporation Chandigarh constructed and preserved 26 large gardens and over 400 green belts, spanning approximately 579.07 acres of area, with dense vegetation and great floristic variety (<http://mcchandigarh.gov.in/?q=gardens-green-belts>).

The main sources of anthropogenic emission for the city predominantly account for vehicular and industrial emission, whereas other regional activities include biomass burning (agricultural residue and solid biomass in nearby rural areas). As per the State of Environment Report (2016), Chandigarh has recorded the highest vehicular density, i.e., 878 motor vehicles registered per thousand persons in India. Vehicular emissions are one of the most significant causes of background air pollution in the city (Ravindra et al., 2020).

2.2 Aerobiological data

Atmospheric pollen records were obtained from Burkard volumetric spore sampler installed at rooftop of Centre for Public Health (30°45'4.85"N, 76°45'43.90"E), Sector-25, Panjab University, Chandigarh, approximately 4–5meters above the ground-level. This site actively calculates the daily pollen concentrations (grains/m³), adhering to the guidelines specified by Spanish Aerobiological Network (Soldevilla et al., 2007; Ravindra et al., 2021d). Only 6 pollen taxa of high interest were considered because of their abundance and allergenic significance: Poaceae, *Parthenium hysterophorus*, *Morus alba*, *Eucalyptus* sp., *Celtis*

occidentalis and *Cannabis sativa* for the period between June 2018- June 2020. The main pollen parameters considered for the current study evaluation were: Annual Pollen Integral (APIn- summation of the daily average of pollen concentration over a year), Seasonal Pollen Integral (SPIn- summation of daily average pollen concentration during the main pollen season (MPS)) (Ruiz-Valenzuela et al., 2018). Several different methods are available to define and calculate MPS: Nilsson and Persson (1981), Andersen (1991) and Galán et al., (1995). The Anderson (1991) strategy of 95% seasonal pollen catch, commencing with 2.5% of total pollen and ending with 97.5% of total pollen, was used in this investigation.

2.3 Climatological, air pollution and Land-use land cover (LULC) data

The meteorological parameters (average temperature, relative humidity, precipitation, wind direction and speed) and atmospheric pollutant emission levels for the two years (2018–2020) were retrieved from the Meteomanz database (<http://www.meteomanz.com/?l=1>) and Chandigarh Pollution Control Committee (CPCC), Chandigarh (<https://app.cpcbcr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data>), respectively. The observational data taken from the Meteomanz.com website was aggregated for every 3 hours from the official weather stations near Chandigarh and hence a reliable source. The daily 24h average of PM₁₀, PM_{2.5} and NO_x, temperature (°C), relative humidity (%) and precipitation (mm) for Chandigarh were considered for this study.

The daily wind data, i.e., wind direction and speed, were also freely downloaded from the website of Meteomanz.com -

Weather data SYNOPS/BUFR (<http://www.meteomanz.com/index?l=1>). This website provides accurate data supplied by Chandigarh Airforce station (30°44'N, 76°53'E), located in the northeast of the city, approximately 14 km from the aerobiological station. Every 3 hours daily, data were reported for wind speed and direction, assuming the wind rose classified into eight sectors, i.e., N, NE, E, SE, S, SW, W and NW. In order to understand the effects of different wind data on airborne pollen transport, the study is limited to hours and days without calm/blank wind speed. Pollen concentration rose for 2-year pollen concentrations for each selected taxa along wind data were plotted using RStudio Desktop version 1.3.1093.

Further, the Land-use land cover (LULC) map of the study area was retrieved using Bhuvan – Indian Geo-Platform of Indian Space Research Organisation (ISRO) (<https://bhuvan.nrsc.gov.in/home/index.php#>) to understand the pollen dynamics better. A

radial circular area of 20-km was chosen around the pollen sampling location and images were further processed using QGIS 3.16 'Hannover' version.

2.4 Statistical analysis

Statistical analysis was performed using RStudio, OpenAir-Package (www.rstudio.com), which is a system for statistical computation and graphics. The package generates Normalized time plots, non-parametric smoothTrend plots, Correlation plots, Windrose and pollen concentration rose (Carslaw et al., 2012). In addition, Spearman's correlation coefficient approach was considered to examine the potential existing relationships among the dynamics of airborne pollen data for each taxon, meteorological parameters and air pollutants. The Spearman correlation was chosen over standard Pearson correlation because it is more robust and resistant to outliers (Rahman et al., 2019). These non-parametric correlation tests were used to examine the data to emphasize the strength and direction of the relationship among the number of variables. For this, three significance levels were considered, i.e., $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$.

3. Results and Discussion

3.1 Descriptive statistics of total airborne pollen, air pollutants and meteorological data

3.1.1 Summary plot

The time-series data were shown in the left-hand panel of Figure 2, with a cyan blue line below showing available data and a red color showing the missing data period. In contrast, the distribution of each variable was established in the right-hand panel using a histogram plot. Each panel also summarises the key statistics, i.e., maximum, minimum, mean, median and 95th percentile. Pollen concentration data was missing for the two periods, 18 July to 17 August 2018 and 1 January to 18 February 2020, due to some technical issues with the pollen sampler. Meteorological data are briefly described in Figure 2 with mean temperature was 23.2 °C and the mean relative humidity was 67.2 % for 2018-2020.

PM₁₀ and PM_{2.5} 24-hr average values exceeded the NAAQS standards and WHO guidelines regularly, but a sharp increase was recorded in the wintertime and lower values during the summertime. NO_x rarely exceeded their standard value, occurring in lower concentrations. The decreasing trend may be due to government mitigation policies and adaptive measures to reduce air pollution. Figure 2 depicts a sharp spike in PM₁₀ and PM_{2.5} values in mid-Nov-Feb

in both years; NO_x shows a higher spike during Nov-Feb in both years and also displayed some higher trends in May-Jun 2019; whereas pollen concentration was consistent during the winters and highest in the months of Feb-April during the spring season (flowering period).

The higher fraction of PM₁₀, PM_{2.5} and NO_x levels during the winters can be attributed to regional biomass burning, haze events, and increasing vehicular activities (Rai et al., 2021; Ravindra et al., 2021c). Higher levels of fine particles, i.e., PM_{2.5}, can also be responsible for the formation of secondary aerosols, as described by Ravindra et al. (2019) in Chandigarh.

3.1.2 SmoothTrend Analysis

The smoothTrend Plot function computes smooth trends in the monthly mean concentrations of pollutants, pollen concentration and meteorology parameters. It plots monthly concentrations, fits a smooth line to the data and displays 95 % confidence intervals for the fit. However, in this study, the plot was a relationship between time, pollutant concentration, pollen concentration and meteorological parameter i.e., a trend and daily fluctuations of parameters. The primary benefit of this plot is the smoothness in the trend, which was optimized to fit the 'noise' in the data rather than depicting real effects.

Figure 3 shows a smooth trend plot of all parameters considered under study. PM₁₀, PM_{2.5}, NO_x and total pollen concentration trend show some rise and other parameters follow an evident seasonal cycle. A robust seasonal cycle was also observed with some deviation in pollen concentration and PM₁₀, PM_{2.5}. NO_x and temperature smooth trend curves display an inverse relationship, partly attributed to the increased use of fossil fuel for domestic heating and vehicular activity (Yang et al., 2019; Ravindra et al., 2021c). Therefore, anthropogenic sources appear to influence NO_x buildup more than local meteorological conditions during the winters. Seasonal variation of pollen vs. PM₁₀ and PM_{2.5} by temperature has also been studied. The maximum pollen concentration was observed in March when PM₁₀ and PM_{2.5} levels were moderate. With the increase in temperature during summers (April-June), pollen concentration gradually decreases along with the PM₁₀ and PM_{2.5} levels.

Both pollen concentration and PM₁₀ and PM_{2.5} values fall to their significant level during July with optimum temperature. After July, PM₁₀ and PM_{2.5} values started increasing and attained their peak value in January when temperature and pollen concentration were minimum. For PM₁₀ and PM_{2.5}, the winter season had the highest values, followed by the pre-monsoon and monsoon seasons. Monsoon values are the lowest measured values because of the pollutants washout due to increased precipitation. The increased air pollution levels during winter and

post-monsoon seasons may be due to the local emissions and transported pollutants, as well as stable thermal inversion layer over the entire region, which help in amplifying the level of pollutants causing high concentrations across the research area (Pancholi et al., 2018). Lower depth of mixed layer, low temperatures, and lower wind speed allow pollutants to stagnate, resulting in a considerable rise in concentration across the region throughout the winters.

3.2 Seasonal variation in airborne pollen concentration and its relationship with meteorological variables

The airborne pollen showed a significantly diverse level of seasonality in accordance with four seasons, i.e., Pre-Monsoon, Monsoon, Post-Monsoon and Winter. Figure 4 depicts the daily pollen concentration of total pollen and six major taxa plotted against meteorological parameters. Pollen concentration values were very similar across the two years. The overall pollen concentration were nearly identical, with two distinct peak periods: February to April and August to October.

There were three arboreal (*Celtis occidentalis*, *Eucalyptus* sp. and *Morus alba*) and three non-arboreal taxa (*Cannabis sativa*, *Parthenium hysterophorus* and Poaceae), which shows apparent variation in the timing of their occurrence. The most obvious difference was seen in the spring and autumn flowering periods. Arboreal types showed a clear peak in the pre-monsoon period, i.e., spring, whereas non-arboreal showed occurrence throughout the year with a major peak post-monsoon i.e., autumn, as shown in Figure 4. Similar results were also reported by Malik et al. (1991), Ahlawat et al. (2014) and Singh et al. (2017).

Detailed evaluation of SPIn for each taxon revealed higher records for Poaceae, *Parthenium hysterophorus*, *Morus alba*, *Eucalyptus* sp., *Celtis occidentalis* and *Cannabis sativa* during 2019-20 as compared to 2018-19. On the contrary, the pollen SPIn for *Morus alba* was lower for 2019-20 and not much variation was noticed for *Eucalyptus* sp. for both years (Table 1). Meteorological factors significantly affect the distribution pattern of pollen in ambient air. The major peaks of airborne pollen were observed during favorable weather conditions, i.e., moderate temperature, low humidity and low precipitation (Figure 4). However, pollen phenology is the best way to track the alteration in the behavior of plant biology in response to bio-climatic factors. As pollen concentrations are majorly regulated by climatic parameters, where temperature plays a significant role in flowering, inflorescence, maturation, fruiting phenophases, pollen release and dispersal (Damialis et al., 2007; Aguilera et al., 2014).

The large proportion of rainy days have resulted in lower pollen concentration by eliminating them from the environment more rapidly than usual/dry days. Pollen grains are hygrophilous, i.e., they absorb moisture from the surrounding air due to the coalescent effect of water droplets and increase their weight. This results in settling down of heavy pollen gravity phenomenon known as rain washing. Thus, pollen concentration in the atmosphere decreases during precipitation and high relative humidity (Galán et al., 1998; Galán et al., 2000). Also, a negative correlation was observed with relative humidity for pollen concentration. Maximum relative humidity was reported in July and August (monsoon season) when a considerable decrease in the pollen concentration was also reported. Higher RH levels were recorded in January 2019 due to heavy precipitation, which can be seen from summary plots (Figure 2).

3.3 Correlation between pollen concentration, meteorological parameters and air pollutants

3.3.1 Rolling correlation

Figure 5 shows the rolling correlation between the total pollen concentration and various meteorology parameters to visualize the change in correlation over time. It was observed there was a significant correlation between temperature and pollen concentration. A major dip was noticed in May 2019 & 2020 and Dec-Jan 2018 & 2019. The reason for the negative correlation can be low pollen concentration due to extreme summer and winter temperatures. Pollen concentration substantially decreased at temperature extremities, i.e., both at very low temperature during winters as well as a very high temperature during summers in both years might be due to lag effect from hot and dry conditions or cold and dry conditions which caused physiological stress resulting in a negative impact on floral production (Fang et al., 2018).

In contrast, a correlation between daily precipitation and pollen concentration can be observed with some volatility over the period and a significant decrease in Mar and Apr 2019 and Feb- Mar in 2020 due to the inverse correlation between precipitation and pollen concentration (Fang et al., 2018). Likewise, relative humidity was negatively correlated with pollen concentration for the given time series with significant dips during the monsoon period. The average concentration of pollen grains decreases during the monsoon season, indicating that the moisture content of the surroundings negatively influences the pollen concentration.

3.3.2 Correlation between pollen concentration and meteorological parameters

The Spearman correlation coefficients were performed among API_n and SPI_n pollen concentration (total pollen, Poaceae, *Parthenium hysterophorus*, *Morus alba*, *Eucalyptus* sp., *Celtis occidentalis* and *Cannabis sativa*), meteorological parameters (mean temperature (T), relative humidity (RH), precipitation (P) and wind speed (WS)). Each of the six taxa studied had a unique response to weather conditions. API_n and SPI_n of *Cannabis sativa*, *Parthenium hysterophorus*, Poaceae and total pollen showed a significant positive correlation with temperature and inverse with precipitation and relative humidity (Table 2). Figure 6 illustrates that temperature showed a significant positive correlation with API_n total pollen concentration ($r=0.30$; $p<0.001$), *Cannabis sativa* ($r=0.52$; $p<0.001$), *Parthenium hysterophorus* ($r=0.27$) and Poaceae ($r=0.32$; $p<0.001$) and insignificant with *Eucalyptus* sp. and *Morus alba*.

In contrast, precipitation showed a negative correlation with API_n total pollen concentration, *Eucalyptus* sp., and Poaceae except for *Parthenium hysterophorus* ($r=0.01$; $p<0.05$). The relative humidity was negatively correlated to total pollen and major taxa except for *Celtis occidentalis* ($r=0.59$) and insignificant results for *Cannabis sativa*. Similar results were noticed with SPI_n of total pollen concentration, six major taxa and meteorological variables. Table 2 depicts a negative correlation between API_n and SPI_n of all taxa with windspeed except for API_n of *Eucalyptus* sp. ($r=0.45$, $p<0.005$).

3.3.3 Correlation between pollen concentration and air pollutants

The Spearman correlation coefficients were performed for API_n and SPI_n of total pollen, Poaceae, *Parthenium hysterophorus*, *Morus alba*, *Eucalyptus* sp., *Celtis occidentalis* and *Cannabis sativa* and atmospheric pollutant (PM₁₀, PM_{2.5} and NO_x). NO_x showed a significant positive correlation among API_n and SPI_n of *Celtis occidentalis* and insignificant among API_n and SPI_n of *Eucalyptus* sp. and *Morus alba* (Table 2). Several studies have shown NO_x can increase the pollen allergenicity and increase the fragility of pollen, leading to disruption in the exine and subsequently releasing the inner cytoplasmic granules into the ambient air (Ouyang et al., 2016; Hong et al., 2018). The effect of NO_x on pollen concentration had only marginal significance during the study.

Table 2 and Figure 6 show PM₁₀ and PM_{2.5} were negatively correlated among API_n and SPI_n of total pollen concentration and major taxa considered for study except for *Eucalyptus* sp. Several studies have illustrated that particulate matter attaches to the surface of many pollen species (Ribeiro et al., 2015; Visez et al., 2020), causing anomalies and morphological

alterations in pollen structure (Majd et al., 2004; Rezanejad et al., 2007). Some investigations discovered a significant correlation between airborne pollen and particulate matter (Manninen et al., 2014; Rahman et al., 2019), while some have found an inverse between the both (Oduber et al., 2019; Berger et al., 2020).

The increase in PM in the atmosphere can lead to mechanical breakdown of airborne pollen, thereby releasing sub-micronic allergens not directly linked to pollen concentration (Cariñanos et al., 2021). The sensitivity of the trend also incorporates the COVID-19 lockdown period, which subsequently reveals positive impacts on the environment, particularly air quality, thereby decreasing air pollution over the region of India (Biswal et al., 2020; Biswal et al., 2021; Mor et al., 2021; Ravindra et al., 2021b). The current study findings show that meteorological parameters and air pollutants have a considerable yet complex and obscure impact on airborne pollen of diverse plant taxa. Hence, long-term monitoring is recommended.

3.4 Relationship between pollen concentration and wind data

Pollen concentration rose in Figure 7a) depicts the fluctuation of daily pollen concentrations in Chandigarh based on wind direction and speed throughout the study period. It basically illustrates the dominant wind direction and maximum wind speed over time. As shown in Figure 7a), the major airborne pollen sources were found to be near the sampling station and primarily from the Northwest (NW) direction. The wind speed and direction indicated the pollutant dispersion from the source to the receptor. The dominant pollen taxa come from the native species present in the vicinity of the sampling location.

The average wind speed was recorded at 3.9 m/s with a calm condition of 19.2% (Figure 7b)). It was shown that the northwest was the major contributor of pollen direction, followed by the southeast for all the species. The dominant wind direction was northwest with a frequency of 25%, followed by southeast with a frequency of between 10-15% for *Cannabis sativa*. Figure 7a) shows similar trends with changing frequencies for all other species. Figure 7c) summarized the land cover and each land-use and land-cover (LULC) community. The main communities in a 20-km radial circle surrounding the aerobiological station cover evergreen, deciduous forest and shallow land, all of which contain abundant taxa sources, implying that local vegetation is the primary provider of airborne pollen types.

Figure 7c) shows northwest was the major contributor of pollen as there is a botanical garden including the neighboring rural areas, which is about 12-15km from the sampling site. The

potential sources for the southeast directions can be from the Zakir Hussain rose garden and Sukhna Wildlife Sanctuary, which is about 5-8km from the sampling location. Numerous studies have been conducted to analyze the wind data in response to arboreal species dispersion (Skjøth et al., 2013; Maya-Manzano et al., 2017). The distribution indicates that airborne pollen originates in the vicinity of the aerobiological sampling station. In general, higher wind speed resulted in lower pollen concentration.

The wind speed affects the horizontal dispersion of particles and the hourly distribution of pollen concentrations (Perez-Badia et al., 2011). However, all species are wind-pollinated and produce large copious amounts of pollen to facilitate easy dispersal and fertilization. This allows us to depict the influence of wind data on the pollen assemblages, thus representing the spatial variability of pollen dynamics.

4. Conclusions

The current study investigated the correlation between the meteorological parameters, air pollutants and airborne pollen in Chandigarh, situated in the Indo-Gangetic plain of India, using the OpenAir-R package and Spearman's correlation. All the pollen types considered for the study showed great sensitivity to the meteorological parameters and air pollutants. Among meteorological parameters, temperature and wind data stand out as the most influential pollen concentration variables. In contrast, relative humidity and precipitation were found to have an inverse relationship with pollen levels. Plant phenology, inflorescence, flowering and pollination period largely depend on bio-climatic variables. Increasing temperature in early spring was connected with the pollination period, i.e., another dehiscence. In contrast, rainfall washes out pollen from the atmosphere due to the water droplet's coalescent effect, leading to low pollen concentration. Statistically, negative or insignificant correlations were mostly found between PM_{10} , $PM_{2.5}$ and Annual Pollen Index (APIn) and Seasonal Pollen Index (SPIn) of total pollen and six pollen taxa. In contrast, NO_x showed no apparent influence on the pollen data. The localization of major taxa studied was close to the sampling unit and is majorly reported from the Northwest direction.

The study also revealed that meteorological parameters and air pollutants have a considerable yet complex and obscure impact on airborne pollen of diverse plant taxa considered under the entire study. In terms of climatic future, it is expected that the urban environment will significantly impact plant biological and phenological parameters. By understanding pollen prominent presence in the atmosphere of Chandigarh, due to green

landscaping pattern, it is projected that its importance as an allergen will continue to grow in the near future due to high pollution levels in Indo-Gangetic Plains. Therefore, the findings of the study generate useful hypotheses that air pollutants influence pollen concentration and can be further explored as the data set expands in the future. Moreover, the study could help improve the knowledge regarding the interaction of pollen, meteorological parameters and air pollutants to address pollen allergy and its dynamics.

5. Acknowledgment

The authors gratefully acknowledge the Department of Science and Technology (DST), Government of India, for financing research work under this project: "Impact of climate change on air quality including pollen and their relation with symptoms and control among patients with chronic respiratory diseases" sanctioned vide DST/CCP/NHH/111/2017(G), 24th March 2017. We also like to thank Prof. Carsten Ambers Skjøth, University of Worcester, United Kingdom and Dr. Preety Rattan, PGIMER, Chandigarh, for their support and help with statistical analysis in R Software. The authors would also like to acknowledge Chandigarh Pollution Control Committee (CPCC), Bhubaneswar Indian Geo-Platform of Indian Space Research Organisation (ISRO) and MeteoManz.com website for making freely available air pollution, high-resolution LULC and meteorological data, respectively, for users.

6. References

- Aguilera, F. and Ruiz-Valenzuela, L., 2014. Forecasting olive crop yields based on long-term aerobiological data series and bioclimatic conditions for the southern Iberian Peninsula. *Spanish Journal of Agricultural Research*, 12(1), pp.215-224.
- Agustine, I., Yulinawati, H., Suswantoro, E. and Gunawan, D., 2017. Application of open air model (R package) to analyze air pollution data. *Indonesian Journal of Urban and Environmental Technology*, 1(1), pp.94-109.
- Ahlawat, M. and Dahiya, P., 2014. Risk of pollen allergy in Rohtak city (Haryana), India: A pollen calendar. *Plant Arch*, 14, pp.177-84.
- Andersen, T.B., 1991. A model to predict the beginning of the pollen season. *Grana*, 30(1), pp.269-275.

Anderegg, W.R., Abatzoglou, J.T., Anderegg, L.D., Bielory, L., Kinney, P.L. and Ziska, L., 2021. Anthropogenic climate change is worsening North American pollen seasons. *Proceedings of the National Academy of Sciences*, 118(7).

Azzazy, M., 2016. Environmental impacts of industrial pollution on pollen morphology of *Eucalyptus globulus* Labill.(Myrtaceae). *J. App. Biology Biotech*, 4(05), pp.057-062.

Basak, T., Chakraborty, A. and Bhattacharya, K., 2019. Identification of airborne pollen allergens from two avenue trees of India. *International journal of environmental health research*, 29(4), pp.414-429.

Beck, I., Jochner, S., Gilles, S., McIntyre, M., Buters, J.T., Schmidt-Weber, C., Behrendt, H., Ring, J., Menzel, A. and Traidl-Hoffmann, C., 2013. High environmental ozone levels lead to enhanced allergenicity of birch pollen. *PloS one*, 8(11), p.e80147.

Beggs, P.J., 2004. Impacts of climate change on aeroallergens: past and future. *Clinical & Experimental Allergy*, 34(10), pp.1507-1513.

Beggs, P.J., 2015. Environmental allergens: from asthma to hay fever and beyond. *Current climate change reports*, 1(3), pp.176-184.

Berger, M., Bastl, K., Bastl, M., Dirr, J., Hutter, H.P., Moshhammer, H. and Gstöttner, W., 2020. Impact of air pollution on symptom severity during the birch, grass and ragweed pollen period in Vienna, Austria: importance of O₃ in 2010–2018. *Environmental Pollution*, 263, p.114526.

Bhuvan – Indian Geo-Platform of Indian Space Research Organisation (ISRO), 2021. <https://bhuvan.nrsc.gov.in/home/index.php#>

Bishan, C., Bing, L., Chixin, C., Junxia, S., Shulin, Z., Cailang, L., Siqiao, Y. and Chuanxiu, L., 2020. Relationship between airborne pollen assemblages and major meteorological parameters in Zhanjiang, South China. *Plos one*, 15(10), p.e0240160.

Biswal, A., Singh, T., Singh, V., Ravindra, K. and Mor, S., 2020. COVID-19 lockdown and its impact on tropospheric NO₂ concentrations over India using satellite-based data. *Heliyon*, 6(9), p.e04764.

Biswal, A., Singh, V., Singh, S., Kesarkar, A.P., Ravindra, K., Sokhi, R.S., Chipperfield, M.P., Dhomse, S.S., Pope, R.J., Singh, T. and Mor, S., 2021. COVID-19 lockdown-induced

changes in NO₂ levels across India observed by multi-satellite and surface observations. *Atmospheric Chemistry and Physics*, 21(6), pp.5235-5251.

Boral, D. and Bhattacharya, K., 2000. Aerobiology, allergenicity and biochemistry of three pollen types in Berhampore town of West Bengal, India. *Aerobiologia*, 16(3), pp.417-422.

Boral, D., Chatterjee, S. and Bhattacharya, K., 2004. The occurrence and allergising potential of airborne pollen in West Bengal, India. *Ann Agric Environ Med*, 11(1), pp.45-52.

Bruffaerts, N., De Smedt, T., Delcloo, A., Simons, K., Hoebeke, L., Verstraeten, C., Van Nieuwenhuysse, A., Packeu, A. and Hendrickx, M., 2018. Comparative long-term trend analysis of daily weather conditions with daily pollen concentrations in Brussels, Belgium. *International journal of biometeorology*, 62(3), pp.433-491.

Cariñanos, P., Foyo-Moreno, I., Alados, I., Guerrero-Pascual, J.L., Ruiz-Peñuela, S., Titos, G., Cazorla, A., Alados-Arboledas, L. and de la Guardia, C.D., 2021. Bioaerosols in urban environments: Trends and interactions with pollutants and meteorological variables based on quasi-climatological series. *Journal of Environmental Management*, 282, p.111963.

Carslaw, D.C. and Ropkins, K., 2012. Openair—an R package for air quality data analysis. *Environmental Modelling & Software*, 27, pp.52-61.

Cecchi, L., d'Amato, G., Ayres, J.G., Galan, C., Forastiere, F., Forsberg, B., Gerritsen, J., Nunes, C., Behrendt, H., Akdis, C. and Dahl, R., 2010. Projections of the effects of climate change on allergic asthma: the contribution of aerobiology. *Allergy*, 65(9), pp.1073-1081.

Chandigarh Pollution Control Committee (CPCC), Chandigarh, 2021. <https://app.cpcbcr.com/cr/#/caaqm-dashboard-all/caaqm-landing/data>

Chehregani, A., Majde, A., Moin, M., Gholami, M., Shariatzadeh, M.A. and Nassiri, H., 2004. Increasing allergy potency of Zinnia pollen grains in polluted areas. *Ecotoxicology and environmental safety*, 58(2), pp.267-272.

Chaurasia, S., AIRBORNE POLLEN SURVEYS IN INDIA DURING LAST FIFTEEN YEARS (2006-2020): A REVIEW. *International Journal of Advanced Research and Review*, IJARR, 6(6), 2021; 14-21

Clot, B., 2003. Trends in airborne pollen: an overview of 21 years of data in Neuchâtel (Switzerland). *Aerobiologia*, 19(3), pp.227-234.

D'amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi- Maesano, I., Behrendt, H., Liccardi, G., Popov, T. and Van Cauwenberge, P., 2007. Allergenic pollen and pollen allergy in Europe. *Allergy*, 62(9), pp.976-990.

Damialis, A., Charalampopoulos, A., Lazarina, M., Diamanti, E., Almpnidou, V., Maraidoni, A.M., Symeonidou, A., Staikidou, E., Syropoulou, E., Leontidou, K. and Tsiripidis, I., 2020. Plant flowering mirrored in airborne pollen seasons? Evidence from phenological observations in 14 woody taxa. *Atmospheric Environment*, 240, p.117708.

Damialis, A., Halley, J.M., Gioulekas, D. and Vokou, D., 2007. Long-term trends in atmospheric pollen levels in the city of Thessaloniki, Greece. *Atmospheric Environment*, 41(33), pp.7011-7021.

Fang, Y., Ma, C., Bunting, M.J., Ding, A., Lu, H. and Sun, W., 2018. Airborne pollen concentration in Nanjing, eastern China, and its relationship with meteorological factors. *Journal of Geophysical Research: Atmospheres*, 123(19), pp.10-842.

Fernández-Rodríguez, S., Tormo-Molina, R., Mava-Manzano, J.M., Silva-Palacios, I. and Gonzalo-Garijo, Á., 2014. A comparative study on the effects of altitude on daily and hourly airborne pollen counts. *Aerobiologia*, 30(3), pp.257-268.

Fröhlich-Nowoisky, J., Kampf, C.J., Weber, B., Huffman, J.A., Pöhlker, C., Andreae, M.O., Lang-Yona, N., Burrows, S.M., Gunthe, S.S., Elbert, W. and Su, H., 2016. Bioaerosols in the Earth system: Climate, health, and ecosystem interactions. *Atmospheric Research*, 182, pp.346-376.

Galán, C., Alcázar, P., Cariñanos, P., Garcia, H. and Domínguez-Vilches, E., 2000. Meteorological factors affecting daily Urticaceae pollen counts in southwest Spain. *International Journal of Biometeorology*, 43(4), pp.191-195.

Galán, C., Emberlin, J., Domínguez, E., Bryant, R.H. and Villamandos, F., 1995. A comparative analysis of daily variations in the Gramineae pollen counts at Córdoba, Spain and London, UK. *Grana*, 34(3), pp.189-198.

Galán, C., Fuillerat, M.J., Comtois, P. and Dominguez-Vilches, E., 1998. Bioclimatic factors affecting daily Cupressaceae flowering in southwest Spain. *International Journal of Biometeorology*, 41(3), pp.95-100.

- Ghiani, A., Aina, R., Asero, R., Bellotto, E. and Citterio, S., 2012. Ragweed pollen collected along high- traffic roads shows a higher allergenicity than pollen sampled in vegetated areas. *Allergy*, 67(7), pp.887-894.
- Ghosal, K., Pandey, N. and Bhattacharya, S.G., 2015. Biomonitoring of pollen grains of a river bank suburban city, Konnagar, Calcutta, India, and its link and impact on local people. *Annals of Agricultural and Environmental Medicine*, 22(2).
- Hong, Q., Zhou, S., Zhao, H., Peng, J., Li, Y., Shang, Y., Wu, M., Zhang, W., Lu, S., Li, S. and Yu, S., 2018. Allergenicity of recombinant *Humulus japonicus* pollen allergen 1 after combined exposure to ozone and nitrogen dioxide. *Environmental pollution*, 234, pp.707-715.
- Li, J., Li, Y.C., Zhang, Z., Li, Y. and Wang, C.Y., 2018. The dispersion characteristics of airborne pollen in the Shijiazhuang (China) urban area and its relationship with meteorological factors. *Aerobiologia*, 34(1), pp.89-104.
- Mandal, J., Chakraborty, P., Roy, I., Chatterjee, S. and Gupta-Bhattacharya, S., 2008. Prevalence of allergenic pollen grains in the aerosol of the city of Calcutta, India: a two year study. *Aerobiologia*, 24(3), pp.151-164.
- Majd, A., Chehregani, A., Moin, M., Ghulam, M., Kohno, S., Nabe, T. and Shariatzade, M.A., 2004. The effects of air pollution on structures, proteins and allergenicity of pollen grains. *Aerobiologia*, 20(2), pp.111-118.
- Majeed, H.T., Periago, C., Alarcón, M. and Belmonte, J., 2018. Airborne pollen parameters and their relationship with meteorological variables in NE Iberian Peninsula. *Aerobiologia*, 34(3), pp.375-388.
- Malik, P., Singh, A.B., Jabu, C.R. and Gangal, S.V., 1991. Atmospheric concentration of pollen grains at human height. *Grana*, 30(1), pp.129-135.
- Manninen, H.E., Back, J., Sihto-Nissila, S.L., Huffman, J.A., Pessi, A.M., Hiltunen, V., Aalto, P.P., Hidalgo, P.J., Hari, P., Saarto, A. and Kulmala, M., 2014. Patterns in airborne pollen and other primary biological aerosol particles (PBAP), and their contribution to aerosol mass and number in a boreal forest. *Boreal Environment Research*.
- Makra, L., Puskás, J., Matyasovszky, I., Csépe, Z., Lelovics, E., Bálint, B. and Tusnády, G., 2015. Weather elements, chemical air pollutants and airborne pollen influencing asthma

emergency room visits in Szeged, Hungary: performance of two objective weather classifications. *International journal of biometeorology*, 59(9), pp.1269-1289.

Maya-Manzano, J.M., Sadyś, M., Tormo-Molina, R., Fernández-Rodríguez, S., Oteros, J., Silva-Palacios, I. and Gonzalo-Garijo, A., 2017. Relationships between airborne pollen grains, wind direction and land cover using GIS and circular statistics. *Science of the Total Environment*, 584, pp.603-613.

Mor, S., Kumar, S., Singh, T., Dogra, S., Pandey, V. and Ravindra, K., 2021. Impact of COVID-19 lockdown on air quality in Chandigarh, India: understanding the emission sources during controlled anthropogenic activities. *Chemosphere*, 263, p. 127978.

Motta, A.C., Marliere, M., Peltre, G., Sterenberg, P.A. and Lacroix, G., 2006. Traffic-related air pollutants induce the release of allergen-containing cytoplasmic granules from grass pollen. *International archives of allergy and immunology*, 139(4), pp.294-298.

Municipal Corporation Chandigarh, Chandigarh Administration, India, 2021. <http://mcchandigarh.gov.in/?q=gardens-green-belts>

Nilsson, S. and Persson, S., 1981. Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana*, 20(3), pp.179-182.

Oduber, F., Calvo, A.I., Blanco-Alegre, C., Castro, A., Vega-Maray, A.M., Valencia-Barrera, R.M., Fernández-González, D. and Fraile, R., 2019. Links between recent trends in airborne pollen concentration, meteorological parameters and air pollutants. *Agricultural and Forest Meteorology*, 264, pp.16-26.

Ouyang, Y., Xu, Z., Fan, E., Li, Y. and Zhang, L., 2016, January. Effect of nitrogen dioxide and sulfur dioxide on viability and morphology of oak pollen. In *International forum of allergy & rhinology* (Vol. 6, No. 1, pp. 95-100).

Pancholi, P., Kumar, A., Bikundia, D.S. and Chourasiya, S., 2018. An observation of seasonal and diurnal behavior of O₃–NO_x relationships and local/regional oxidant (OX= O₃+ NO₂) levels at a semi-arid urban site of western India. *Sustainable Environment Research*, 28(2), pp.79-89.

Pawankar R, Canonica GW, Holgate ST, Lockett RF, Blaiss MS. White Book on Allergy: Update 2013: WAO World Allergy Organization; 2013. <http://www.worldallergy.org/wao-white-book-on-allergy>).

Perez-Badia, R., Rapp, A., Vaquero, C. and Fernandez-Gonzalez, F., 2011. Aerobiological study in east-central Iberian Peninsula: pollen diversity and dynamics for major taxa. *Annals of Agricultural and Environmental Medicine*, 18(1).

Poole, Jill A., Charles S. Barnes, Jeffrey G. Demain, Jonathan A. Bernstein, Mahesh A. Padukudru, William J. Sheehan, Guillermo Guidos Fogelbach et al. "Impact of weather and climate change with indoor and outdoor air quality in asthma: A Work Group Report of the AAAAI Environmental Exposure and Respiratory Health Committee." *Journal of Allergy and Clinical Immunology* 143, no. 5 (2019): 1702-1710.

Rahman, A., Luo, C., Khan, M.H.R., Ke, J., Thilakanayake, V. and Kumar, S., 2019. Influence of atmospheric PM_{2.5}, PM₁₀, O₃, CO, NO₂, SO₂, and meteorological factors on the concentration of airborne pollen in Guangzhou, China. *Atmospheric Environment*, 212, pp.290-304.

Rai, P., Furger, M., Slowik, J.G., Zhong, H., Tong, Y., Wang, L., Duan, J., Gu, Y., Qi, L., Huang, R.J. and Cao, J., 2021. Characteristics and sources of hourly elements in PM₁₀ and PM_{2.5} during wintertime in Beijing. *Environmental Pollution*, 278, p.116865.

Ravindra, K., Singh, T., Mor, S., Singh, V., Mandal, T.K., Bhatti, M.S., Gahlawat, S.K., Dhankhar, R., Mor, S. and Beig, G., 2019. Real-time monitoring of air pollutants in seven cities of North India during crop residue burning and their relationship with meteorology and transboundary movement of air. *Science of the total environment*, 690, pp.717-729.

Ravindra, K., Singh, T., Pandey, V. and Mor, S., 2020. Air pollution trend in Chandigarh city situated in Indo-Gangetic Plains: understanding seasonality and impact of mitigation strategies. *Science of The Total Environment*, 729, p.138717.

Ravindra, K., Goyal, A. and Mor, S., 2021a. Does airborne pollen influence COVID-19 outbreak?. *Sustainable Cities and Society*, 70, p.102887.

Ravindra, K., Singh, T., Biswal, A., Singh, V. and Mor, S., 2021b. Impact of COVID-19 lockdown on ambient air quality in megacities of India and implication for air pollution control strategies. *Environmental Science and Pollution Research*, 28(17), pp.21621-21632.

Ravindra, K., Singh, T., Sinha, V., Sinha, B., Paul, S., Attri, S.D. and Mor, S., 2021c. Appraisal of regional haze event and its relationship with PM_{2.5} concentration, crop residue burning and meteorology in Chandigarh, India. *Chemosphere*, 273, p.128562.

Ravindra, K., Goyal, A., Kumar, S., Aggarwal, A. and Mor, S., 2021d. Pollen Calendar to depict seasonal periodicities of airborne pollen species in a city situated in Indo-Gangetic plain, India. *Atmospheric Environment*, p.118649.

Rezanejad, F., 2007. The effect of air pollution on microsporogenesis, pollen development and soluble pollen proteins in *Spartium junceum* L.(Fabaceae). *Turkish Journal of Botany*, 31(3), pp.183-191.

Ribeiro, H., Guimarães, F., Duque, L., Noronha, F. and Abreu, I., 2015. Characterisation of particulate matter on airborne pollen grains. *Environmental Pollution*, 206, pp.7-16.

RStudio, 2021. www.rstudio.com

Ruiz-Valenzuela, L. and Aguilera, F., 2018. Trends in airborne pollen and pollen-season-related features of anemophilous species in Jaén (south Spain): a 23-year perspective. *Atmospheric Environment*, 180, pp.234-243.

Sedghy, F., Varasteh, A.R., Sankian, M. and Mojtahadam, M., 2018. Interaction between air pollutants and pollen grains: the role on the rising trend in allergy. *Reports of biochemistry & molecular biology*, 6(2), p.219.

Sénéchal, H., Visez, N., Charpin, D., Shahali, Y., Peltre, G., Biolley, J.P., Lhuissier, F., Couderc, R., Yamada, O., Malrat-Domenge, A. and Pham-Thi, N., 2015. A review of the effects of major atmospheric pollutants on pollen grains, pollen content, and allergenicity. *The Scientific World Journal*, 2015.

Singer, B.D., Ziska, L.H., Franz, D.A., Gebhard, D.E. and Straka, J.G., 2005. Increasing Amb a 1 content in common ragweed (*Ambrosia artemisiifolia*) pollen as a function of rising atmospheric CO₂ concentration. *Functional Plant Biology*, 32(7), pp.667-670.

Singh, A.B. and Kumar, P., 2003. Aeroallergens in clinical practice of allergy in India. An overview. *Annals of Agricultural and Environmental Medicine*, 10(2), pp.131-136.

Singh, N., Singh, U., Singh, D., Daya, M. and Singh, V., 2017. Correlation of pollen counts and number of hospital visits of asthmatic and allergic rhinitis patients. *Lung India: Official Organ of Indian Chest Society*, 34(2), p.127.

Skjøth, C.A., Ørby, P.V., Becker, T., Geels, C., Schlünssen, V., Sigsgaard, T., Bønløkke, J.H., Sommer, J., Søgaard, P. and Hertel, O., 2013. Identifying urban sources as cause of

elevated grass pollen concentrations using GIS and remote sensing. *Biogeosciences*, 10(1), pp.541-554.

Soldevilla, C.G., González, P.C., Teno, P.A. and Vilches, E.D., 2007. Spanish Aerobiology Network (REA): management and quality manual. *Servicio de publicaciones de la Universidad de Córdoba*, 184, pp.1-300.

Sousa, R., Duque, L., Duarte, A.J., Gomes, C.R., Ribeiro, H., Cruz, A., Esteves da Silva, J.C. and Abreu, I., 2012. In vitro exposure of *Acer negundo* pollen to atmospheric levels of SO₂ and NO₂: effects on allergenicity and germination. *Environmental science & technology*, 46(4), pp.2406-2412.

State of Environment Report, 2016. State of Environment Report
<http://chandigarhenvi.gov.in/beta/asp/header.asp?page=index.asp> (2016)

Suárez-Cervera, M., Castells, T., Vega-Maray, A., Civantos, E., del Pozo, V., Fernández-González, D., Moreno-Grau, S., Moral, A., López-Iglesias, C., Lahoz, C. and Seoane-Camba, J.A., 2008. Effects of air pollution on Cup 3 allergen in *Cupressus arizonica* pollen grains. *Annals of Allergy, Asthma & Immunology*, 101(1), pp.57-66.

Visez, N., Ivanovsky, A., Roose, A., Gosseuin, S., Sénéchal, H., Poncet, P. and Choël, M., 2020. Atmospheric particulate matter adhesion onto pollen: a review. *Aerobiologia*, 36(1), pp.49-62.

Wan, S., Yuan, T., Bowdish, S., Wallace, L., Russell, S.D. and Luo, Y., 2002. Response of an allergenic species, *Ambrosia psilostachya* (Asteraceae), to experimental warming and clipping: implications for public health. *American Journal of Botany*, 89(11), pp.1843-1846.

Weather data SYNOPS/BUFR -

GFS/ECMWF forecast, 2021. <http://www.meteomanz.com/?l=1>

Yang, Y., Liu, X., Zheng, J., Tan, Q., Feng, M., Qu, Y., An, J. and Cheng, N., 2019. Characteristics of one-year observation of VOCs, NO_x, and O₃ at an urban site in Wuhan, China. *Journal of Environmental Sciences*, 79, pp.297-310.

Zhao, F., Elkelish, A., Durner, J., Lindermayr, C., Winkler, J.B., Ruëff, F., Behrendt, H., Traidl-Hoffmann, C., Holzinger, A., Kofler, W. and Braun, P., 2016. Common ragweed (*Ambrosia artemisiifolia* L.): allergenicity and molecular characterization of pollen after plant exposure to elevated NO₂. *Plant, cell & environment*, 39(1), pp.147-164.

Ziska, L.H. and Caulfield, F.A., 2000. Rising CO₂ and pollen production of common ragweed (*Ambrosia artemisiifolia* L.), a known allergy-inducing species: implications for public health. *Functional Plant Biology*, 27(10), pp.893-898.

List of Figures and Tables:

Figure 1: Map of the city Chandigarh, India

Figure 2: Summary Plot of air pollutants, total pollen concentration and meteorological parameters.

Figure 3: Smooth Trend of air pollutants, Pollen concentration and meteorological parameters.

Figure 4: Daily mean pollen concentration recorded in 2018 – 2020 for Chandigarh.

Figure 5: Rolling correlation graph of meteorological variable and daily average pollen concentration.

Figure 6: Spearman coefficients between pollen concentration (total pollen, *Cannabis sativa*, *Celtis occidentalis*, *Eucalyptus* sp., *Morus alba*, *Parthenium hysterophorus* and Poaceae), meteorological parameters (mean temperature (T), relative humidity (RH), precipitation (P) and wind speed (WS)) and atmospheric pollutant (PM₁₀, PM_{2.5} and NO_x).

Figure 7: a) Pollen concentration rose for a) *Cannabis sativa* b) *Celtis occidentalis* c) *Eucalyptus* sp. d) *Morus alba* e) *Parthenium hysterophorus* f) Poaceae from 2018 to 2020 b) Windrose for the period of 2018-2020 c) Landcover landuse map for 20-km radius around aerobiological station.

Table 1: Annual Pollen Integral (APIn) of Total Pollen and Seasonal Pollen Integral (SPIn) of the six pollen types for 2018-2020.

Table 2: Spearman correlation coefficients between Annual pollen Integral (APIn) and Seasonal Pollen Integral (SPIn) of total pollen, *Cannabis sativa*, *Celtis occidentalis*, *Eucalyptus* sp., *Morus alba*, *Parthenium hysterophorus*, Poaceae, meteorological parameters (average temperature (AT), relative humidity (RH), precipitation (Prec.) and wind speed (WS)) and atmospheric pollutant (PM₁₀, PM_{2.5} and NO_x).

Table 1: Annual Pollen Integral (APIn) of Total Pollen and Seasonal Pollen Integral (SPIn) of the six pollen types for 2018-2020.

Year	APIn (pollen/m ³)	SPIn (pollen/m ³)					
	Total	<i>Cannabis sativa</i>	<i>Celtis occidentalis</i>	<i>Eucalyptus</i> sp.	<i>Morus alba</i>	<i>Parthenium hysterophorus</i>	Poaceae
2018-19	21,244	578	331	249	14621	142	955
2019-20	20,412	1918	537	262	19532	409	1489

Table 2: Spearman correlation coefficients between Annual pollen Integral (APIn) and Seasonal Pollen Integral (SPIn) of total pollen, *Cannabis sativa*, *Celtis occidentalis*, *Eucalyptus* sp., *Morus alba*, *Parthenium hysterophorus*, Poaceae, meteorological parameters (average temperature (AT), relative humidity (RH), precipitation (Prec.) and wind speed (WS)) and atmospheric pollutant (PM₁₀, PM_{2.5} and NO_x).

	AT (°C)		RH (%)		Prec. (mm)		WS (km/h)		PM ₁₀ (µg/m ³)		PM _{2.5} (µg/m ³)		NO _x (µg/m ³)	
	APIn	SPIn	APIn	SPIn	APIn	SPIn	APIn	SPIn	APIn	SPIn	APIn	SPIn	APIn	SPIn
<i>Cannabis sativa</i>	0.52	0.53	0.74	0.03	-0.02	-0.03	0.05	0.06	-0.44	-0.46	-0.56	-0.57	-0.54	-0.54
<i>Celtis occidentalis</i>	-0.63	-0.48	0.59	0.41	-0.08	-0.14	-0.23	-0.22	-0.24	-0.14	-0.18	-0.28	0.50	0.54
<i>Eucalyptus</i> sp.	-0.02	0.12	-0.43	-0.09	-0.28	-0.09	0.45	0.002	0.11	-0.21	0.07	-0.28	-0.03	0.06
<i>Morus alba</i>	0.12	-0.05	-0.09	-0.07	-0.04	0.10	0.01	-0.03	-0.43	-0.07	-0.36	-0.01	0.03	-0.13
<i>Parthenium hysterophorus</i>	0.27	0.30	-0.27	-0.36	0.01	-0.05	0.02	0.04	-0.26	-0.24	-0.42	-0.40	-0.41	-0.40
Poaceae	0.32	0.53	-0.29	-0.39	-0.19	-0.12	0.02	0.04	-0.36	-0.40	-0.48	-0.55	-0.28	-0.37
Total pollen	0.30	0.40	-0.29	-0.40	-0.17	-0.21	0.13	0.18	-0.41	-0.44	-0.53	-0.56	-0.31	-0.34

*p≤0.05,

**p≤0.01

and

***p≤0.001

Credit Author Statement

Khaiwal Ravindra: Conceptualization, Methodology, Formal analysis, Writing - review & editing, Visualization, Funding acquisition.

Akshi Goyal: Methodology, Formal analysis, Data curation, Writing - review & editing.

Suman Mor: Supervision, Formal analysis, Validation, Writing - review & editing, Funding acquisition

Title: Influence of meteorological parameters and air pollutants on the airborne pollen of city Chandigarh, India

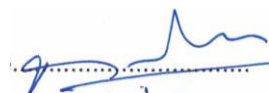
Journal: Science of the Total Environment

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

On behalf of all authors



13/11/2021

Figure 1

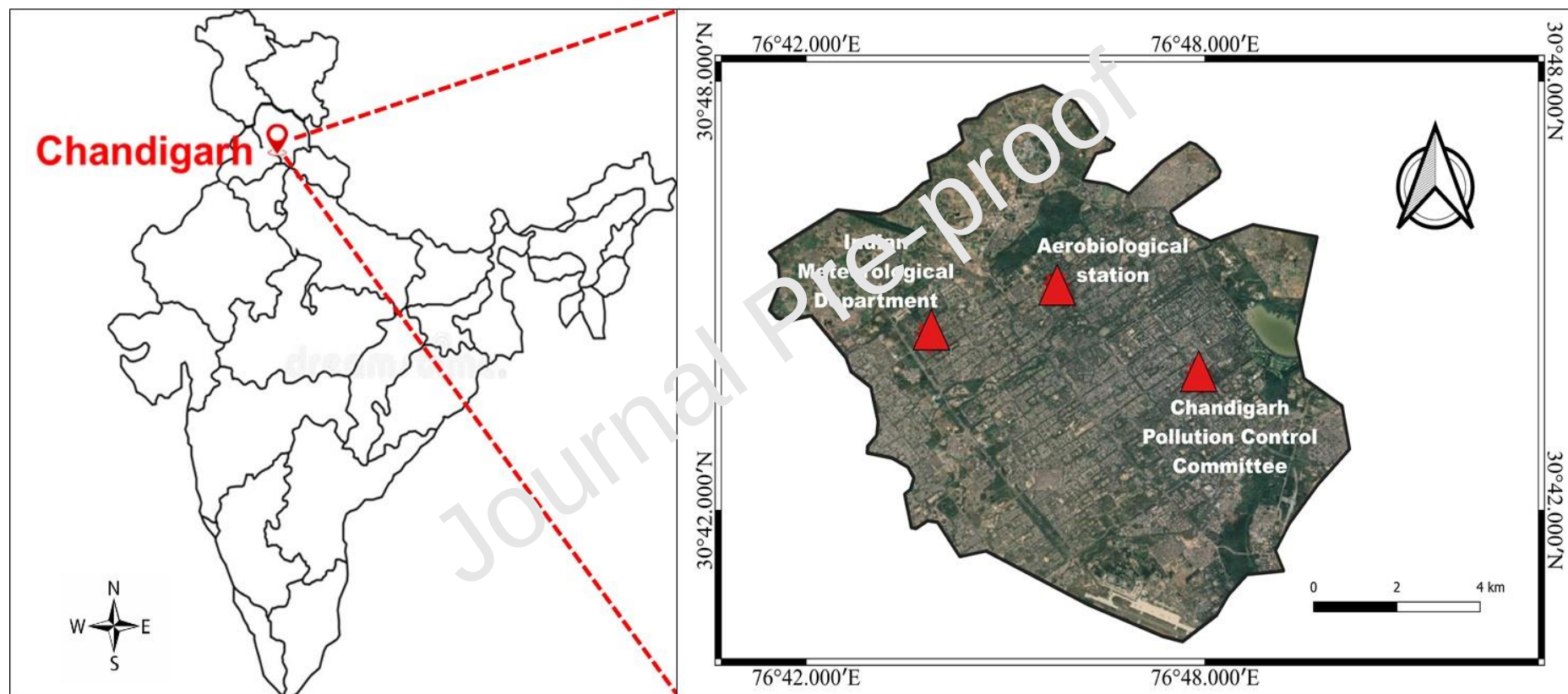


Figure 2

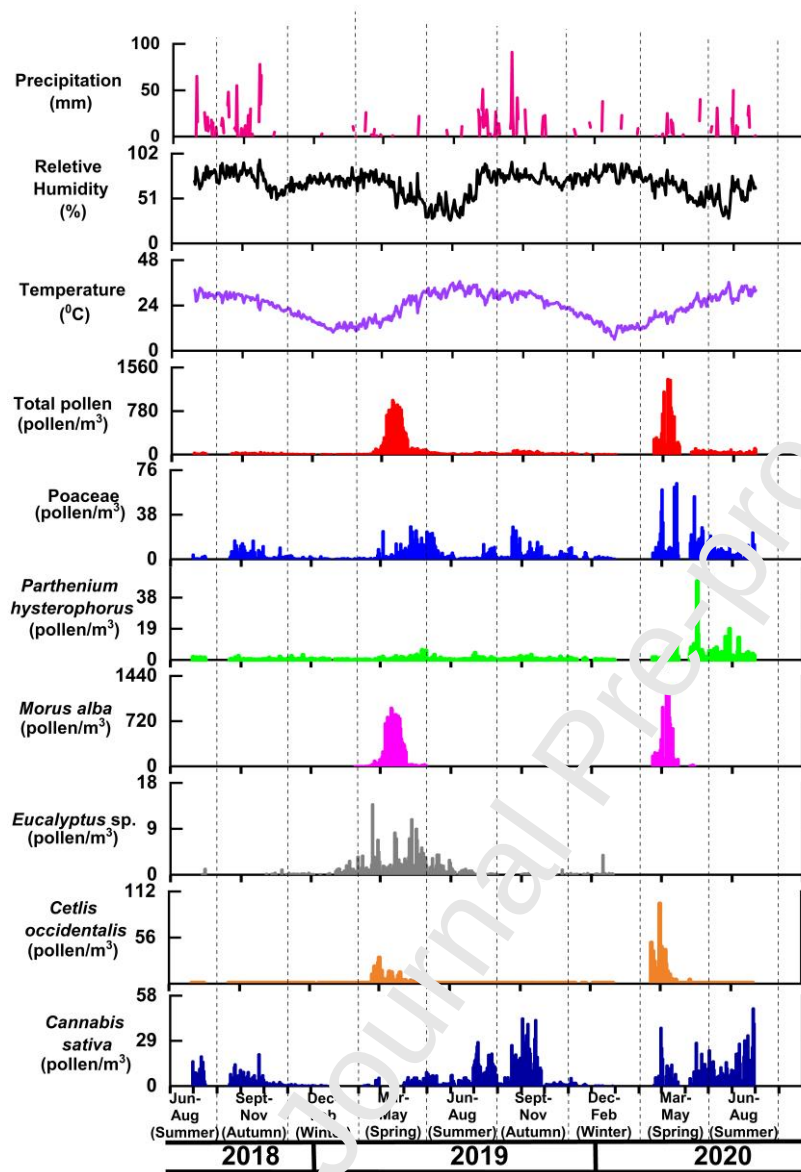


Figure 3

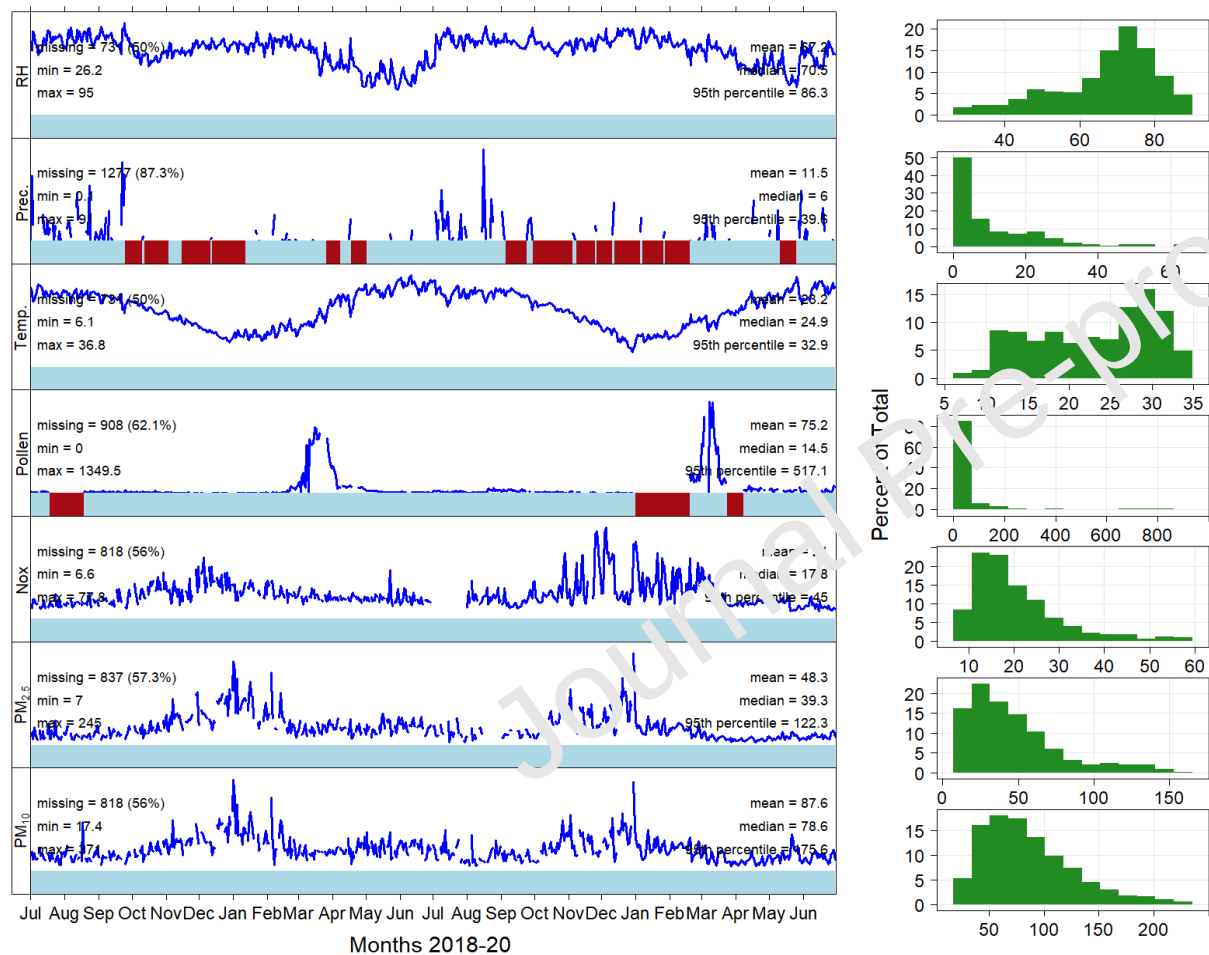


Figure 4

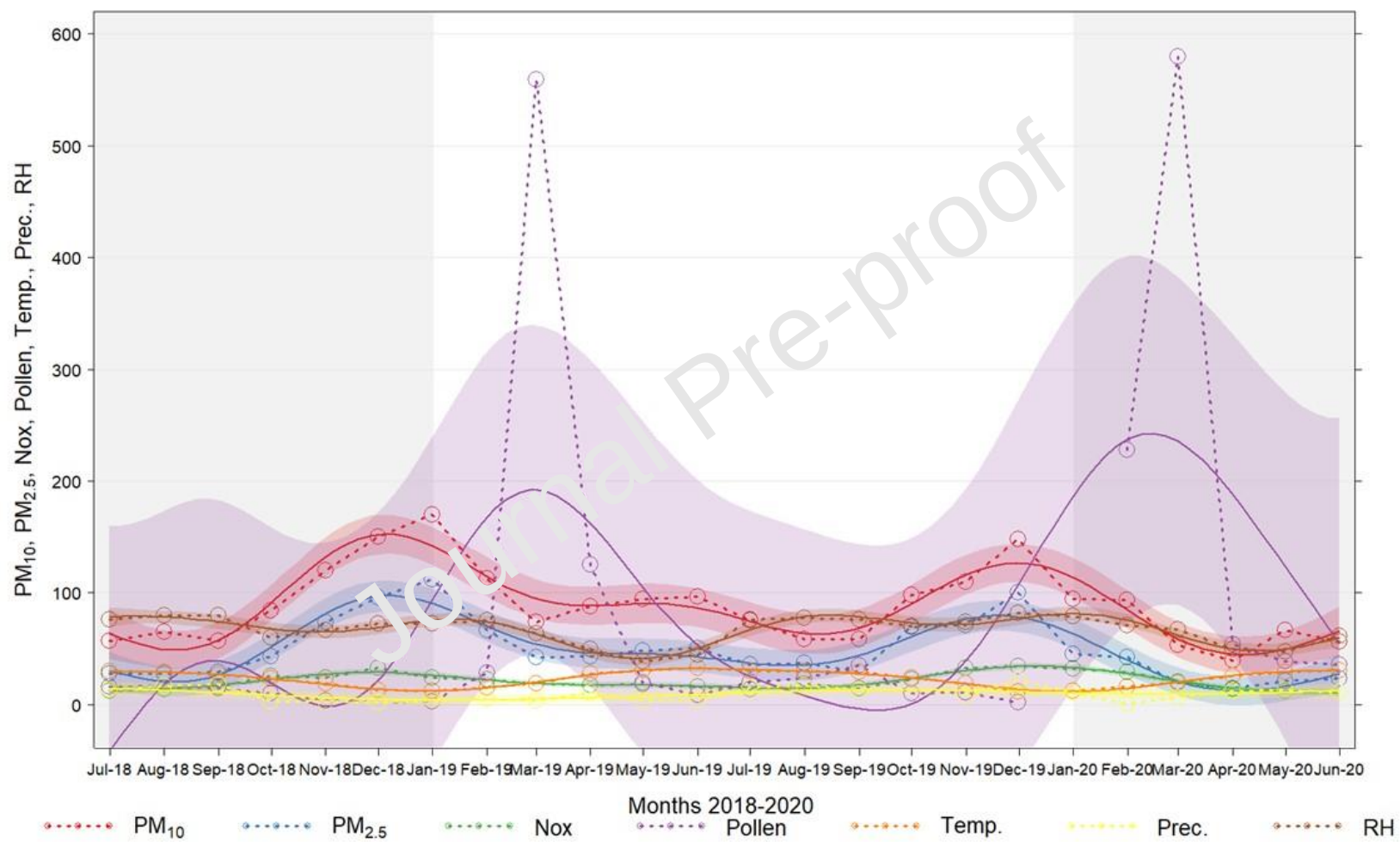


Figure 5

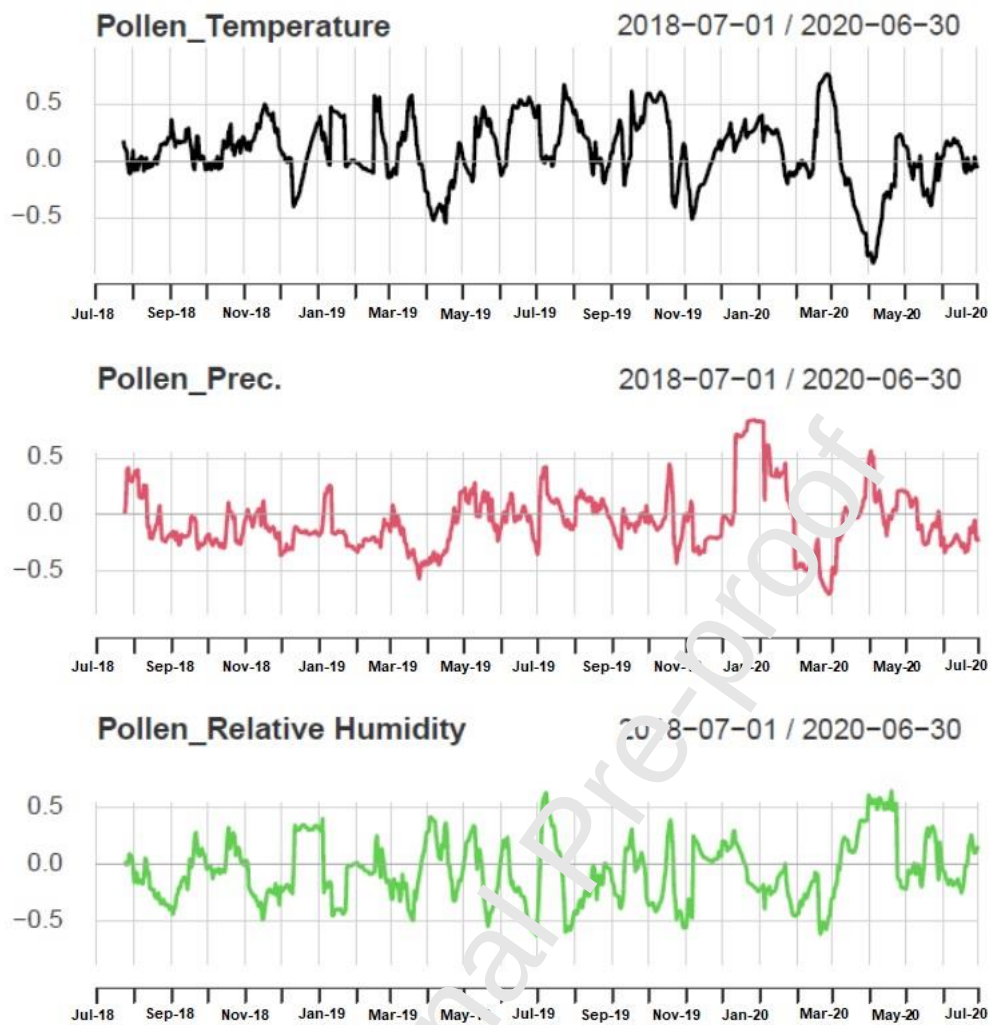
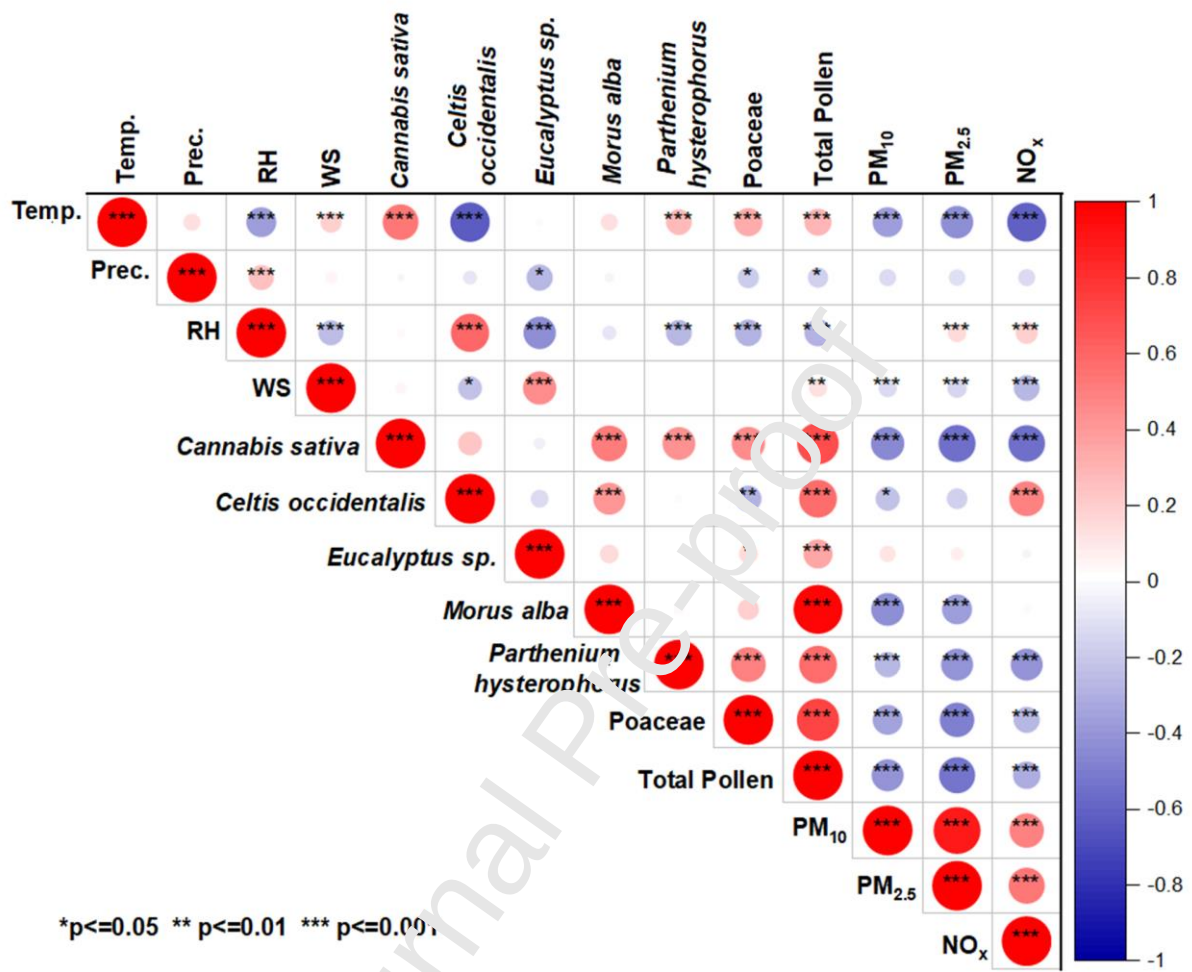


Figure 6



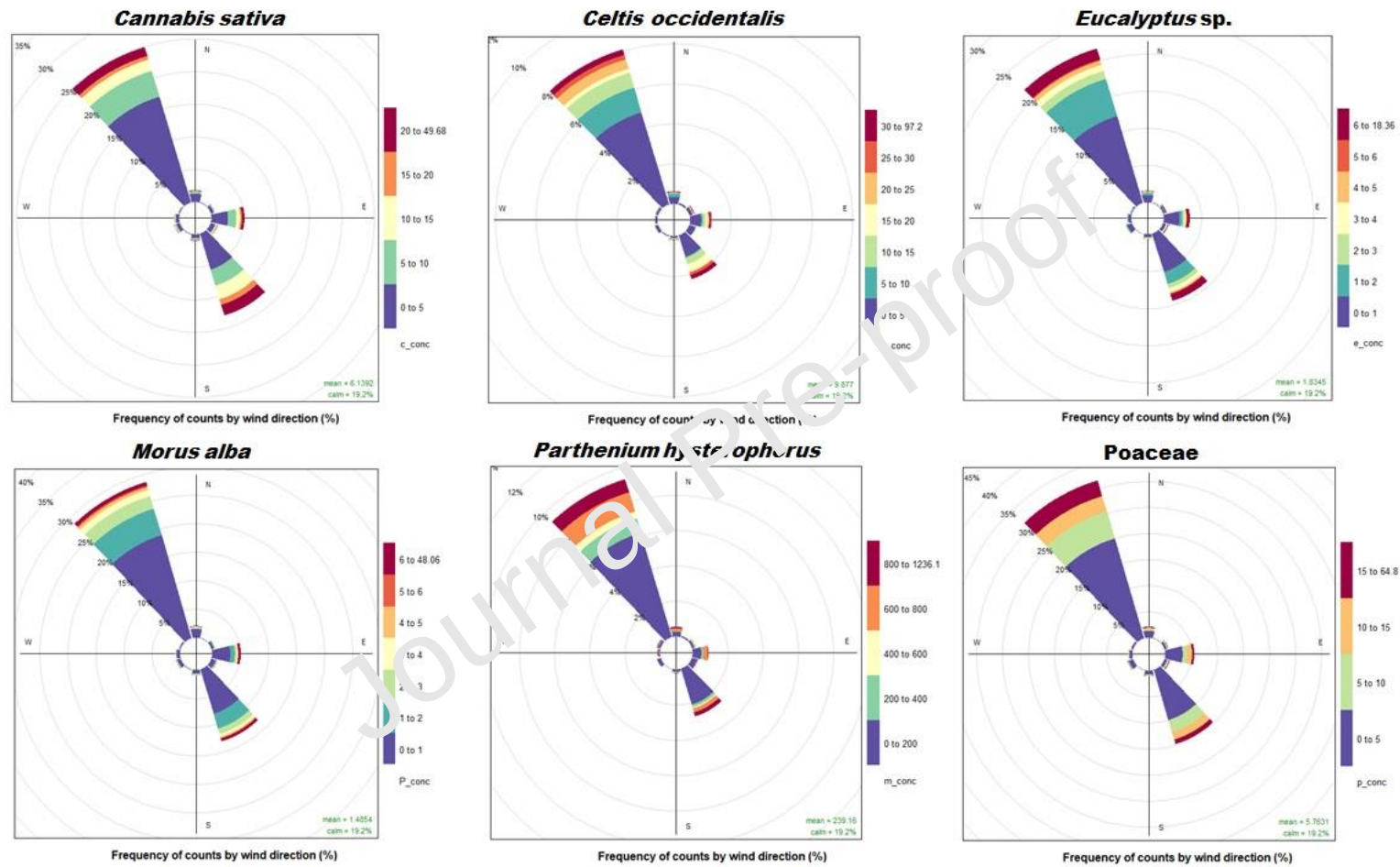
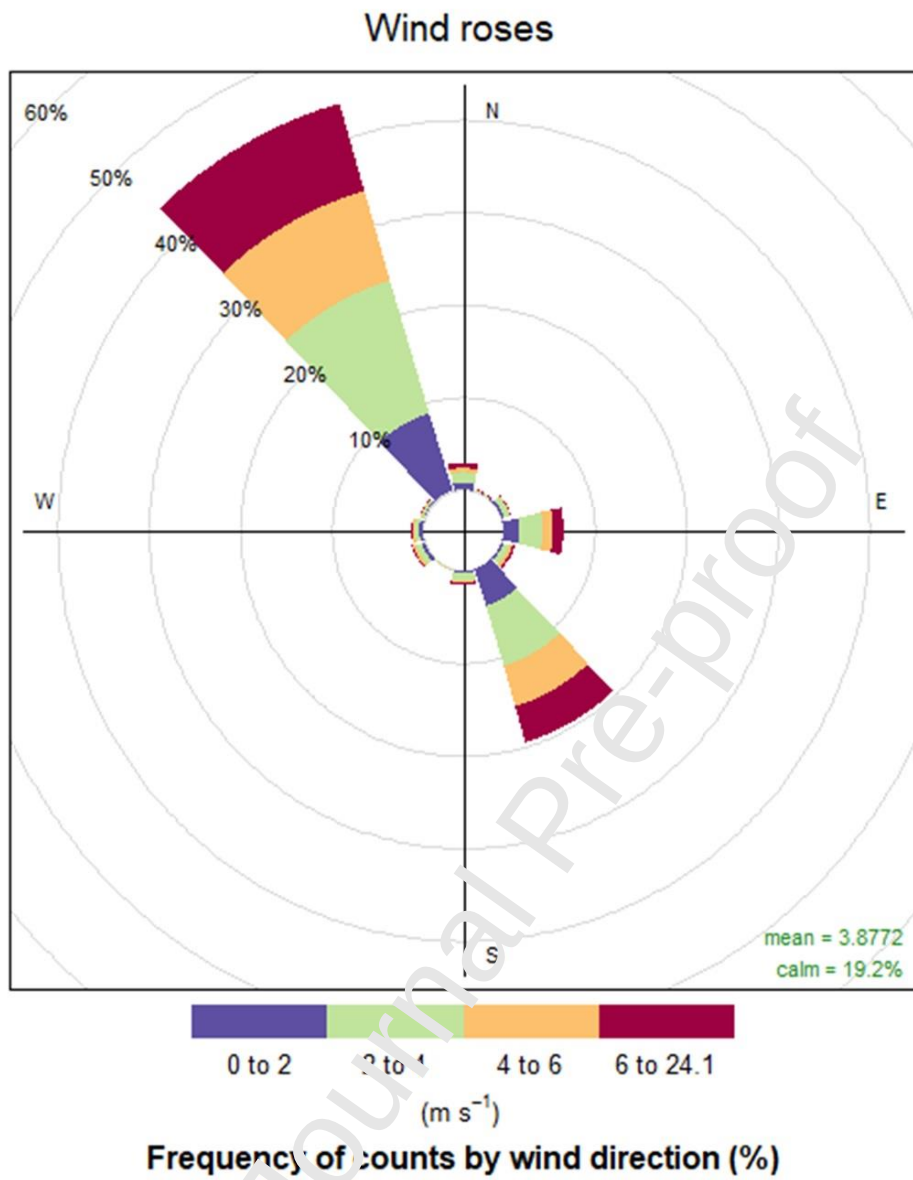


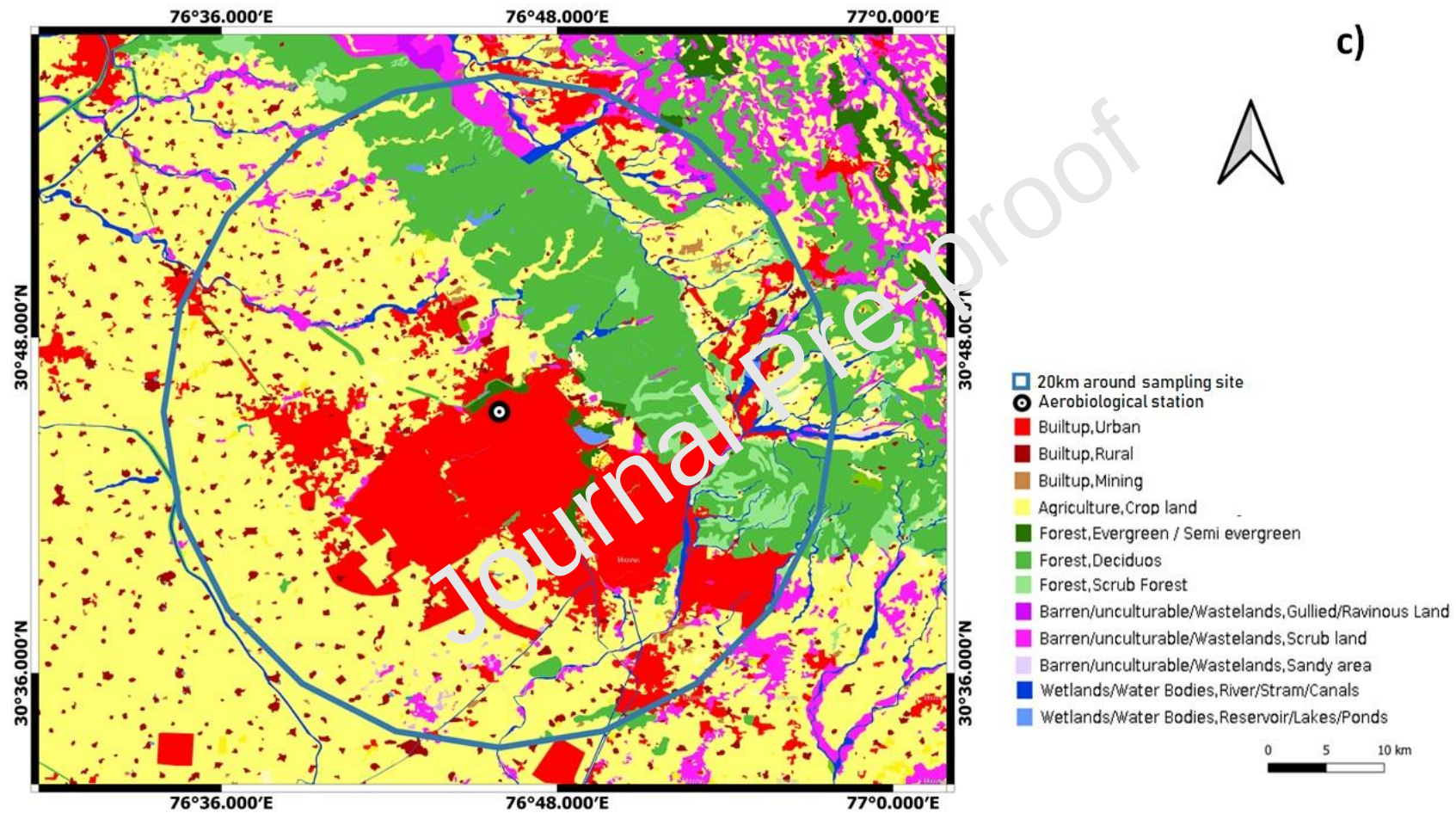
Figure 7a

Figure 7b

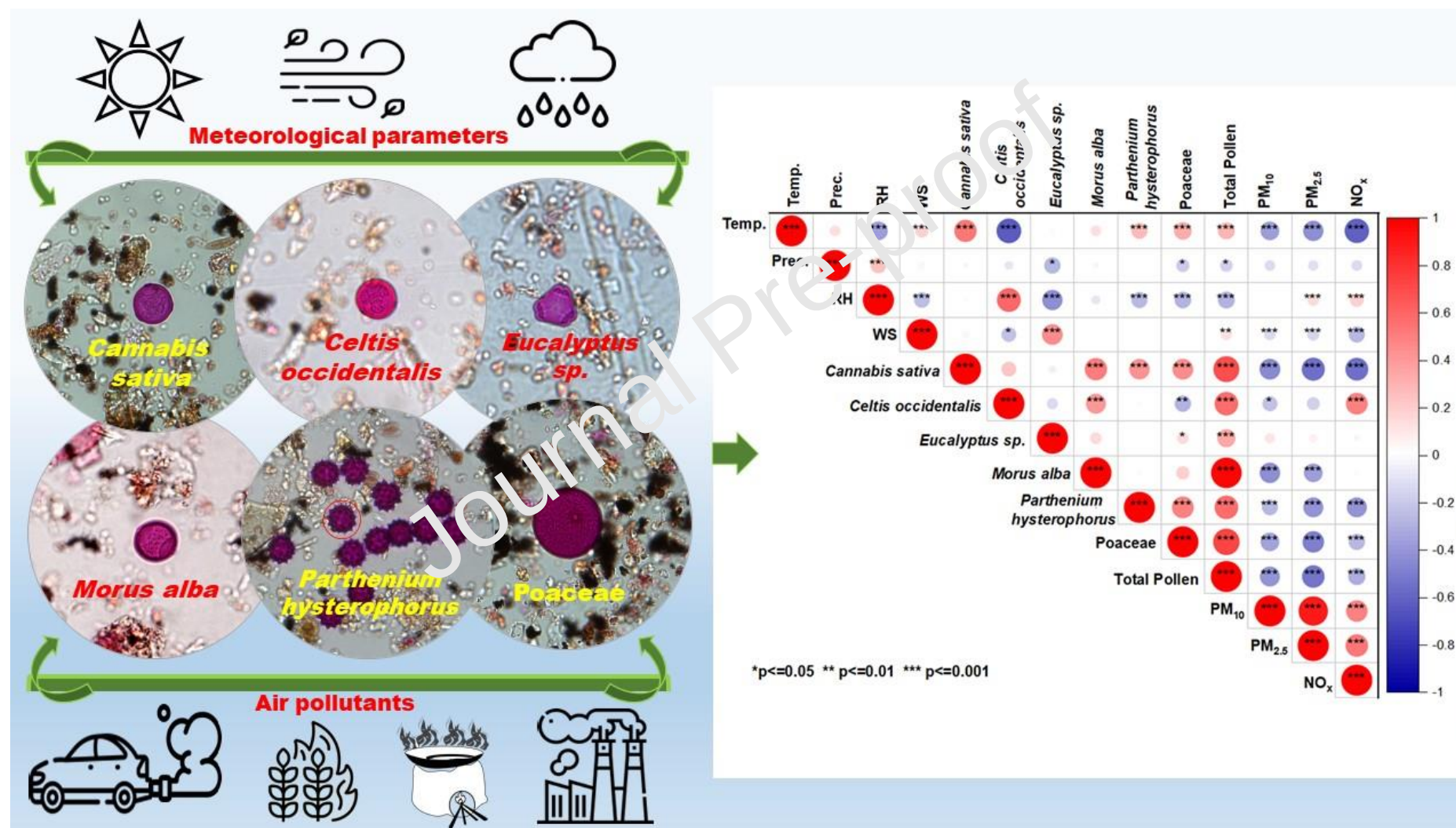


b)

Figure 7c



Graphical abstract



Highlights

- Explore the relationship between airborne pollen, meteorology and air pollutants.
- Temperature and wind significantly influence the pollen concentration.
- Spearman's correlation of Annual and Seasonal pollen integral (APIn and SPIn) for key pollen taxon were computed.
- Relative humidity and precipitation were negatively correlated with pollen data.
- PM₁₀, PM_{2.5} and NO_x showed no clear relationship with pollen concentration.