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Research article

Influence of meteorological and ambient air quality factors on *Artemisia* pollen counts in Urumqi, Northwest China

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ABSTRACT

The exposure of *Artemisia* pollen in the air to humans causes adverse allergenic effects on the respiratory system. However, the relationship between *Artemisia* pollen counts and meteorological and air quality factors in the arid and semiarid cities of northwest China has not attracted significant attention. Here, we observed the seasonal pollen counts of *Artemisia*, as well as the main meteorological variables (temperature/T, relative humidity/RH, and wind speed/WS, and ambient air quality factors ($PM_{2.5}$, PM_{10}, and CO_2). This was conducted from May to September 2021 at three sampling sites in Urumqi, Xinjiang. The results showed that *Artemisia* pollen counts gradually increased from May (121 grains/1000 mm^2) to August (563 grains/1000 mm^2) and decreased till the end of the sampling period in September (247 grains/1000 mm^2). Pearson correlation analysis revealed a significant positive correlation between the variation in *Artemisia* pollen counts and $PM_{2.5}$ ($R = 0.545$, $P < 0.01$), the average temperature ($R = 0.424$, $P < 0.05$), and PM_{10} ($R = 0.466$, $P < 0.05$). Oppositely, a significant negative correlation was observed between the RH ($R = 0.503$, $P < 0.01$) and WS ($R = 0.653$, $P < 0.01$). Variation partitioning analysis showed that meteorological factors contributed the highest (44 %) to the variation in pollen counts. The study results provide basic information for future case studies on allergenic plant pollen in Urumqi and serve as a reference for the development of sustainable healthy cities in arid regions.

1. Introduction

The presence of high concentrations of *Artemisia* pollen in the air is a leading cause of allergenic diseases that threaten public health [1]. As a major herbaceous allergen source, *Artemisia* pollen is strongly associated with the incidence rate of allergenic rhinitis (AR) and asthma [2,3]. The number of allergic individuals in China has been recently reported [4]. The results of skin prick tests show that 11.3 % of respiratory allergy patients are susceptible to *Artemisia* pollen. This is 50 % higher in the northern region of China [1].

Artemisia species are perennial herbaceous plants frequently associated with a strong aroma. These invasive, widespread species are

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commonly found along urban and suburban roadsides, forest edges, or in the wilderness [2]. The pollen grains of *Artemisia* are approximately 19–25 μm in size and are spherical or nearly spherical [5]. Owing to its small grain size, high buoyancy, and long pollination period, *Artemisia* pollen can remain in the air for several months, causing allergenic reactions in humans [6]. In addition to local sources in the study area, potential sources of *Artemisia* have been identified in central and southern Inner Mongolia, southern Mongolia, and northwest China (the present study area) [7]. Pollen dispersal is directly influenced by meteorological parameters, such as air temperature (T), relative humidity (RH), precipitation, wind speed (WS), and wind direction (WD) [8,9].

According to a telephone survey conducted on the prevalence rate of AR in 11 cities in China, Urumqi had the highest rate (21.4 %) in 2004–2005. This rate increased to 37.9 % in 2008 [10,11]. Lv [11] and Jiapaer [12] conducted skin prick tests and observed that *Artemisia* pollen caused a higher positive rate of allergic reactions compared with other plant species in Urumqi. It was also linked to sex, ethnicity, and age. To date, little is known regarding the main reason for the changes in *Artemisia* pollen counts in the air, particularly the characteristics of seasonal variation and the relationship with ambient air quality factors.

Ecological studies have demonstrated that meteorological factors and air pollutants significantly impact the concentration of airborne pollen [13,14]. Meteorological conditions play roles in the dispersal of pollen grains in the atmosphere, which affects pollen concentration, dispersal patterns, and the duration that the pollen remains in the air [15]. Certain studies suggest a correlation between pollen concentration and air temperature, RH, WS, WD, and precipitation [16–18]. Air pollutants, such as $PM_{2.5}$ and PM_{10}, which are commonly used to assess air quality, can lead to respiratory and respiratory-related diseases [19]. Elevated CO_2 levels accelerate pollen release, increasing pollen production and leading to intense inflammation [14,20,21]. In arid oasis cities in northwest China where air pollution and high pollen levels are prevalent, the effects of ambient air quality factors (including $PM_{2.5}$, PM_{10}, and CO_2) on *Artemisia* pollen levels remain unclear.

The present study was aimed at determining (1) the seasonal variation of *Artemisia* pollen, and (2) its correlation with meteorological and air quality factors.

2. Materials and methods

2.1. Site information

The study was conducted in Urumqi (42°45″-44°08″ N, 86°37″-88°58″ E, above sea level (a.s.l.) 850–940 m), the capital city of the

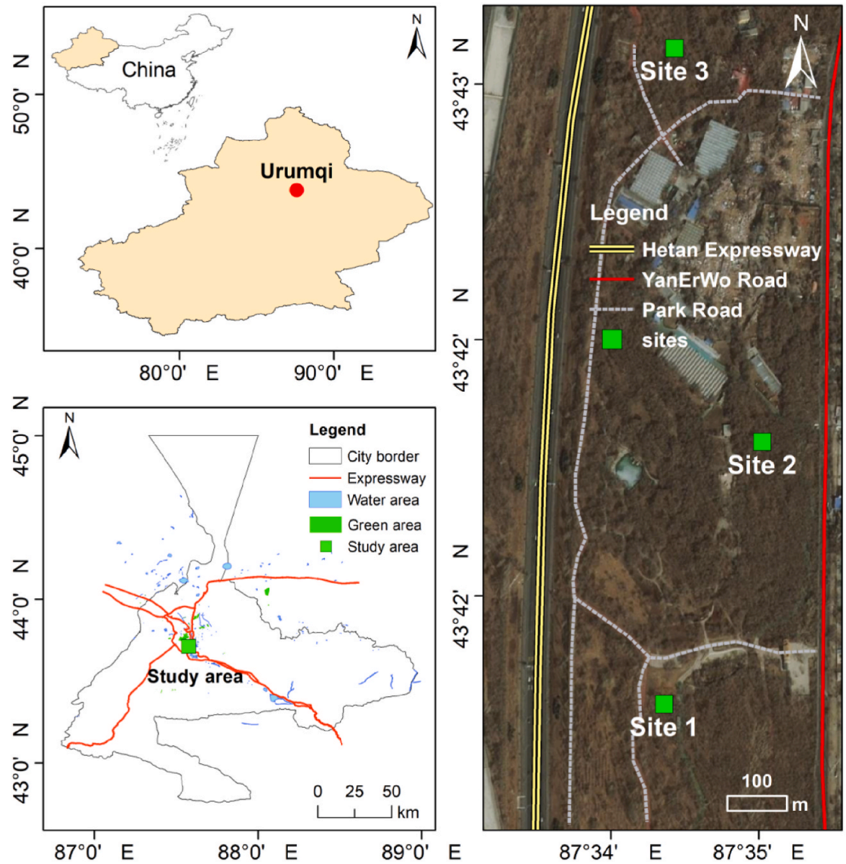

Fig. 1. Location of Yan-Er-Wo scenery and sampling sites.

Xinjiang Uyghur Autonomous Region in northwest China (Fig. 1). The population of this medium-sized oasis city is 3.55 million, covering an administrative area of 1.4 × 10^4 km^2 [22]. Urumqi is characterized by a typical arid climate, with a chill winter and hot-dried summer. The average annual air temperature and precipitation are 7 °C and 250 mm, respectively. Urumqi experiences four distinct seasons, and winter is the lengthiest season, spanning from November to April.

The study area was the Yan-Er-Wo forest landscape scenery, which is the solitary conserved natural green area in the southern suburbs of Urumqi, occupying an area of 350,000 m^2. The region features numerous indigenous plants and is home to many native tree species, including ancient elm (*Ulmus pumila*), which ranges from 150 to 300 years in age. In addition, the area is populated by species, such as *Populus alba* var. *pyramidalis, Fraxinus chinensis*, and *Salix alba*. Herbaceous plants, such as *Artemisia* sp, *Urtica dioica*, *Plantago major*, *Humulus lupulus*, *Salvia japonica*, and *Taraxacum mongolicum*, are also common, with *Artemisia* sp. being the most abundant. During sampling periods, we observed *Artemisia annua, Artemisia vulgaris*, *Artemisia sieversiana*, *Artemisia macrocephala*, etc. We selected three locations in Yan-Er-Wo where *Artemisia* pollen was collected and climate and air quality variables were measured.

2.2. Pollen sampling

The typical pollen season for herbaceous species in Urumqi spans from May to September. Thus, sampling was conducted over 5 months (May 15th to September 17th, 2021), until the *Artemisia* plants began to wilt. *Artemisia* pollen was collected using a Durham gravity sampler affixed to a glass slide with an adhesive object. The sampler was placed at the three selected locations in the Yan-Er-Wo area, ensuring a relatively even distribution of the target plant. Sampling was conducted between 8:00 a.m. to 6:00 p.m. (local time) at a height of 1.5 m, corresponding to the breathing level. This period coincided with when citizens typically participated in outdoor activities, and meteorological factors in Urumqi underwent significant changes in the morning and evening. The collected pollen samples were identified and counted in a laboratory using a Nikon Eclipse Ni-type microscope (Nikon Corporation, Tokyo, Japan) at 40× magnification. The daily amount of pollen for each site was calculated by summing the pollen counts during five time intervals, each 2 h replaced the glass slide (8:00 a.m. to 6:00 p.m.) and averaging them across all three sites. These values were used for further analysis. The total number of pollen grains in the cover glass area (22 × 22 mm) was counted under the microscope and expressed in grains per 1000 mm^2.

2.3. Meteorological and air quality data

During the sampling period, objective meteorological factors were recorded at 2 - h intervals using a handheld weather station (YGY-QX, YiGu, Wuhan, China). The data included the average air temperature/T_{Avg} (°C), relative air humidity/$RH_{Avg.}$ (%), and average WS/$WS_{Avg.}$ (m/s). These factors were calculated and used for subsequent analysis. The WD data were corrected based on information from the National Weather Service (Fig. 2). Air quality factors, such as $PM_{2.5}$, PM_{10}, and CO_2, were recorded at 2-h intervals using an air quality monitor (BR-HOL-1216, BLATN, Peking, China). The ArcGIS software (V. 10, Esri, Co.Ltd. California, CA, United States) was used to mapping the sketch up of sampling area.

Fig. 3 shows the meteorological and air quality factors. The predominant WD in Urumqi was from the north and northwest. The average temperature in the study area during the sampling period, from May to September, was 27.5 °C, with 25 % RH. The measured average WS was 2.57 m/s.

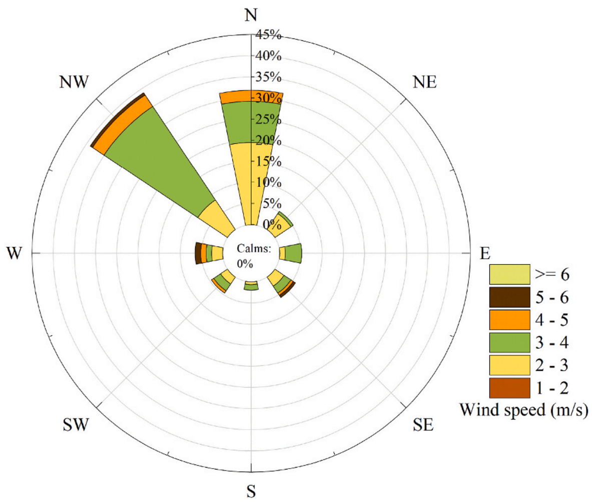

Fig. 2. Wind direction frequency of Urumqi from May to September.

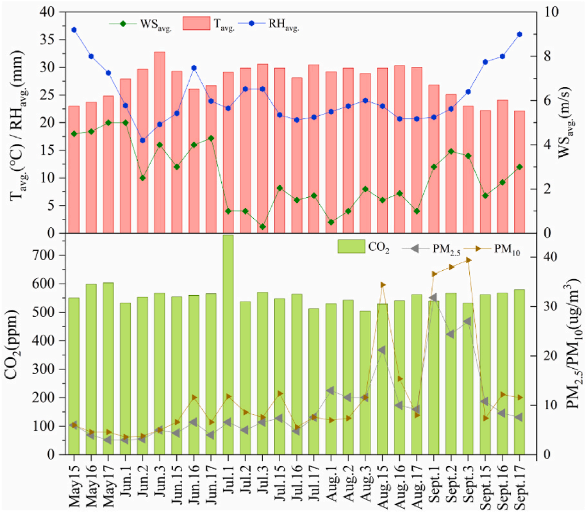

Fig. 3. Meteorological and environmental conditions of the Yan-Er-Wo Scenic Spot during the study period.

2.4. Statistical analysis

Pearson correlation analysis was employed to analyze the relationship between *Artemisia* pollen counts and meteorological and air quality factors. VPA was employed to determine the proportion of variation in the pollen counts explained by the meteorological and environmental factors provided. The specified factors were subjected to ranking analysis while constraining non-specified factors to calculate the correlation between the influencing factors and pollen counts.

To elucidate the relationship between air quality and meteorological factors and pollen concentration, variation partitioning analysis (VPA) was performed using the "vegan" package [23] of the R software version 4.1.2 [24]. Statistical analysis was performed using SPSS AU [25], Origin 2022 (Origin Lab, Northampton, USA).

3. Results

3.1. Pollen counts

Fig. 4 shows the seasonal fluctuation in *Artemisia* pollen counts. The pollen counts varied over the months, increasing from an average of 121 grains/1000 mm^2 in May to 563 grains/1000 mm^2 in August, followed by a decline to 247 grains/1000 mm^2 in September. Although slight monthly fluctuations were observed, the pollen counts remained relatively consistent across different days in each month.

Differences were also observed in terms of the sampling sites. Site 2 had relatively low pollen counts (97–565 grains/1000 mm^2) throughout the entire sampling period. This could be because Site 2 is in the middle of the scenic area, where herbs are regularly cultivated and pruned. This differed from the other two sampling sites located south and north of the scenic area. The pollen counts for Sites 1 and 3 were 122 and 144 grains/1000 mm^2, respectively, in mid-May. Peaks were observed on different days in August (August 15 and 17). The peak pollen count for Site 1 was the highest among the three sites, reaching 599 grains/1000 mm^2.

Pollen was sampled at three locations during five time intervals from 8 a.m. to 6 p.m. daily, and Fig. 5 shows the average pollen

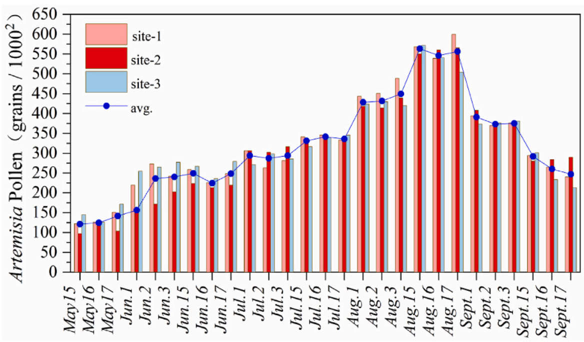

Fig. 4. Changes in pollen grain counts from the three sampling sites in Yan-Er-Wo over the study period.

count. Based on the daily pollen collection in the study area, the quantity of released pollen was typically higher in the afternoon than in the morning. The highest pollen count was recorded between 4 p.m. and 6 p.m., particularly during the peak pollen period. The amount of pollen gathered between 8 a.m. and 10 a.m. was generally minimal, with occasional exceptions, probably influenced by the accumulation of pollen that did not disperse in time because of the influence of the WS, WD, and RH.

3.2. Pearson correlation analysis

Pearson correlation was performed between *Artemisia* pollen and various meteorological and air quality factors (Table 1) to examine their influence on pollen variability. The results revealed that the $T_{Avg.}$ ($R = 0.424$, $P < 0.05$), $PM_{2.5}$ ($R = 0.545$, $P < 0.01$), and PM_{10} ($R = 0.466$, $P < 0.05$) exhibited a significant positive correlation with the pollen counts. However, the $RH_{Avg.}$ ($R = -0.503$, $P < 0.01$) and WS_{Avg} exhibited a significant negative correlation with the pollen counts ($R = -0.653$, $P < 0.01$). The pollen counts did not correlate with the CO_2 concentration ($R = -0.30$, $P > 0.05$).

3.3. Variance partitioning analysis (VPA)

VPA was employed to determine the proportion of variation in the pollen counts explained by the meteorological and environmental factors provided. The specified factors were subjected to ranking analysis while constraining non-specified factors to calculate the correlation between the influencing factors and pollen counts.

Fig. 6 shows the VPA results of the influence of the environmental and meteorological variables on the count of airborne *Artemisia* pollen. According to the VPA results, meteorological factors (44 %) were more important than air quality factors (19 %) for the variation in pollen counts. The joint effect of both factors was considerably lower (0.04 %) than their individual effects. These findings suggested that meteorological factors significantly influenced the seasonal changes in the pollen count in the study area.

To further clarify the meteorological factors influencing the pollen count, Fig. 7 shows the VPA of the temperature, RH, and WS in relation to the results shown in Fig. 6. The analysis revealed that the WS and RH accounted for 24 % and 12 %, respectively, with some overlap, whereas temperature contributed considerably less (2 %). The VPA findings were consistent with the correlation results.

4. Discussion

The release of Artemisia pollen correlated with the prevalence of allergenic respiratory ailments [26,27]. In Urumqi, the peak season for *Artemisia* pollination was early autumn, which aligned with high evidence of respiratory ailments [11]. Following Table 2 of the Pollen Grade Standards, the YanErWo area experienced high *Artemisia* pollen counts from June to August. This prompted regular pruning practices aimed at reducing excess growth. A study conducted in the 1970s in Xinjiang revealed that the pollen counts of *Artemisia* sp. peaked in Urumqi during September [28]. After 40 years, the peak season for *Artemisia* pollen shifted, with the highest counts observed in June and August [11,12]. In the present study, the pollen season lasted for approximately 5 months (from the latter half of May through September). Peak daily counts were recorded in mid-August, and the results were consistent with those of a study by Lv conducted in 2010 [11]. The daily pollen peak time was observed from 16:00 to 18:00, which slightly differed from the daily pollen peaks reported by Gu et al., in 1978 (10:00 to 16:00) [28].

The pollen peak season of *Artemisia* in Urumqi, which overlaps with that of Lanzhou, Beijing, and Nanjing in China, indicates that these cities also exhibit concurrent periods of heightened pollen allergies [6,29]. This differed from certain European countries or regions because of their climate conditions. For example, winter is the main pollination season for Murcia (southeastern Spain) [30]. Notably, the peak pollination season of Urumqi is similar to that of western Poland [31].

Here, the gravity method was employed to collect airborne pollen. This method is commonly employed in the investigation of airborne pollen dispersion because of its low cost and case of execution. In addition, this method can distinguish between pollen species and observed pollen seasons. These advantages are vital in comprehending the dispersal period of distinct species in a designed

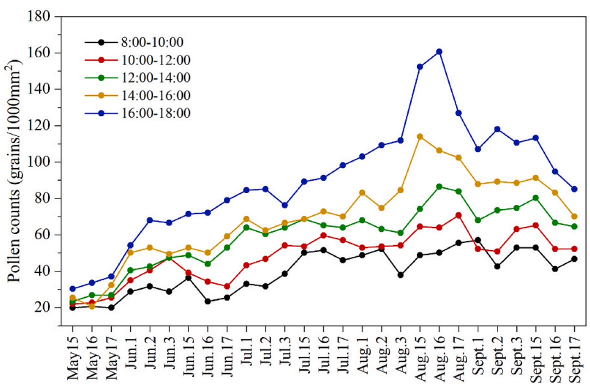

Fig. 5. Mean inter-diurnal variation in pollen count in Yan-Er-Wo during the study period.

Table 1
Correlation coefficients between seasonal pollen counts with meteorological and air quality factors.

Parameters	*Artemisia* pollen counts	
	Correlation coefficient	*P*-Value
$T_{Avg.}$ (°C)	0.424[b]	0.028
$RH_{Avg.}$ (%)	−0.503[a]	0.008
$WS_{Avg.}$ (m/s)	−0.653[a]	0.000
$PM_{2.5}$ (μg/m^3)	0.545[a]	0.003
PM_{10} (μg/m^3)	0.466[b]	0.014
CO_2 (ppm)	−0.279	0.158

[a] and.
[b] indicate significance at the 0.01 and 0.05 levels, respectively.

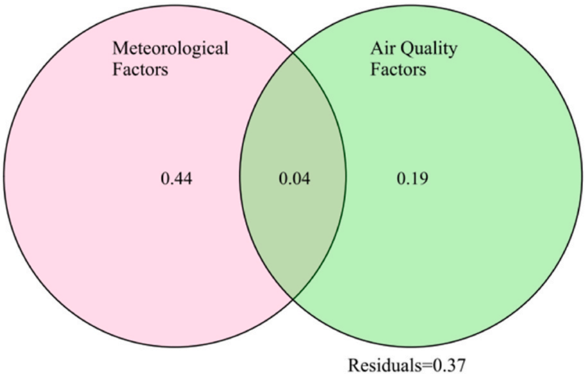

Fig. 6. Variation partitioning analysis of air quality factors ($PM_{2.5}$, PM_{10}, and CO_2) and meteorological factors ($T_{Avg.}$, $RH_{Avg.}$, and $WS_{Avg.}$).

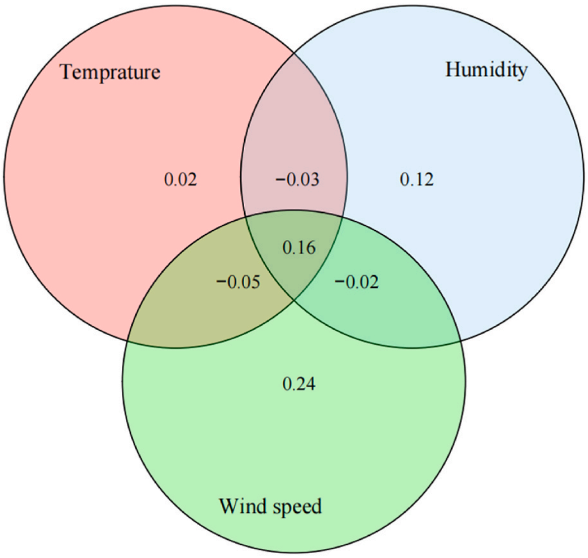

Fig. 7. Variation partitioning analysis of meteorological factors ($T_{Avg.}$, $RH_{Avg.}$, and $WS_{Avg.}$).

region. However, various factors can affect pollen collection, including the WS and WD, size, shape, weight, and other characteristics of pollen. The volumetric method is advantageous for airborne pollen concentration because it can capture the smallest particles that are difficult to settle. Since 2000, ecological researchers in Beijing, Shenyang, Guangzhou, and other major cities have gathered allergenic pollen to investigate its correlation with other air pollutants. Their research focused on the interaction and impact of allergenic airborne pollen with air pollutants, meteorological factors, and the prevalence of pollen-related diseases [17,33,34].

This study established a connection between Artemisia pollen and meteorological factors in the peri - urban environment.

Table 2
Grades of pollen count [32].

Grades	Allergenic description	Pollen of woody plant (grains/1000 mm^2)	Herbaceous pollen (grains/1000 mm^2)	Incidence rate (%/‰)
1	low	≤100	≤50	$P < 1$
2	lower	101–250	51–100	$1 \leq P < 2$
3	moderate	251–400	101–150	$2 \leq P < 3$
4	higher	401–800	151–300	$3 \leq P < 6$
5	high	>800	>300	$P > 6$

Temperature, RH, and WS were observed to be important determinants of the count of airborne pollen. Previous studies have confirmed the significant influence of temperature on the growth, development, and pollination stages of plants [35–37]. The temperature gradually increased from May to August in Urumqi, corresponding to the upward trend of the pollen count.

Previous studies by L. Lv and M. Jiapaer in Urumqi revealed slight variations in the duration of the pollen season [11,12]. Lv (2010) and Jiapaer's (2015) studies respectively indicated that the pollen season occurred from April to October or May to September, with a peak in August and a pollen deposition of approximately 500 grains/1000 mm^2. While the timing of the pollen season in our study aligns with these findings, there are differences in pollen quantities. These discrepancies may be attributed to variations in pollen sampling height (20 m and 1.5 m) and sampling duration (24-h continuous sampling and 2-h intervals).

During the peak pollen season of *Artemisia* in Beijing, as investigated by Hou et al., in 2007, pollen quantities exhibited significant fluctuations throughout the day, ranging from 19 to 1600 grains/1000 mm^2, using the same sampling height and interval (2-h interval) [38]. Although our study also falls within this range, the fluctuations may not be as pronounced. This divergence could be due to their selection of study areas with higher *Artemisia* plant densities and climatic variations between the study regions.

In addition, changes in WS and WD can play a role in pollen dispersion [39]. The study findings indicated that $WS_{Avg.}$ significantly correlated with the pollen counts in the air and negatively impacted the accumulation of *Artemisia* sp. pollen in the study area. Furthermore, the high WS_{Avg}. values are associated with low accumulation of pollen in the air, which may be related to the fact that the amount of pollen collected by the gravity method is more susceptible to wind speed.

The detection of the air pollutants, $PM_{2.5}$ and PM_{10}, exhibited a positive correlation with certain airborne pollen grains [17,39]. The findings indicated that as particulate matters the $PM_{2.5}$ and PM_{10} and pollen grains dispersion may experiencing similar atmospheric process impacts.

Climate change affects the concentration of air pollutants and allergenic particles, which can enhance the productivity of allergenic plants and hasten their flowering period [20,21]. A recent study on climate effects on plants showed that increased temperature and CO_2 levels may alter the flowering time of allergenic species, leading to a longer pollen season and increased pollen release [40]. However, the present results did not reveal a significant correlation between the pollen counts and CO_2. This was probably because the CO_2 concentration in the study area remained relatively stable. It did not significantly fluctuate during the sampling period.

Overall, the Pearson correlation and VPA revealed that meteorological conditions exhibited a more significant impact on the counts of pollen in the air. However, the difference between suburban and urban environments indicated that the meteorological factors and air quality conditions individually and collectively affected pollen counts at varying degrees. Thus, comparative studies of the urban environments may be required. Further research into the association between allergenic plants in suburban areas and pollen counts in urban areas can help uncover the path of pollen migration.

5. Conclusion

This study investigated the seasonal variation of *Artemisia* pollen counts with respect to meteorological and ambient air quality factors. The results showed that from late May to mid-August, *Artemisia* pollen levels gradually increased and then decreased. Correlation revealed a relationship between the temperature, relative humidity and wind speed, $PM_{2.5}$, PM_{10} and seasonal variation of *Artemisia* pollen counts, except for CO_2. Furthermore, VPA revealed that different meteorological and air quality factors played a role in determining the *Artemisia* pollen counts. In addition, influencing factors for the 2021 flowering season of the allergenic plant, *Artemisia*, in Urumqi are presented. Further research in Urumqi is required to investigate the relationship between urban/rural pollen levels, particularly by examining allergenic pollen trajectories.

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Data availability statement

All data analyzed in this manuscript are available upon request to the corresponding author.

CRediT authorship contribution statement

Kadeliya Jiapaer: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ümüt Halik:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Maierdang Keyimu:** Writing – review & editing, Software. **Imin Bilal:** Writing – review & editing, Conceptualization. **Lei Shi:** Writing – review & editing, Conceptualization. **Reyila Mumin:** Investigation, Conceptualization.

Declaration of competing interest

We declare that this manuscript entitled "Influence of meteorological and ambient air quality factors on *Artemisia* pollen concentration in Urumqi, northwest China" is original; it has not been published before and is not currently being considered for publication elsewhere. We unanimously approved the manuscript for publication in "Heliyon".

All authors declared that they have no conflicts of interest exists to this work.

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