• Investigation •

Monthly variations and climatic factors on acute primary angle-closure admissions: a 5-year retrospective hospital-based study in Shenzhen, China

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Abstract

● **AIM:** To investigate the monthly distribution of acute primary angle-closure (APAC) admissions in a specialized hospital in Shenzhen and its association with climatic factors.

● **METHODS:** A 5-year retrospective study of APAC inpatients from 2017 to 2021 at Shenzhen Eye Hospital were conducted. The medical records were retrieved and climate information was obtained from the government website. The monthly APAC admissions and evaluated the correlation with climatic factors were compared, including precipitation, air pressure, temperature, sunshine duration, humidity, and evaporation.

● **RESULTS:** The overall mean age of 997 APAC inpatients was 64.63±9.89y, with females predominating (72.12%) and exhibiting significantly shorter axial lengths than males (22.26±0.89 *vs* 22.87±0.87 mm, $P<0.001$). APAC admissions peaked in May, especially for males ≤65y. Significant positive correlations were identified between admissions and humidity ($r=0.498$, $P<0.01$) as well as precipitation ($r=0.306$, $P<0.05$), while evaporation correlated negatively ($r=-0.333$, $P<0.05$). Males exhibited elevated APAC risk under high humidity [odds ratio (OR)=2.76, $P=0.038$], while increased air pressure (OR=0.12; 95%CI: 0.07–0.19), higher temperature (OR=0.22; 95%CI: 0.15–0.31), and greater evaporation (OR=0.92; 95%CI: 0.90–0.94) each exerted protective effects against such humidity-associated risk (all $P<0.001$).

● **CONCLUSION:** Elevated relative humidity in May is the primary climatic driver, significantly increasing the risk of APAC attack in males ≤65y. However, these correlations are not significant in female, suggesting the possibility of an associated confounding factor.

● **KEYWORDS:** acute primary angle closure; admission; climate factors; humidity

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INTRODUCTION

Glaucoma is the leading cause of irreversible blindness worldwide, and is characterized by vision loss, optic nerve damage, and visual field defects[1-2]. Among the several types of glaucoma, primary angle-closure glaucoma (PACG) is associated with devastating visual outcomes[3-5]. The global number of individuals with PACG is projected to increase from 23.36 million in 2020 to 32.04 million by 2040, with approximately 76.47%–76.88% of cases residing in Asia[3,6]. Acute primary angle-closure (APAC) is a common ophthalmic emergency that, if not treated in time to lower the markedly increased intraocular pressure, can lead to severe visual impairment or even blindness[7-9].

Ocular risk factors for APAC include a small corneal diameter, shallow anterior chamber, narrow drainage angle, forward rotation of the ciliary body, relaxation of the zonules, thickened or anteriorly positioned lens, and short axial length[10-12].

However, these anatomical factors can only partially explain the occurrence of APAC attacks. Additional factors, including demographic, genetic, psychological, physiological, and environmental factors, have also been identified as potentially triggers for APAC in anatomically susceptible eyes[6,13-16].

Over the past decades, only a limited number of studies have investigated the relationship between APAC attacks and climatic factors, and their conclusions remain inconsistent across different populations[16-18]. Some studies demonstrate positive associations between the APAC attacks and sunshine duration, relative humidity, seasonal variation (summer/winter), precipitation, and surface temperature[16-17,19-20]. In contrast, others report an inverse association with sunshine duration[19,21]. Additionally, several studies found no significant association with sunshine duration, seasonal variation, temperature, precipitation, or air pressure[20,22-23]. These discrepancies are likely attributable to the regional dependency of climatic factors.

Therefore, in this study, we aimed to investigate the relationship between APAC attack admissions and the monthly climate factors including average temperature, air pressure, precipitation, humidity, sunshine duration, and evaporation in Shenzhen, a subtropical monsoon climate city in southern China.

PARTICIPANTS AND METHODS

Ethical Approval The retrospective study was conducted at the Shenzhen Eye Hospital, Southern Medical University, Shenzhen, China. Participants were recruited from January 2017 to December 2021. All procedures in this study strictly adhered to the Declaration of Helsinki and received ethical approval from the Research Ethics Committee of Shenzhen People's Hospital (No.LL-KY-2021945-01). The Research Ethics Committee of Shenzhen People's Hospital specifically waived the requirement for informed consent as the research involved only retrospective analysis of medical records containing no identifiable personal information.

Patients and Data Collection Patients diagnosed with the principal diagnosis of APAC attack at Shenzhen Eye Hospital were enrolled in this study. The diagnosis criteria for APAC were as follows[11,24-25]: 1) at least two symptoms of acute attack: a history of intermittent blurring of vision with rainbow-colored haloes, ocular or periocular pain, nausea and/or vomiting; 2) intraocular pressure at presentation of 21 mm Hg or more [by Goldmann applanation tonometry or non-contact tonometry (Topcon CT-80, USA)]; 3) at least three of the following signs: conjunctival injection, corneal epithelial edema, shallow anterior chamber (central anterior chamber depth <2 cornea thickness or peripheral anterior chamber depth <1/4 cornea thickness), a fixed mid-dilated pupil, iris atrophy, or glaucoma spots; 4) the presence of an occluded angle in the affected eye on gonioscopy. Patients with secondary glaucoma, such as neovascular glaucoma, traumatic glaucoma, uveitic glaucoma, lens-induced glaucoma, or pigmentary glaucoma were excluded.

Data was collected including medical history of systemic and ocular diseases, APAC attack information (including onset date and affected eye), demographic information (gender, age, height, and weight), biometric measurements [axial length measured by IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany)], and monthly climate data (average temperature, air pressure, precipitation, humidity, sunshine duration, and evaporation). Climate information was obtained from the Shenzhen government open-data platform (https://opendata.sz.gov.cn/) and the official website of the Shenzhen Meteorological Bureau (http://weather.sz.gov.cn/). Subgroup analysis was conducted with an age threshold of 65y (based on the overall mean age of the population, 64.63±9.89y).

Statistical Analysis All data underwent normality testing using the Shapiro-Wilk test. Normally distributed quantitative variables were expressed as mean±standard deviation and compared between groups using independent sample *t*-tests and analysis of variance. Non-normally distributed quantitative variables were analyzed using the Kruskal-Wallis test. To assess the potential impact of the COVID-19 pandemic on APAC admission trends, we compared the monthly admission numbers before and during the pandemic. The pre-pandemic period was defined as the years 2017 to 2019, and the pandemic period as 2020 to 2021. The non-parametric Wilcoxon signed-rank test was employed for the comparison. Categorical variables were expressed as numbers (percentages) and analyzed using Chi-square (χ^2) tests. Spearman correlation analysis was used to analyze the correlation between the APAC admissions and meteorological factors, stratified by age and gender groups. Multiple linear regression analysis was used to investigate the effect of climate factors on the APAC admissions in different groups. A binary logistics regression model was used to predict the impact of multiple factors on the probability of APAC attacks under high humidity. Circular distribution analysis was used to predict the peak of admissions. SPSS software (IBM Corp., version 26.0) was used for statistical analysis. A $P<0.05$ was considered statistically significant.

RESULTS

A total of 997 hospitalized APAC patients were enrolled in this study, comprising 719 females (72.12%) and 278 males (27.88%). No significant difference was observed in monthly admissions when comparing the pre-pandemic period (2017–2019) with the pandemic period (2020–2021; P=0.15). The overall mean age was 64.63±9.89y. Most patients were aged 61–70y (n=420, 42.13%), with comparable age distributions

Table 1 Demographic characteristics of acute primary angle-closure patients *n* (%) or mean±SD

Characteristics	Total	Male	Female	*P*
Number	997	278 (27.88)	719 (72.12)	
Age, y	64.63±9.89	63.87±10.39	64.93±9.69	0.127
Range of age, y				
≤50	82 (8.22)	30 (10.79)	52 (7.23)	
51–60	229 (22.97)	69 (24.82)	160 (22.25)	
61–70	420 (42.13)	110 (39.57)	310 (43.12)	0.199
71–80	213 (21.36)	52 (18.71)	161 (22.39)	
≥81	53 (5.32)	17 (6.11)	36 (5.01)	
Systemic diseases				
Hypertension	290 (29.09)	77 (27.70)	213 (29.62)	0.548
Diabetes	90 (9.03)	24 (8.63)	66 (9.18)	0.787
Affected eye				
Right eye	493 (49.45)	136 (48.92)	357 (49.65)	
Left eye	428 (42.93)	123 (44.24)	305 (42.42)	0.782
Both eyes	76 (7.62)	19 (6.84)	57 (7.93)	
Axial length, mm	22.43±0.96	22.87±0.87	22.26±0.89	< 0.001

SD: Standard deviation.

in male and female (P=0.199). Among the 997 patients, 290 (29.09%) had hypertension and 90 (9.03%) had diabetes. Though females showed higher rates of hypertension (29.62% *vs* 27.7%) and diabetes (9.18% *vs* 8.63%) than males, these differences lacked statistical significance (P>0.05). The 49.45% of the APAC attacks were in the right eye, 42.93% in the left eye, and 7.62% for both eyes, with no significant difference in the affected eyes between genders (Table 1).

Monthly Distribution of APAC Attack Admissions The monthly distribution of APAC admissions peaked in May in the overall group. Male admissions demonstrated distinct clustering in May and June, whereas females exhibited no significant monthly concentration pattern (Figure 1). In the age subgroups, the peak of admissions was in May for patients ≤65 years old, but in August for those >65 years old (Figure 2). When stratified by both gender and age, males aged ≤65y demonstrated concentrated admissions in May and June, while there was little difference in the admissions per month for males aged >65y or females of different ages (Figure 3).

Circular distribution analysis predicted a significant peak of admissions in May for both the overall group (P=0.01) and all male group (P<0.01; Table 2). Following stratification by age and gender, the peak of admissions is still in May for patients ≤65y (P=0.02) and males ≤65y (P<0.001). In contrast, no significant peak of admissions was identified for patients >65y or female patients (P>0.05).

Correlation Between Monthly APAC Attack Admissions and Climatic Factors Spearman correlation analysis revealed that the monthly APAC admissions were positively correlated with precipitation (r=0.306, P<0.05) and relative humidity (r=0.498, P<0.01), but negatively correlated with evaporation (r=-0.333, P<0.05; Table 3). Stratified analyses demonstrated that in males ≤65y, monthly APAC admissions exhibited consistent correlations with the overall group. However, the admissions of males >65y only maintained positive

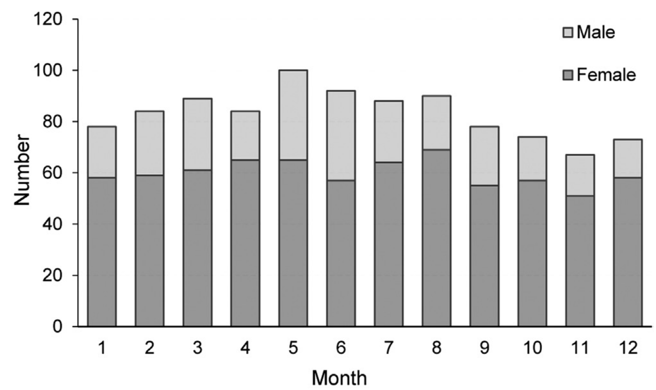

Figure 1 Monthly distribution of acute primary angle-closure (APAC) admissions by gender Stacked bars represent the total number of APAC admissions per month, with breakdown by gender.

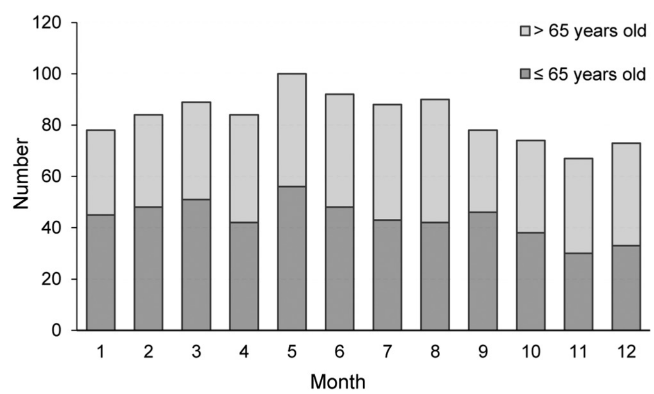

Figure 2 Monthly distribution of acute primary angle-closure (APAC) admissions by age Stacked bars represent the total number of APAC admissions per month, with breakdown by age.

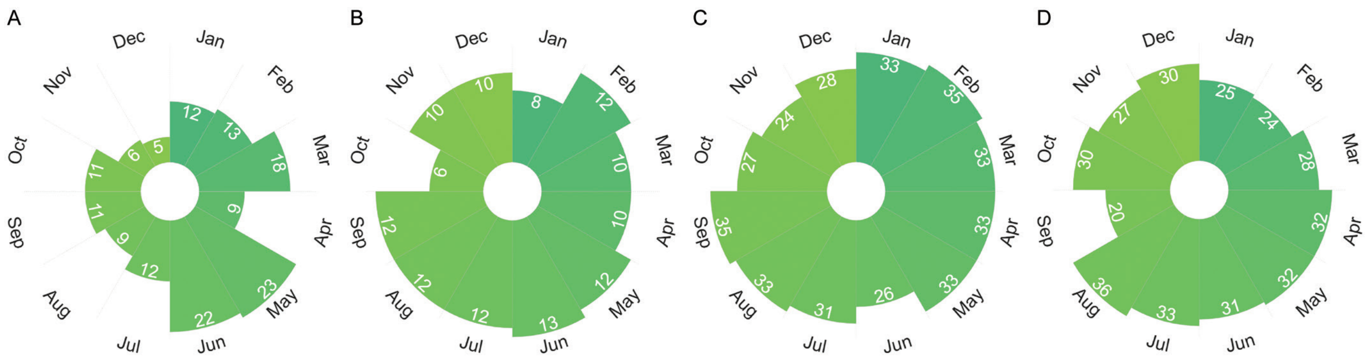

Figure 3 Rose plots of monthly distribution of acute primary angle-closure (APAC) admissions in stratified subgroups Each panel shows the monthly number of APAC admissions: A) male aged ≤65y; B) male aged >65y; C) female aged ≤65y; D) female aged >65y. The radial length of each sector corresponds to the number of admissions for that month, with months labeled around the circumference (Jan.–Dec.).

Table 2 Estimated monthly-based peak admissions of acute primary angle closure

Groups	*n*	*r*	*α*	*S*	*Z*	*P*	Peak month
Total	997	0.07	142.99°	132.31	4.82	0.01	May
Male	278	0.15	140.55°	110.87	6.57	<0.01	May
Female	719	0.04	146.92°	147.10	0.99	0.37	May
≤65y							
Total	522	0.09	126.51°	127.18	3.78	0.02	May
Male	151	0.22	134.04°	99.43	7.43	<0.001	May
Female	362	0.04	115.94°	148.38	0.44	0.64	April
>65y							
Total	475	0.06	168.30°	135.07	1.83	0.16	June
Male	127	0.08	162.39°	128.66	0.82	0.44	June
Female	348	0.06	171.40°	137.70	1.08	0.34	June

Circular distribution method: *r*: Concentration trend; *α*: Average angle; *S*: Dispersion trend; *Z*: Rayleigh value.

Table 3 Spearman rank correlation analysis of acute primary angle-closure monthly-based admissions rate with individual climatic factors

Groups	Air pressure	Air temperature	Sunshine hours	Precipitation	Humidity	Evaporation
Total	-0.281	0.243	-0.130	0.306[a]	0.498[b]	-0.333[a]
≤65y						
Male	-0.257	0.199	-0.040	0.286[a]	0.480[b]	-0.296[a]
Female	0.012	0.044	-0.093	0.096	0.192	-0.262
>65y						
Male	-0.160	0.085	-0.155	0.351[a]	0.328[a]	-0.226
Female	-0.219	0.172	0.031	0.085	0.174	0.135

[a]$P<0.05$; [b]$P<0.01$.

correlations with precipitation (r=0.351, P<0.05) and humidity (r=0.328, P<0.05), while showing no significant correlation with evaporation. Additionally, no significant correlations were observed between monthly APAC admissions and climatic factors in all age subgroups of females.

Effects of Climatic Factors on the APAC Attack Admissions Multiple linear regression analysis was used to study the effects of various meteorological factors on APAC admissions in different subgroups. For males ≤65y, the Durbin-Watson test values (1.669) and analysis of variance (P<0.05) supported model validity, with goodness-of-fit (R^2=0.308) and normally distributed residuals. Similarly, males >65y exhibited comparable model adequacy (Durbin-Watson=1.692, analysis of variance: P<0.05, R^2=0.252). Regression modeling demonstrated that for males aged ≤65y, humidity exhibited a significant positive linear relationship with APAC admissions (β=0.218, P=0.008), indicating an increase of 0.218 admissions per unit increase in humidity. For males >65y, precipitation showed a significant positive linear association with APAC admissions (β=0.008, P=0.015), corresponding to an increase of 0.008 admissions per unit rise in precipitation (Table 4).

When incorporating all 6 climatic factors into the multivariable model, their contribution to APAC admissions was minimal. Therefore, stepwise regression was employed to eliminate non-

Table 4 Multivariate linear regression analysis of acute primary angle-closure monthly-based admissions rate with climatic factors

Factors	Total		Male				Female			
			≤65y		>65y		≤65y		>65y	
	β	*P*	*β*	*P*	*β*	*P*	*β*	*P*	*β*	*P*
Air pressure	0.157	0.789	0.109	0.636	0.193	0.271	0.217	0.487	-0.363	0.315
Air temperature	0.061	0.909	0.036	0.862	0.015	0.927	0.179	0.529	-0.169	0.606
Sunshine duration	0.009	0.695	0.013	0.143	-0.004	0.547	0.007	0.546	-0.007	0.587
Precipitation	0.003	0.793	-0.003	0.510	0.008	0.015[a]	-0.001	0.789	-0.001	0.914
Humidity	0.287	0.154	0.218	0.008[b]	0.048	0.416	0.115	0.282	-0.094	0.443
Evaporation	-0.027	0.509	-0.014	0.402	0.006	0.608	-0.025	0.261	0.005	0.848

[a]$P<0.05$; [b]$P<0.01$.

significant variables and optimize model performance. The results revealed humidity as a significant positive predictor for both the overall group (β=0.303, P=0.002) and the male subgroup (β=0.201, P<0.001). Conversely, stepwise modeling for female subgroup demonstrated no significant associations between APAC admissions and climatic factors.

Effects of Climatic Factors on the APAC Attack Admissions in Humidity Subgroups Given the significant impact of humidity on APAC admissions, a subgroup analysis was performed based on the median of humidity (79.65%): low-humidity group (≤79.65%) and high-humidity group (>79.65%). We included 851 APAC patients with complete height, weight, body mass index (BMI), and axial length data. The results revealed a significant difference in gender distribution between the two humidity subgroups (P=0.003), consistent with the trend observed in the overall group. Specifically, males constituted 31.96% (n=140) in the high-humidity subgroup, a higher proportion than the 23.00% (n=95) in the low-humidity subgroup. In contrast, no statistically significant variations were found in age, height, weight, hypertension status, diabetes prevalence, or axial length between the two subgroups (P>0.05). Climate factors such as precipitation, air pressure, temperature, sunshine duration and evaporation all differed between the two groups (P<0.001), but the distribution of age, height, weight, hypertension, diabetes, and axial length did not have statistical differences between the two groups (P>0.05).

A binary logistic regression was employed to evaluate the effects of the aforementioned climatic factors on APAC admissions under high humidity. The analysis revealed that the odds ratio (OR) of males was 2.76 (95%CI: 1.06–7.20, P=0.038), indicating that males are at high risk for APAC attack under high humidity. The OR values for air pressure, temperature, and evaporation were 0.12 (95%CI: 0.07–0.19), 0.22 (95%CI: 0.15–0.31), and 0.92 (95%CI: 0.90–0.94), respectively, indicating that air pressure and temperature were protective factors against APAC attack under high humidity.

DISCUSSION

By investigating the relationship between APAC attack admissions and the monthly climate factors in Shenzhen, we observed that the APAC admission rates were significantly higher in May, especially for males ≤65y. The monthly admissions demonstrated positive correlations with humidity and precipitation, but a negative correlation with evaporation. For male patients, elevated air pressure and temperature exerted protective effects against APAC attacks under high humidity conditions.

Previous studies have reported correlations between humidity and multiple clinical conditions, including acute endogenous iridocyclitis[26], laser *in situ* keratomileusis (LASIK) flap thickness[27], LASIK enhancement rates[28], corrected distance visual acuity after myopic LASIK[29], conjunctival bacteria of patients undergoing cataract surgery[30], acute post-cataract surgery endophthalmitis[31], and dry eye[32-34]. In this subtropical monsoon region, our study established significant positive correlations between monthly humidity levels and APAC admission rates. This finding aligns with reports from different climatic zones—Hu *et al*[20] in Taiwan's humid subtropical and tropical monsoon regions, and Zhong *et al*[16] in Shantou's coastal subtropical marine climate zone. In addition, we observed that air pressure and temperature were protective factors against APAC attack under high humidity. One potential mechanism regarding the relationship between relative humidity and APAC attacks may involve the effect of humidity on corneal hydration. Prior studies have reported that endothelial pumps contribute only 20% to the recovery of 60 μm corneal swelling, whereas tear evaporation contributes 80%[35]. Thus, we postulate that when relative humidity increases, tear evaporation decreases, thereby prolonging the duration of corneal edema. This, in turn, may induce anterior chamber angle occlusion in susceptible individuals and trigger subsequent APAC attacks. However, as this was a retrospective study, central corneal thickness measurements were not routinely available. Therefore, future prospective studies incorporating central corneal thickness measurements are warranted to explore and validate this hypothesis. Collectively, individuals at high risk for APAC are advised to minimize outdoor exposure during weather with high humidity or precipitation. Concurrently, indoor humidity control through environmental interventions such as dehumidifiers or air conditioning is recommended.

Peak admission periods for APAC attack demonstrate marked geographic variability. In our study, the peak month of APAC attack admission was in May, especially among males ≤65y. Shenzhen (22.45°–22.87°N) experiences a subtropical monsoon climate characterized by extended summers (>200d) and substantial precipitation. Due to the hot and humid weather, people are prone to discomfort, especially in May. Similarly, Shantou's coastal subtropical marine climate shows summer peaks (June–July for females; August for males >65y)[16]. Taiwan reports March as its peak month[20]. A survey of the US emergency department found that the peak incidence of APAC is in December[18]. While in Beijing and Israel, the peak seasons of APAC admission are both in summer and winter[17,36]. The peak season of APAC attack in Finland is also in winter (December, January, and February)[37], and in Malaysia, APAC is most frequent from October to March[38]. These discrepancies can be attributed to the regional dependency of climatic factors. In general, the higher incidence of APAC attacks in winter and summer could be related to the extreme weather. Extreme climate environments may trigger APAC attack by changing patients' emotions, behavioral activities, and psychological state[39]. It has been reported that in extreme weather, serotonin and dopamine levels may be altered, disrupting the stability of body temperature regulation and exacerbating psychological anxiety[40]. Moreover, emotional stress may elevate intraocular pressure by interfering with systemic cortisol levels[39].

Globally, females are more likely to suffer from APAC attacks than males. In our study, the incidence in female patients was 2.59 times that in males, which is similar to other researches[16-17,37]. Anatomically, female patients exhibited significantly shorter axial lengths (22.26±0.89 *vs* 22.87±0.87 mm, $P<0.001$). Regarding gender-specific variations in the impact of climatic factors on APAC admissions, previous studies have reported inconsistent findings. Our study found that APAC admissions in males (especially aged ≤65y) were more vulnerable to climate factors, which is similar to the results of the Taiwan study[20], while the studies in Shantou and Beijing showed the opposite results[16-17]. Therefore, the influence of gender and climate on APAC attack may be multifactorial.

There are several limitations in our study. First, the reported APAC admission rates may underestimate actual incidence, as a small proportion of outpatients were not captured. Second, the climate exposure assessment was geographically restricted to Shenzhen meteorological data and did not account for participants' travel history. Third, our analysis is limited to the period of 2017–2021. Data collection was not extended because subsequent shifts in Shenzhen's COVID-19 pandemic control policies—such as the decentralization of specialist care to community and primary hospitals—fundamentally altered APAC admission patterns to our tertiary center, making later data incomparable. Nonetheless, the consecutive five-year dataset revealed robust and consistent results, which we believe sufficiently support the conclusions. Finally, as a single-center study, our findings may only reflect the effect of climate factors in the subtropical monsoon region. Multicenter investigations across diverse geographic regions with larger sample sizes are required to validate these associations and minimize selection bias.

In conclusion, this study identified May as the peak month for APAC admissions, especially for males ≤65y. The monthly admissions were positively correlated with humidity and precipitation, while negatively correlated with evaporation. Therefore, individuals at high risk for APAC are advised to minimize outdoor exposure during weather with high humidity or precipitation. Concurrently, indoor humidity control through environmental interventions is recommended. Any ocular discomfort should prompt immediate ophthalmic consultation. Raising public awareness of climate-associated APAC triggers may help reduce the incidence of APAC attacks.

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Data Availability Statement: The datasets used and/or analyzed during this study are available from the corresponding author on request.

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