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Research article

Variations in airborne pollen and spores in urban Guangzhou and their relationships with meteorological variables

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ABSTRACT

Airborne pollen causes various types of allergies in humans, and the extent of allergic infection is related to the presence of different types of sporo–pollen and existing meteorological conditions in a certain area. Therefore, an aeropalynological study of 72 airborne samples with a hydrofluoric acid (HF) treatment was conducted in the Haizhu district of Guangzhou, China, in 2016, to identify the temporal variations in airborne sporo–pollen and the relationship between airborne sporo–pollen concentrations and different meteorological variables in Guangzhou, China. Forty-five types of airborne pollen, seven types of airborne spores, and some undetermined sporo–pollen taxa were identified with two separate plant habitats occurring during this period (from January to December 2016): arboreal pollen (tree-based) and non-arboreal pollen (herb, shrub, aquatic, liane, etc.). Furthermore, the daily records of four key meteorological variables (temperature, precipitation, relative humidity, and wind speed) were acquired to distinguish the pollen seasons and correlated with Spearman's rho test to establish a pollen-weather data book with the seasonal variations. The two leading seasons were identified based on pollen abundance: spring and autumn. Among them, the primary dominant sporo–pollen families during the spring season were Poaceae, Pinaceae, Euphorbiaceae, Moraceae, *Microlepia* sp., and Polypodiaceae. Conversely, *Artemisia* sp., Asteraceae, Cyperaceae, Poaceae, *Alnus* sp., *Corylus* sp., Myrtaceae, and Rosaceae were the dominant pollen species during autumn. However, few pollen grains were identified in January, May–July, and December. The statistical analysis revealed that temperature had both positive and negative correlations with sporo–pollen concentrations. However, precipitation and relative humidity had a strong impact on the sporo–pollen dispersion and exhibited a negative correlation with the sporo–pollen concentrations. The wind speed had a positive but strong correlation with the sporo–pollen concentration during the study period. Some inconsistent results were found due to environmental variations, vegetation type, and climate change around the study area. This study will facilitate the identification of pollen seasons to prevent the occurrence of pollen-related allergies in the Guangzhou city area.

1. Introduction

Currently, many people suffer from myocardial infarction and cardiovascular diseases, which cause disruptions in the lung's immune system due to viral attacks and asthma, among others. Various types of allergic diseases, including rhino conjunctivitis, asthma, and allergic rhinitis, are caused by the inhalation of airborne pollen and atmospheric pollutants (Weichenthal et al., 2016; Gilles et al., 2020; D'Amato et al., 2020). The World Allergy Organization (WAO) estimated that over the past 15 years, approximately 39.8% of inhabitants in Oceania suffered from pollen allergies, which is the highest in the world. In contrast to Oceania, people in Northern and Eastern Europe suffer the least (approximately 12.3%) from pollen allergies (World Allergy Organization, 2016). In addition to the regional prevalence of pollen allergies, approximately 22.1% of the world population is affected by hay fever, increasing by 0.3% each year (World Allergy Organization, 2016).

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Pollens are fine to coarse (size range 0.01 mm–0.1 mm) powder-like plant reproductive substances, whose specific grains contain male generative microgametophytes of seed plants, and their outer layer is extremely resistant to chemical and physical attack (Bennett and Willis). After flowers blossom, pollen is dispersed into the surroundings and are transported long distances in the environment, including topsoil, ambient air, and water. The pollen content in the air is directly dependent on the plant species, vegetation, and weather conditions of a particular area (Maya-Manzano et al., 2017). Weather factors, such as temperature, precipitation, relative humidity, and wind speed, play crucial roles in increasing and decreasing the airborne pollen percentage in the atmosphere (Cabezudo et al., 1997; Todea et al., 2013; Stickleya et al., 2017; Khan et al., 2019). Changes in the weather also affect the atmospheric transport, all of which are key factors in pollen dispersal (Ediger et al., 1997; Luo et al., 2015). In addition, the atmospheric transport of pollen occurs more frequently during the flowering season because during these periods, the weather is hot and humid, the wind is strong, many flowers bloom, and a high concentration of pollen is produced (Xu et al., 2012; Medek et al., 2016).

Most of the previous studies in China have established that sporo–pollen concentrations change from season to season, and a high concentration of pollen has primarily been found in two seasons: spring (February–April) and autumn (August–November) (Detweiler and Hurst, 1930; Pasha and Hossain, 2009; Xu et al., 2012). A study conducted by Xu et al. (2012) on airborne pollen in Chong Wen District, Beijing, from March 21, 2006, to March 20, 2007, identified a total of 1,670 pollen grains from 37 taxa. The study detected trees and shrub pollen, including *Cupressus* sp.*, Pinus* sp.*, Populus* sp.*, Betula* sp.*, Corylus* sp.*, Salix* sp.*, Juglans* sp.*, Fraxinus* sp.*,* Anacardiaceae, and *Livistona* sp. in March, and herb pollen, including *Artemisia* sp.*,* Amaranthaceae*,* Gramineae*, Humulus* sp., and *Labiatae* sp. in September. Few pollen grains were observed between December and January. Another air pollen research study was performed by Badya and Pasha (1991) in the Chittagong University Campus, Chittagong (Bangladesh), who identified a total of 9, 225 pollen/cm^2 and classified them into 36 pollen types belonging to 26 families from March 1988 to February 1990. Considerable amounts of pollen have been identified in March, October, and November (Badya and Pasha, 1991). Zhang and Zheng (2005) collected airborne pollen data from the campus of Sun Yat-sen University (SYSU) based on Cour's air pollen collector (Cour, 1974; Tomas et al., 1997; Giesecke et al., 2010). In this study, a rotating rod-type air-volume method was employed for sampling to reveal the type, quantity, and distribution of airborne fungal spores in Guangzhou city. However, this study chose only one observation site on the SYSU campus. Another airborne pollen research was conducted by Rahman et al. (2019), who correlated the airborne sporo–pollen data with the air pollution data of 2017 and identified 44 types of pollen and three types of spore taxa. Their study revealed that in the Guangzhou city area, spring and autumn were the primary airborne pollen seasons, and the tree types of pollen were frequently available in the area during 2017. The details of the study on airborne pollen and its characteristics in the entire city of Guangzhou remain poorly understood, and there have been few reports on sporo–pollen grains. The relationship between pollen and meteorological values of other year (e.g., 2016) is not yet fully understood.

Therefore, the key objectives of this study were to provide an aeropalynological survey in the center of Guangzhou city and identify the present types and abundance of airborne pollen in 2016, in addition to identifying the monthly variations in airborne pollen and their relationships with meteorological variables (temperature, humidity, precipitation, and wind speed) in the area.

2. Study area

The study area was Guangzhou, the capital city of Guangdong, Southern China, and a megacity along the Pearl River (Yang et al., 2014). The central area of Guangzhou comprises a greenery hilly basin, while the southern area is comprised of coastal alluvial plains forming part of the Pearl River Delta (Figure 1) (Xu et al., 2016; Chen and Yu 2016). The city of Guangzhou covers an area of approximately 7,434.4 km^2 between the latitudes of 22°26′N and 23°56′N and longitudes of 112°57′E and 114°3′E. The city is in a humid subtropical climate zone primarily controlled by the Asian monsoons. The urban area of Guangzhou is warm, and it experiences a subtropical maritime monsoon climate (Guan and Chen, 2003; Zhao et al., 2009). The coldest months in Guangzhou are predominantly December and January, while the hottest months are June and July. The monthly average temperature ranges from 13.9 °C in January to 28.9 °C in July, while the annual mean temperature is 22.6 °C. The average relative humidity is 68%–77%, and the annual rainfall in the urban areas is over 1,600 mm (Xiong et al., 2012; Xu et al., 2016; Chen and Yu 2016; Zhu et al., 2016). However, recent studies have reported that the mean daily temperature of the central area of Guangzhou is increasing due to rapid urbanization (Fan et al., 2006; Feng and Pan, 2011; Xiong et al., 2012). The average maximum and minimum temperatures are consistent; conversely, the average temperature fluctuates and is increasing gradually. The precipitation rate in this area has been slightly increasing with an annual average precipitation of 1,690 mm (Yu et al., 2016).

Approximately 49.17% of the city's total area is forest land, grassland, water areas, and wetlands (Guan and Chen, 2003; Xu et al., 2016; Chen and Yu 2016). The predominant vegetation types in Guangzhou are evergreen seasonal rain forests, evergreen broad-leaved forests, coniferous broad-leaved mixed forests, and evergreen shrubs (Fuwu and Faguo, 2007; Hu et al., 2009). The original vegetation was destroyed due to urbanization in the central city of Guangzhou. At present, most vegetation types are artificial, and these types of vegetation have relatively low diversity values (Figure 1 and Table 1) (Guan and Chen, 2003; Liu et al., 2013). The primary dominant plant species are discussed in Table 2 (Dong and Yu, 2003; Fuwu and Faguo, 2007; Rahman et al., 2019).

3. Material and methods

3.1. Airborne pollen and spore sampling

In this study, 72 samples (Supplementary data 1) were collected from Haizhu, a central district of Guangzhou (January 2 through December 30, 2016). Samples were collected using a large flow volumetric pollen collector (KB-1000 TSP, Qingdao Jin Shida Electronic Technology Co. Ltd., China) which uses the high-precision sensors for flow monitoring and it has high sampling accuracy and good flow stability. It also can automatically record the accumulated flow and accumulated time during the sampling process. A standard volume of air is estimated from the air pressure and temperature, enabling the calculation of the volume concentration of pollen and spores (Luo et al., 2015; Kumar et al., 2019; Rahman et al., 2019, 2020; Bishan et al., 2020). The instrument was placed above 60 m from ground level on the roof of building No. 2 at the South China Sea Institute of Oceanology (SCSIO), Chinese Academy of Sciences. Samples were collected every five days (six samples/month) at an instantaneous airflow rate of 1.050 m^3/min.

After collecting the airborne samples, they were analyzed at the Key Laboratory of Ocean and Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences (CAS). Briefly, the glass fiber membranes were dissolved in 15–20 mL of 37% HF and a *Lycopodium* spore tablet with a known concentration of 27,637 ± 563 spores/tablet was added. Subsequently, the digested mass was washed three times with distilled water. The solution was centrifuged at regular intervals for approximately 10 min at 1,800 rpm to allow the residues to settle. The same procedure was repeated with 10–15 mL of 10% HCl to remove the organic matter. Finally, the solution was passed through a 7 μm nylon filter to remove impurities smaller than 7 μm with sonication for 5 min (CNC ultrasonic cleaner, Brand Shu Mei, Kunshan Ultrasonic Instrument Co., Ltd., Shanghai, China). The material collected on the filter represents a clean and concentrated sporo–pollen residue.

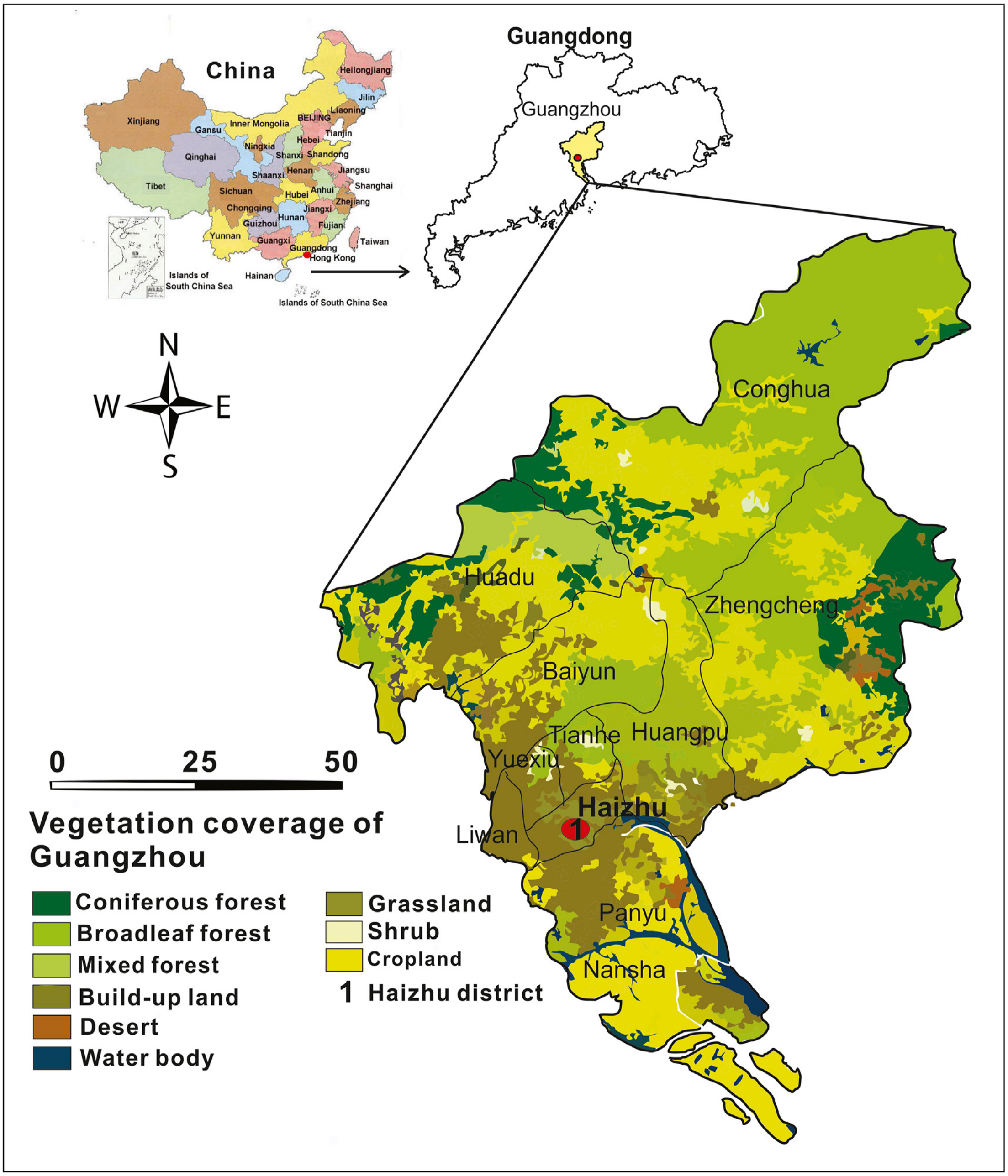

Figure 1. Vegetation coverage map of Guangzhou, China (modified from Zhu et al., 2016; Rahman et al., 2019).

3.2. Pollen and spore extraction and identification

The pollen and spores were counted under 400× magnification, and the identification was performed using a 1,000 × oil immersion lens (Nikon ECLIPSE E100, China) (Luo et al., 2015; Kumar et al., 2019; Rahman et al., 2019, 2020). The primary references for identifying the pollen grains were “An Illustrated Handbook of Quaternary Pollen and Spore in China” (Tang et al., 2016), “Color Atlas of Airborne Pollens and Plants in China” (Qiao, 2005), “Airborne and Allergen Pollen Grains in China” (Ye et al., 1988), and “Pollen Flora of China” (Wang et al., 1995).

The standard count for a statistically significant number of sporo–pollen for each sample is more than 200 (Luo et al., 2015; Kumar et al., 2019; Rahman et al., 2019, 2020), and if the sample contains a sporo–pollen number less than 200, then 1,000 *Lycopodium* spores are counted to make it statistically significant (Wang et al., 1995; Luo et al., 2015; Liu et al., 2017; Kumar et al., 2019). The number of *Lycopodium* spores counted in a sample was used as a reference to normalize the concentration values (Zhang et al., 2002a, 2002b; Luo et al., 2015; Kumar et al., 2019; Rahman et al., 2019, 2020) per sample. Interestingly, all 72 slides from the 72 samples of the study contained sufficient numbers of sporo–pollen grains (more than 200 sporo–pollen grains per sample) to provide a statistically significant sample. The pollen percentages were calculated based on the total sporo–pollen sum, and the sporo–pollen concentrations (R) in grains/m^3 of the airborne samples were calculated using the following equation:

$$R = \left(\frac{27637}{\textit{Lycopodium}\ \text{spore counted for each slide}}\right) \times \left(\frac{\text{sporo–pollen counted for each slide}}{\text{volume of each sample}}\right) \tag{1}$$

The pollen percentage and concentration diagram were constructed

Table 1. Total plants and their community in the urban area of Guangzhou and its neighboring area (Guan and Chen, 2003).

Area	Location	Community*	Tree Layer			Shrub Layer		
			Area/m^2	Species	Total	Area/m^2	Species	Total
Guangzhou	Xiaogang Park	1	1000	4	70	250	7	51
	Liuhuahu Park	2	1000	1	17	250	1	1
	Martyr Tombs	3	1000	2	137	250	13	36
	Huanghuagang Park	4	1000	8	101	250	24	443
	Yuexiu Park	5	1000	15	157	250	35	680
	Yuexiu Park	6	1000	16	143	250	17	644
	Yuexiu Park	7	1000	15	92	250	25	1280
Zhaoqing	Ding hu mountain	8	1000	61	1310	250	68	1041
Fengkai	Heishiding	9	1000	50	346	250		
Ruyuan	Jigongkeng	10	1000	48	206	250		

* [(1) *Cinnamomum camphora* + *Pinus elliottii* forest; (2) *Ficus microcarpa* forest; (3) *Pinus massoniana* forest; (4) *Eucalyptus tereticornis* forest; (5) *Pinus massoniana* mixed needle-broad leaves forest; (6) *Acacia confusa* mixed broad leaves forest; (7) *Cinnamomum burmannfi* forest; (8) *Castanopsis chinensis* + *Schima superba* + *Cryptocarya Chineniss* forest; (9) Mountain evergreen broad-leaved forest; (10) Evergreen broad-leaved forest].

Table 2. Primary dominant plant species around the study area (Dong and Yu, 2003; Fuwu and Faguo, 2007; Rahman et al., 2019).

Pollen name	Plant type
Araliaceae	*Schefflera heptaphylla*
Aquifoliaceae	*Ilex asprella*
Asparagaceae	*Liriope spicata*
Asphodelaceae	*Dianella Ensifolia*
Blechnaceae	*Blechnum Orientale*
Cyperaceae	*Hypolytrum Nemorum*
Clusiaceae	*Garcinia Oblongifolia*
Chloranthaceae	*Sarcandra glabra*
Elaeocarpaceae	*Elaeocarpus sylvestris*
Euphorbiaceae	*Breynia fruticosa*
Fabaceae	*Archidendron clypearia, Acacia confusa*
Fagaceae	*Castanopsis chinensis*
Leiothrichidae	*Phyllanthus cochinchinensis*
Lauraceae	*Litsea Rotundifolia, Cinnamomum camphora, Cinnamomum burmannii, Cryptocarya chinensis*
Malvaceae	*Sterculia lanceolata*
Myrtaceae	*Eucalyptus tereticornis*
Moraceae	*Ficus microcarpa, Ficus variolosa*
Phyllanthaceae	*Antidesma Bunius, Bridelia Insulana*
Primulaceae	*Ardisia quinquegona, Ardisia crenata*
Poaceae	*Lophatherum gracile*
Pinaceae	*Pinus massoniana, Pinus elliottii,*
Rutaceae	*Acronychia pedunculat,*
Rubiaceae	*Psychotria asiatica, Psychotria Serpens, Morinda Parvifolia, Paederia Scandens, Mussaenda Pubescens,*
Smilacaceae	*Heterosmilax Japonica*
Theaceae	*Schima superba*

using Tilia software (version 2.0.41) (Grimm, 2015) and modified in CorelDRAW (Version 12.0).

3.3. Meteorological data

Daily meteorological data were collected from Guangzhou Luhu Weather Station (http://data.cma.cn/) which is approximately 8 km far away from the study area. The total area of Guangzhou city is 7434.40 square km (until 2019), thus 8 km is a very short distance compared the huge Guangzhou area. Taking the temperature as example, there are 158 weather stations in Guangzhou city, the Luhu station is the nearest station to the sample site (Supplementary Figure 1). Thus this temperature data has well representatively (Zhang and Zheng, 2006; Guangzhou Meteorological Bureau, 2016; Ke, 2018), the choice of Luhu weather station is suitable to interpret the relationships between airborne pollen and the meteorological variables in the sample site.

3.4. Data analysis and processing

The inter-relationship between pollen concentration and weather factors was evaluated with Spearman's rho test using SPSS Statistics 22 (SPSS, USA) software. Spearman's rho test is a widely used non-parametric test to study a population that assumes ranked-order values of the variables. In addition, all the rank orders will be equal if there is no trend, and all the observations are independent (Khan et al., 2019; Rahman et al., 2019).

4. Results and discussion

4.1. Biodiversity of airborne pollen and spores

Seventy-two airborne samples were collected between January and December. Based on the pollen and spore analyses, 33 types of tree pollen taxa, 12 types of herb pollen taxa, and 7 types of spore taxa were identified. By observing all the data, we found that tree pollen was the predominant airborne pollen because tree-type vegetation is dominant in the area near the sampling site (Dong and Yu, 2003; Rahman et al., 2019). The primary tree pollen types identified were Apocynaceae, Aquifoliaceae, Araliaceae, *Betula* sp., *Castanea* sp., *Castanopsis* sp., *Carya* sp., *Corylus* sp., Euphorbiaceae, Fabaceae, Hamamelidaceae, *Juglans* sp., *Lithocarpus* sp., Magnoliaceae, Moraceae, *Myrica* sp., Myrtaceae, Meliaceae, Mimosaceae, Oleaceae, *Pinus* sp., Proteaceae, *Quercus* sp., *Rhizophora* sp., Rosaceae, Rubiaceae, Sapindaceae, *Sonneratia* sp., *Symplocos* sp., *Tsuga* sp., and Verbenaceae. In contrast, Amaranthaceae, Asteraceae, *Artemisia* sp., Caryophyllaceae, Cyperaceae, *Dacrydium* sp., Gentianaceae, *Keteleeria* sp., Liliaceae, Poaceae, *Podocarpus* sp., and Typhaceae were found to be the herb-based pollen. Furthermore, *Cibotiumbarometz*, *Cyathea* sp., *Lygodium* sp., *Microlepia* sp., Polypodiaceae, *Pteris* sp., and *Selaginella* sp. spores were identified in most of the months during the study period (Table 3). Most of the pollen–spores originated from nearby vegetation coverage (Dong and Yu, 2003; Fuwu and Faguo, 2007). However, the study also identified several foreign sporo–pollens that may have been transported through the air from long distances outside of Guangzhou. These include *Alnus* sp., Apocynaceae, *Betula* sp., Hamamelidaceae, *Juglans* sp., Meliaceae, Mimosaceae, Oleaceae, Verbenaceae, *Dacrydium* sp., Gentianaceae, *Keteleeria* sp., Liliaceae, *Pteris* sp., and *Selaginella* sp. Some undetermined sporo–pollens were also identified during the study period, although the amount was negligible (Table 3).

Table 3. Annual total pollen-spore amount and their individual percentage in the Guangzhou city.

Plant species	Total	%
Pinus sp.	3082	17.1
Moraceae	1476	8.18
Euphorbiaceae	784	4.26
Myrtaceae	627	3.48
Rosaceae	429	2.38
Corylus sp.	164	0.91
Castanopsis sp.	122	0.68
Betula sp.	115	0.64
Alnus sp.	108	0.6
Oleaceae	84	0.47
Magnoliaceae	71	0.39
Juglans sp.	65	0.36
Acacia sp.	58	0.32
Myrica sp.	55	0.3
Aquifoliaceae	52	0.29
Sapindaceae	49	0.27
Apocynaceae	38	0.21
Carya sp.	23	0.13
Quercus sp.	21	0.12
Tsuga sp.	21	0.12
Araliaceae	19	0.11
Rubiaceae	19	0.11
Lithocarpus sp.	17	0.09
Verbenaceae	17	0.09
Meliaceae	15	0.08
Fabaceae	14	0.08
Mimosaceae	13	0.07
Hamamelidaceae	11	0.06
Castanea sp.	10	0.06
Proteaceae	10	0.06
Rhizophora sp.	10	0.06
Sonneratia sp.	10	0.06
Symplocos sp.	5	0.03
Total Arboreal pollen	**7614**	**42.1**
Poaceae	3695	20.4
Cyperaceae	1047	5.8
Asteraceae	742	4.11
Artemisia sp.	477	2.64
Podocarpus sp.	178	0.99
Amaranthaceae	184	1.02
Liliaceae	104	0.58
Gentianaceae	50	0.28
Dacrydium sp.	34	0.19
Typhaceae	27	0.15
Caryophyllaceae	20	0.11
Keteleeria sp.	18	0.1
Total Non-arboreal pollen	**6576**	**36.4**
Polypodiaceae	1942	10.8
Microlepia sp.	1570	8.75
Lygodium sp.	104	0.58
Pteris sp.	98	0.54
Cyathea sp.	54	0.3
Cibotium barometz	50	0.28
Selaginella sp.	31	0.17
Total Spore	**3849**	**21.4**
Unidentified sporopollen	29	0.15

4.2. Sporo–pollen concentration analysis

The total annual sporo–pollen counts and percentages are presented in Table 3. Based on the plant habits, we classified the sporo–pollen into three groups: (i) arboreal (tree-based pollen), (ii) non-arboreal (herb-, shrub-, aquatic-, and liane-based pollen), and (iii) spores. Throughout the year, all types of sporo–pollen were found in the study area. The total number of pollen grains was 7,614 (42.1%) arboreal, 6,576 (36.4%) non-arboreal, 3,849 (21.4%) spore grains, and 29 (0.15%) unidentified sporo–pollen (Table 3). Arboreal pollen grains were dominant in the atmosphere of the Guangzhou city area (Tables 1, 2, and 3). In general, the frequency of arboreal pollen grains depends on the distribution and density of the local vegetation coverage and the rate of pollen production. Other studies have also concluded that Guangzhou city is primarily dominated by arboreal plants (Guan and Chen, 2003; Rahman et al., 2019). The most significant pollen producers of Guangzhou were found to be the following arboreal plants: *Pinus* sp. (17.1%), Moraceae (8.18%), Euphorbiaceae (4.26%), Myrtaceae (3.48%), and Rosaceae (2.38%). Poaceae (20.4%), Cyperaceae (5.8%), Asteraceae (4.11%), *Artemisia* sp. (2.64%), and Amaranthaceae (1.02%) were frequently identified as the non-arboreal plants in the study area. Furthermore, the weather conditions (humid subtropical climate) of Guangzhou are suitable for growing some ferns, algae, moss, and even fungi, which release spores into the air, often carried by the wind (Jim and Chen, 2008; Rahman et al., 2019). Consequently, approximately 21.4% of the samples were identified as spores in the study area, where Polypodiaceae (10.8%) and *Microlepia* sp. (8.75%) were found frequently in all months.

Monthly variations of the entire sporo–pollen integral and their percentages are presented in Table 4 and Figure 2. Notably, the spring and autumn seasons are the most dominant airborne sporo–pollen seasons in the Guangzhou city area because these two are the flowering seasons in this area (Jim and Chen, 2008; Rahman et al., 2019). Arboreal pollen grains were dominant in spring, and non-arboreal were the most abundant in autumn; spores were found frequently in all the seasons (Figure 2). For the arboreal pollen, a relatively high pollen concentration (>1500) was found in February–March, whereas September–October and December exhibited a moderate amount (500–1000) of pollen grains. Conversely, a relatively high amount of non-arboreal pollen grains was found in October–November; however, a moderate amount of non-arboreal pollen grains was found in the other months of the year. Furthermore, spores were frequently found throughout the year; however, a comparatively high amount was found in January, May–July, and August–September (Figure 2). The total monthly sporo–pollen concentrations and percentages are listed in Table 4. For arboreal pollen, March and February produced the highest pollen percentages (25.45% and 13.65%, respectively), and July and November presented the lowest pollen percentages (3.74% and 3.87%, respectively). A relatively high amount of non-arboreal pollen was found in November and October, 18.31% and 14.02%, respectively. In the other months, May (3.15%) and June (3.54%) had the lowest percentage of non-arboreal pollen. Relatively high amounts of spores were identified for May, July, and August, comprising 11.18%, 11.07%, and 9.91%, respectively. The lowest percentages of spores were identified in February (6.01%) and November (5.37%) (Figure 2). Among all the seasons, summer contained the lowest number of pollen grains (Table 4). Furthermore, the study also identified few unidentified sporo-pollen grains, of which February and September contained a higher amount (17.24%).

The vegetation type and pollination periods vary seasonally, with high variability in different locations due to geography and climate. Consequently, pollen dispersion also changes with the location (Jim and Chen, 2008; Rahman et al., 2019, 2020). During the yearly aeropalynological analysis in this study, two predominant pollen seasons were identified: autumn and spring. The concentration (grains/m^3) of the identified pollen taxa in the atmosphere of Guangzhou City is illustrated in Figure 3. The entire study period can be divided into two subdivisions, which are indicated in Figure 3 as (i) Zone A and (ii) Zone B. Zone A

Table 4. Monthly pollen counts with their percentage.

Taxa	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Acacia sp.	1	3	0	1	0	2	3	3	4	34	3	4
Alnus sp.	11	0	1	1	0	0	2	3	10	52	5	23
Apocynaceae	1	1	1	11	14	5	0	0	0	1	1	3
Aquifoliaceae	4	1	1	2	8	2	3	5	8	9	6	3
Araliaceae	1	1	1	4	5	0	0	1	0	1	4	1
Betula sp.	6	0	0	2	2	0	2	4	11	38	6	44
Castanea sp.	1	0	1	0	1	1	1	2	0	0	1	2
Castanopsis sp.	5	4	2	25	31	13	6	11	1	8	3	13
Carya sp.	1	1	0	1	16	0	2	0	0	0	0	2
Corylus sp.	6	2	0	0	3	3	2	33	57	34	14	10
Euphorbiaceae	75	83	301	65	135	8	5	19	20	29	23	21
Fabaceae	0	0	3	5	0	0	0	0	0	0	3	3
Hamamelidaceae	2	1	0	0	2	4	0	0	0	0	2	0
Juglans sp.	7	5	0	2	11	2	3	4	2	18	10	1
Lithocarpus sp.	0	0	3	2	9	0	1	0	0	1	1	0
Magnoliaceae	4	15	0	1	1	2	0	12	7	10	7	12
Moraceae	93	93	74	81	82	50	203	281	295	147	23	54
Myrica sp.	1	3	2	12	27	3	5	0	0	0	0	2
Myrtaceae	13	0	0	9	11	14	4	48	84	195	67	182
Meliaceae	1	2	1	8	2	1	0	0	0	0	0	0
Mimosaceae	0	0	0	0	10	1	2	0	0	0	0	0
Oleaceae	6	11	1	17	10	5	4	3	2	11	4	10
Pinus sp.	93	744	1528	274	101	212	22	18	18	18	13	41
Proteaceae	0	0	2	2	2	2	0	0	0	0	2	0
Quercus sp.	0	1	0	5	6	8	1	0	0	0	0	0
Rhizophora sp.	0	0	1	0	8	0	1	0	0	0	0	0
Rosaceae	41	51	9	5	6	0	7	44	69	28	87	82
Rubiaceae	1	1	1	1	1	0	2	2	0	2	3	8
Sapindaceae	5	13	1	0	0	0	0	4	2	7	2	15
Sonneratia sp.	0	1	1	1	2	0	0	1	0	0	2	2
Symplocos sp.	1	1	0	1	0	0	0	0	0	0	2	0
Tsuga sp.	3	1	1	4	0	1	3	1	1	2	1	4
Verbenaceae	2	1	3	3	3	1	1	0	0	0	0	3
Total arboreal	**385**	**1040**	**1939**	**545**	**509**	**340**	**285**	**499**	**591**	**645**	**295**	**545**
Monthly %	**5.05**	**13.65**	**25.45**	**7.15**	**6.68**	**4.46**	**3.74**	**6.55**	**7.76**	**8.47**	**3.87**	**7.15**
Amaranthaceae	50	23	20	3	13	3	0	19	10	16	10	17
Asteraceae	70	65	11	8	31	8	4	103	102	113	72	155
Artemisia sp.	47	31	57	19	2	2	4	38	32	211	20	14
Caryophyllaceae	1	4	1	0	6	2	1	0	0	2	1	2
Cyperaceae	43	43	8	15	3	0	68	403	290	74	81	19
Dacrydium sp.	1	1	1	0	8	5	6	3	1	1	0	7
Keteleeria sp.	0	0	0	6	7	0	4	0	0	0	1	0
Liliaceae	25	12	0	2	10	3	2	2	9	5	11	23
Poaceae	191	201	415	260	97	142	139	125	181	489	992	463
Podocarpus sp.	1	0	0	77	28	65	5	0	0	0	2	0
Typhaceae	1	3	0	1	11	0	3	0	0	0	5	3
Total non-arboreal	**429**	**380**	**513**	**390**	**205**	**230**	**233**	**693**	**625**	**911**	**1190**	**700**
Monthly %	**6.60**	**5.85**	**7.89**	**6.00**	**3.15**	**3.54**	**3.59**	**10.66**	**9.62**	**14.02**	**18.31**	**10.77**
Cibotium barometz	5	3	4	3	6	3	9	5	6	2	2	2
Cyathea sp.	4	3	11	10	4	2	3	4	3	4	3	3
Lygodium sp.	11	5	5	19	13	13	10	12	9	2	3	2
Microlepia sp.	101	101	114	127	170	124	233	136	179	108	77	100
Polypodiaceae	199	143	150	186	202	170	160	216	123	149	115	129
Pteris sp.	11	6	8	4	22	12	9	10	11	1	2	2
Selaginella sp.	3	4	4	3	6	0	2	1	2	2	1	3
Total spore	**335**	**268**	**296**	**353**	**434**	**324**	**429**	**384**	**333**	**268**	**208**	**244**
Monthly %	**8.64**	**6.91**	**7.64**	**9.11**	**11.19**	**8.36**	11.07	**9.91**	**8.59**	**6.91**	**5.37**	**6.29**
Unidentified sporopollen	**2**	**5**	**3**	**3**	**1**	**2**	**2**	**2**	**5**	**1**	**1**	**2**
Monthly %	**6.89**	**17.24**	10.34	**10.34**	**3.45**	**6.89**	**6.89**	**6.89**	**17.24**	**3.45**	**3.45**	**6.89**

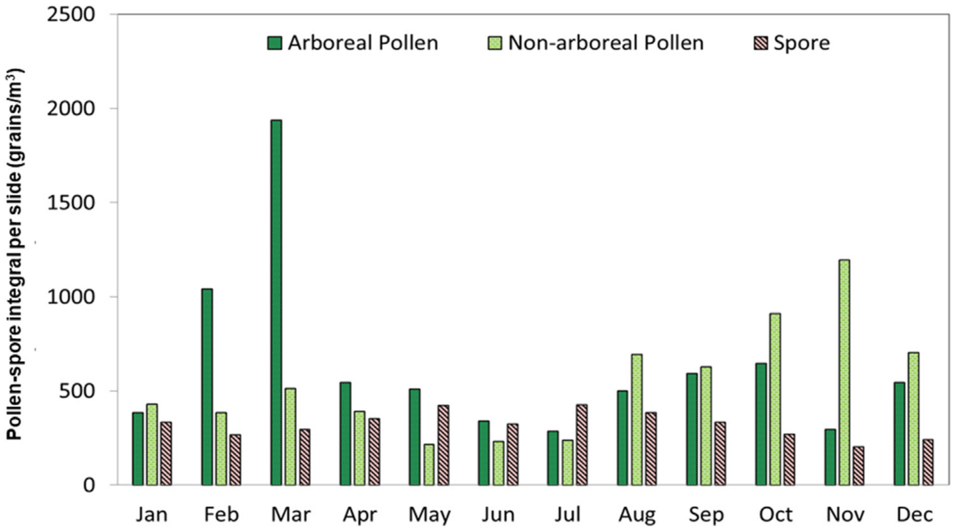

Figure 2. Monthly variations in arboreal pollen, non-arboreal pollen, and spore grains in the atmosphere in the Guangzhou city.

indicates the months from February to June (primarily spring season), and Zone B is from July to November (primarily autumn season). There were high pollen concentrations, with an abundance of *Castanopsis* sp., Euphorbiaceae, Moraceae, *Pinus* sp., Poaceae, Amaranthaceae, and *Podocarpus* sp., pollen grains in Zone A. Comparatively less sporo–pollen was identified in Zone B, with an abundance of *Corylus* sp., *Betula* sp., Moraceae, Myrtaceae, Rosaceae, *Artemisia* sp., Asteraceae, Cyperaceae, and Poaceae pollen grains. Among the seven types of spores, *Microlepia* sp. and Polypodiaceae were the dominant spore types, which are abundant throughout the year, particularly from May to August (Figure 3). Rahman et al. (2019) also identified that spring and autumn were the dominant airborne pollen seasons in this area. Additionally, two or three key seasons during the year for pollen spread have been recognized in other studies and countries; for example, in India, two dominant pollen seasons, namely, summer from March to May and the rainy season from August to September, were identified in West Bengal Province (Banik and Chanda, 1992; Boral et al., 2004). In addition, in Beijing China, two peak seasons of airborne pollen were observed during March and September (Xu et al., 2012). However, in southeastern Bangladesh, four airborne pollen seasons, from October to November, December to February, March to April, and June to September, were reported, with three peak times during March, October, and November (Badya and Pasha, 1991; Pasha and Hossain, 2009). Furthermore, one pollen season, from April to September, was identified in Norway (Ramfjord, 1991); three pollen seasons were determined in Italy: winter–pre-spring (January–March), spring–summer (April–June), and summer–autumn (August–September) (Negrini and Arobba, 1992); and four characteristic pollen cycles were identified in Poland: February–April, May, June–July, and September–October (Zawisza and Samolifiska, 1991; Xu et al., 2016).

The dominance of tree pollen in the urban area of Guangzhou is due to the presence of broadleaf evergreen forests in this region. Herb-type plants are also available in Guangzhou; however, their pollen count was comparatively lower, because herbaceous taxa are less likely to produce long-term transport events than arboreal taxa (Jim and Chen, 2008; Xu et al., 2012).

4.3. Correlation between airborne sporo–pollen and meteorological variables

The daily 24-h mean temperature (T), relative humidity (RH), precipitation mm (PP), and wind speed m/s (WS) for 2016 and 2017 in Haizhu were considered for this study (Supplementary Data 2a and

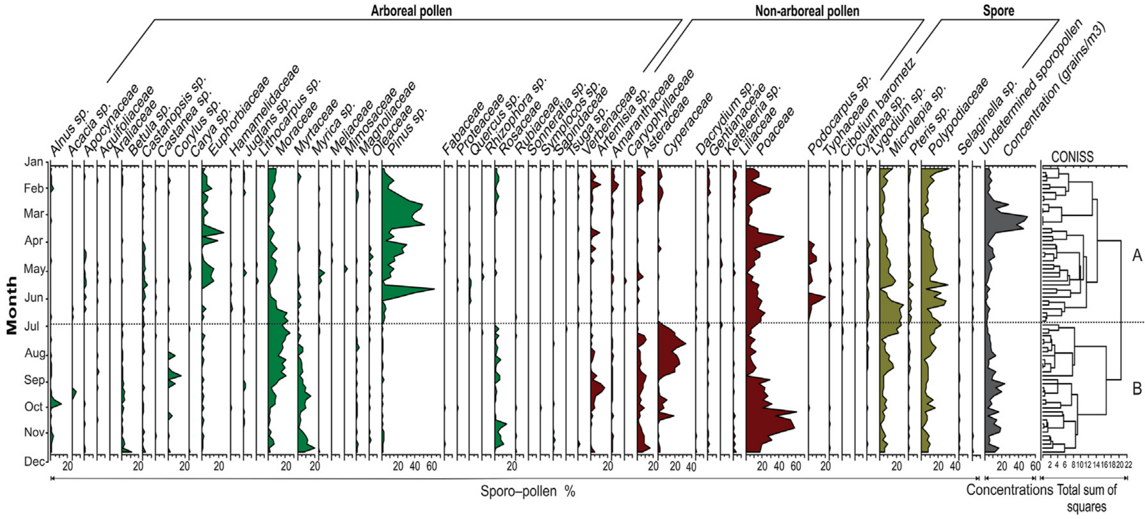

Figure 3. Sporo–pollen diagram for the 72 airborne sporo–pollen samples from Haizhu area: x-axis, sporo–pollen percentage (%) and concentration (grains/m^3); y-axis, months in 2016.

Table 5). The results of Spearman's rho test were calculated for all the sporo–pollen concentrations and meteorological variables, namely, temperature, precipitation, relative humidity, and wind speed (Supplementary Data 2b). In this study, temperature exhibited both positive and negative correlations with most of the sporo–pollen grains. Among them, significant positive correlations were identified with Euphorbiaceae, Moraceae, Mimosaceae, *Pinus* sp., Rosaceae, Sapindaceae, Amaranthaceae, Gentianaceae, and Poaceae. Conversely, significant negative correlations were identified with *Alnus* sp., Oleaceae, Asteraceae, and Cyperaceae (Supplementary Data 2). Generally, temperature has a positive correlation with sporo–pollen dispersion (Sousa et al., 2008). However, when the temperature rises in Guangzhou, the rainfall also increases. Both temperature and rainfall led to positive and negative correlations, respectively. Rahman et al. (2019) also reported some positive and negative correlations between sporo–pollen and temperature.

Most of the sporo-pollen demonstrated strong negative correlations with precipitation and relative humidity. Among them, Rosaceae, Asteraceae, Cyperaceae, and Polypodiaceae were significantly negatively correlated with precipitation. Similarly, *Alnus* sp., *Betula* sp., Euphorbiaceae, Proteaceae, *Quercus* sp., Rosaceae, Sapindaceae, Amaranthaceae, Asteraceae, *Artemisia* sp., Cyperaceae, Poaceae, *Podocarpus* sp., *Microlepia* sp., Polypodiaceae, and *Selaginella* sp. were significantly negatively correlated with relative humidity. Wind speed had an exceptionally strong positive correlation with sporo–pollen concentrations, including, *Acacia* sp., *Betula* sp., Euphorbiaceae, Magnoliaceae, Oleaceae, *Quercus* sp., Rosaceae, Sapindaceae, Amaranthaceae, Asteraceae, *Artemisia* sp., Cyperaceae, Poaceae, and Polypodiaceae (Supplementary Data 2).

Moreover, the monthly distribution of the correlation results is depicted in Figure 4, which indicates that airborne sporo–pollen concentrations are significantly correlated with the meteorological variables. In this study, spring (February to April) was observed to be the most dominant season, with the sporo–pollen concentration reaching its maximum content for the year of 60.67 grains/m^3 (March). During this period, the temperature and wind speed were comparatively high; consequently, the precipitation and relative humidity percentages were relatively low. Likewise, the same situation occurred in autumn (September to November), with the highest airborne pollen-spore concentration of 16.7 grains/m^3 found in October. Generally, the temperature remains tolerable; however, precipitation and relative humidity are moderate to high in May–August; this could have been the cause of the decrease in the pollen-spore concentration during those months to 5.69 grains/m^3, 3.77 grains/m^3, 3.11 grains/m^3, and 8.64 grains/m^3, respectively. Conversely, the temperature is low in January; therefore, the pollen-spore concentration also exhibited a low value of 6.27 grains/m^3 (Figure 4). This is because the pollen grains are highly hygrophilous cells, and they can hydrate under high relative humidity conditions, thus gaining mass and falling to the ground owing to gravitational forces (Stennett and Beggs, 2004; Xu et al., 2012). Both precipitation and relative humidity increase the mass of the pollen grains; therefore, the pollen concentration decreases under high precipitation and humid conditions (Stennett and Beggs, 2004; Xu et al., 2012). Moreover, precipitation and relative humidity not only reduce the pollen concentrations because they hydrate the pollen grains but they also agglutinate the pollen, causing it to precipitate from the atmosphere. Rainfall has a particularly obvious effect on reducing the concentration of pollen. A light rainfall does not require too much rainfall. Rainfall of 1–5 mm can wash away most of the pollen in the air. Therefore, the day after the rain, it will generally be more beneficial for people with pollen allergies to travel. If the rain is continuous, the pollen scattered in the air can be removed, which is not conducive to the spread of pollen; if the weather is clear and dry and the temperature is more suitable, then the number of pollen in the air will increase, which is conducive to the spread of pollen (Maya-Manzano et al., 2016; Recio et al., 2018; Rojo and Pérez-Badia, 2015; Tormo-Molina et al., 2010).

In the present study, a comparison between airborne sporo-pollen and meteorological data indicates that the concentration of airborne sporo-pollen has either a positive or negative correlation with temperature, depending on the type of sporopollen, but a negative correlation with precipitation and relative humidity. This fluctuation in the airborne sporo–pollen numbers may be related to environmental variations, vegetation type, and climate change (Molina et al., 2001; Latalowa et al., 2002; Stennett and Beggs, 2004; Ribeiro et al., 2006; Helfman et al., 2011; Xu and Zhang, 2011). However, the wind speed was positively correlated with the sporo–pollen concentration, which is consistent with the analysis results obtained by Rahman et al. (2019). Weather factors, including temperature, precipitation, wind speed, and relative humidity, are critical factors in controlling the airborne sporo–pollen concentrations in the atmosphere (Molina et al., 2001; Latalowa et al., 2002; Stennett and Beggs, 2004; Ribeiro et al., 2006; Helfman et al., 2011; Xu and Zhang, 2011).

5. Conclusion

An aeropalynological study demonstrating the temporal variations of 45 types of pollen and 7 types of spores was performed. Two specific pollen seasons were detected: from February to April (spring season) and from August to November (autumn season). The predominant pollen producers were tree-based plants, with some herb-based plants identified in the area. Spores were present in almost every season at high concentrations. The highest sporo–pollen count was recorded in the spring season, and the lowest was recorded in the summer season. The statistical analysis indicated that sporo-pollen was either positively or negatively

Table 5. Monthly average meteorological parameters (2016 and 2017).

Month	Temperature (°C)	Precipitation (mm)	Relative Humidity (%)	Wind Speed (m/s)	Temperature (°C)	Precipitation (mm)	Relative Humidity (%)	Wind Speed (m/s)
	2016				2017			
Jan	13.8	43.7	71.3	1.49	15.9	0.7125	80.875	1.85
Feb	14.2	62.2	77.5	1.51	16.15	0.4625	75.125	2.4375
Mar	16.5	87.9	82.1	1.78	20.225	9.4	87	1.975
Apr	20.3	187.7	83.9	2.24	23.5125	3.5125	83.25	1.9875
May	24.7	294.5	84.84	1.98	25.4375	12.9125	85.375	2.1425
Jun	26.9	261.9	84.52	1.69	28.0375	20.8	84.5	2.5
Jul	27.8	233.6	82.48	1.29	28.21	5.78	84.1	2.09
Aug	28.1	211.7	82.8	1.39	29.05	11.3	81.625	2.55
Sep	26.68	174.4	78.3	1.31	27.975	21.45	84.875	1.5875
Oct	25.79	72.1	71.9	1.3	25.13	1.27	76.7	2.48
Nov	18.81	47.4	65.5	1.3	19.59	0.09	78.8	2.17
Dec	15.98	19.9	65.1	1.21	13.9375	0	63.875	2.7

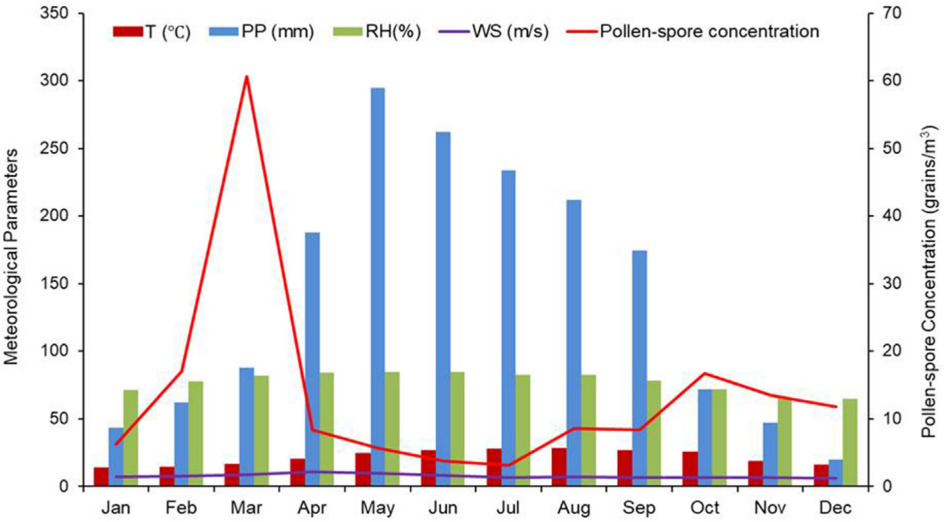

Figure 4. Relationship between the sporo–pollen concentrations and monthly weather parameters in 2016.

correlated with temperature, depending on the type. In contrast, strong significant negative correlations were established between the sporo–pollen concentrations and humidity and precipitation. However, the wind speed exhibited an overall positive correlation with the sporo–pollen concentrations in this area.

Moreover, the study revealed that the spring season (February–April) was the most dangerous season for individuals with allergies because of the frequent sporo-pollen abundance. The amount of sporo-pollen may decrease because of the insignificant flower production during the summer season. Guangzhou contains numerous types of crops, grasses, and pine trees. This may be the primary reason why Poaceae and Pinaceae are frequently found in this area. Furthermore, hot and humid weather is probably the key reason for the distribution of spores throughout the year. When compared with other studies, it was found that the fluctuation in the sporo–pollen concentrations depends primarily on the vegetation types and environmental changes. Thus, this study can facilitate the identification of pollen seasons to prevent the occurrence of pollen-related allergies in the Guangzhou city area.

Declarations

Author contribution statement

Ananna Rahman: Performed the experiments; Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md Hafijur Rahaman Khan: Analyzed and interpreted the data; Wrote the paper.

Chuanxiu Luo: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Zijie Yang, Jinzhao Ke & Weiming Jiang: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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