Title: Impact of climate changes and air quality on asthma-related emergency department visits in a tropical country

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Aims

We reviewed the temporal associations between climate and asthma-related emergency department (ED) visits in a tropical country.

Methods

A time-series analysis was conducted to examine the effect of climate and air quality on asthma-related ED visits in Singapore's largest public healthcare system. Asthma-related ED visits were extracted from the electronic medical record database, while environmental data were retrieved from public databases. Environmental variables (such as pollution standard index, temperature, rainfall and windspeed) were correlated with ED visits from 2015 to 2024, with lagged analysis to account for delayed effects. Changes can have a delayed effect on asthma exacerbations, where individuals may exacerbate only several days after exposure. Poisson regression analysis was used to model the effect of these variables on predicting ED visits.

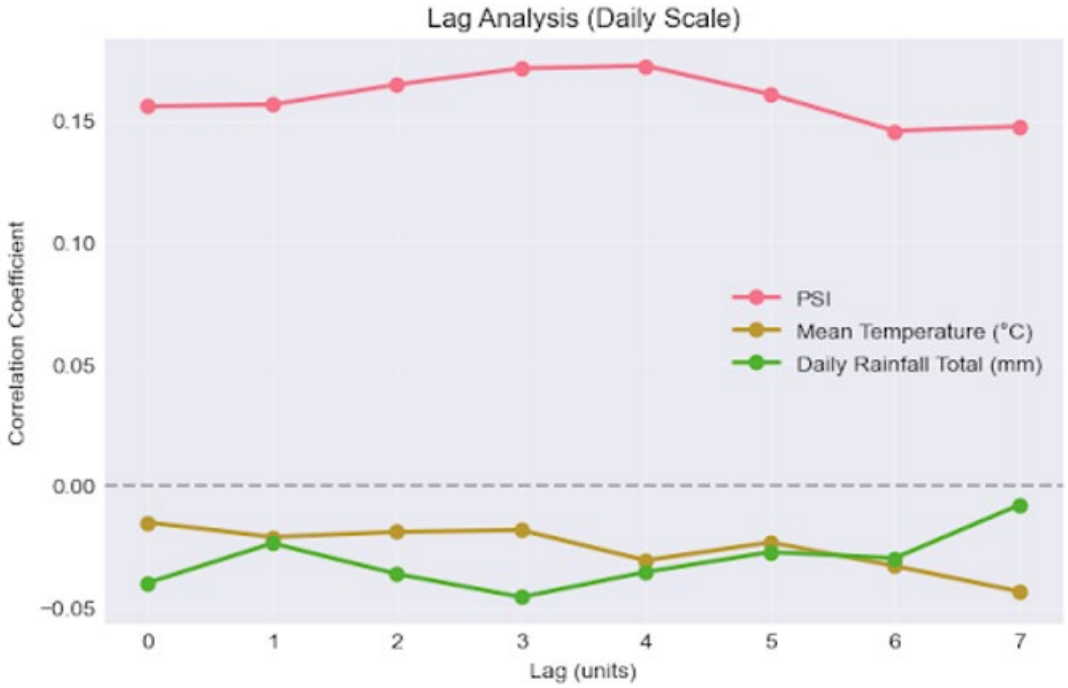
Results

From 2015 to 2024, ED visits declined, with a significant reduction during the COVID-19 lockdown period (2020-2022) (Figure). ED visits were positively correlated with PSI and PM2.5, with the strongest association at the monthly scale (PSI: $r = 0.53$, $p < 0.005$; PM2.5: $r = 0.186$, $p = 0.056$). For every 10-unit increase in PSI, there was a 8% increase in ED visits. In contrast, for every 1°C increase in temperature and 1mm increase in rainfall, there was a 5% and 0.4% decrease in ED visits, respectively. A significant difference in ED visits was observed between extreme temperatures (5th, 95th percentiles) and the rest of the study period.

Conclusion

Air quality and climate changes influence asthma exacerbations even in a small country like Singapore, highlighting the need to raise awareness and develop interventions to reduce asthma burden.

Figure 1 Time-lag correlation between ED visits, air quality and climate (lag 0 to 7).



Declarations

Ethics approval and consent to participate: Ethics board approval was obtained as part of the SDG-CARE collaboration, prior to developing the SCDM (SingHealth Centralized Institutional Review Board Ref No. 2017/2950). Informed consent has been waived by SingHealth Centralized Institutional Review Board Ref No. 2017/2950.

Consent for publication: Not applicable as the research does not involve any individual person's data.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request with de-identified patient data subject to data owners and other stakeholders' approval.

Competing interests:

Ming Ren Toh reports no conflict of interest.

Xingdi Wen reports no conflict of interest.

Gerald Xuan Zhong Ng reports no conflict of interest.

Adam Quek Rop Fun reports no conflict of interest.

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All authors reviewed the manuscript for critical intellectual content.

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Background

Driven by increasing greenhouse gas emissions, global temperatures have been steadily rising over the decades (0.06°C per decade).[1] Resultant climate fluctuations have led to significant impacts on lung health.[2-4] Asthma, an ambulatory care-sensitive condition, is particularly susceptible to climate-related changes.[5] A systematic review published in the *European Respiratory Journal* on extreme weather and asthma revealed that an increase in asthma events with extreme weather changes such as heat waves, hurricanes, floods.[6] Much of the climate-related asthma studies were done in countries experiencing significant seasonal variations, with correlations between asthma exacerbations and poor air quality, extreme weather changes such as thunderstorms, floods.[6, 7] However, less is known about these relationships in equatorial countries.

Situated near the equator, Singapore experiences tropical climate with relative climate stability compared to the temperate regions. There is mostly abundant rainfall, high temperature and humidity all year round, with seasonal monsoons and periods of transboundary haze.[5] It is unclear whether environmental variations in this tropical country have any impact on asthma exacerbations. To address this gap, we reviewed the temporal trends and correlations between climate and asthma-related emergency department (ED) visits between 2015 and 2024.

Methods

We performed a retrospective analysis of patients with asthma seen in the SingHealth cluster (the largest healthcare cluster in Singapore) between 2015 and 2024. Patient records were retrieved from the SingHealth COPD and Asthma Data Mart (SCDM), an integrated real-world data database for the largest public health system in Singapore.[8] Asthma-related emergency department visits were identified using the ICD-10 code J459. Data on climate (temperature, rainfall, wind speed), air quality (pollution standard index and particulate matter 2.5) were retrieved from public database under the National Environment Agency and Singapore

Meteorological Service. The PSI is a composite index that combines the concentrations of multiple pollutants, including particulate matter (PM10), fine particulate matter (PM2.5), sulfur dioxide (SO2), nitrogen dioxide (NO2), ozone (O3), and carbon monoxide (CO). The PSI readings offer a more accurate and comprehensive assessment of air pollution than individual pollutant measurements.

Climate, air quality, and ED visits were analysed at daily, weekly, and monthly scales. Pearson's correlation analysis was used to assess linear associations, while lagged effects (Lag 0 to Lag 7) were evaluated based on prior evidence of delayed impacts of climate and air pollution on asthma exacerbations.[9] Determinants of ED visit were then evaluated using Poisson regression analysis to account for overdispersion and collinearity in the time-dependent count's data. Frequency of ED visits during extreme climate (defined by the 5th and 95th percentiles) was compared with the rest of the study period using the Mann-Whitney U test. All statistical analyses were performed using Python.

In light of the COVID-19 pandemic, we performed a separate analysis on the pre- and post-COVID-19 pandemic. Climate, air quality, and ED visits were compared between the two periods using student t-test and Mann-Whitney U test.

Results

Our cohort consisted of ___ patients and ____ asthma-related ED visits (Table 1). Between 2015 and 2024, emergency department visits showed a gradual decline. Spikes in PSI and PM2.5 could be seen between August and November in 2015, 2016, 2019, and 2023 due to transboundary haze. Climate patterns followed a consistent seasonal trend, with drier and warmer conditions in the second half of each year. However, over the decade, annual rainfall peaked in 2020–2021, while mean temperatures continued to rise, reflecting a broader warming trend (Figure 1). A comparison of the pre- and post-COVID-19 pandemic showed a significant reduction in ED visits, PSI and temperature (Table 2).

ED visits were positively correlated with PSI and PM2.5, with the strongest association observed at the monthly scale (PSI: $r = 0.53$, $p < 0.005$; PM2.5: $r = 0.186$, $p = 0.056$) (Figure 2). No significant correlation was found between ED visits and other climate parameters. Time-lagged analysis revealed that the correlations for PSI, PM2.5, and temperature were strongest on day 4 (Figure 3).

Environmental determinants of ED visits included PSI, temperature and rainfall (Table 2). PM2.5 was excluded from the model due to moderate collinearity with PSI (VIF = 4.23) and PM2.5 (VIF = 3.94). For every 1 unit increase in PSI, there was a 0.0080 increase in ED visits. In contrast, for every 1°C increase in temperature and 1mm increase in rainfall, there was a 0.0471 and 0.0037 decrease in ED visits, respectively (Table 3). Regarding extremes of climate, there was a significant difference in ED visits between the extreme temperatures and the rest of the study period (Figure 4).

Discussion

Climate changes and ED visits

To our knowledge, this is the first study on climate variables and asthma-related ED visits in a tropical country. Our findings highlight the far-reaching consequences of climate change and that extremes of temperature can affect asthma exacerbations even in a tropical country with relative climate stability. The relationship between cold temperature and asthma exacerbations has been demonstrated in studies on thunderstorms and weather extremes.[10] One such outbreak was seen in the United Kingdom, where the ED visits increased by 10-fold during a heavy thunderstorm in London on 24 June 1994.[11] An Australian study attributed the increased asthma exacerbations during thunderstorms to the increased ambient concentration of pollen allergens.[12] Likewise, effects of rainfall, humidity and windspeed on asthma exacerbations may be indirectly related to dispersion of pollutants and allergens.[10]

However, previous studies on these climatic variables have been inconsistent and we did not find any significant associations between these variables and asthma-related ED visits.[10]

Impact of COVID-19 pandemic on ED visit and environmental variables

During the lockdown, ambient air quality improved up to 73% (for PM2.5).[13] Similarly, the limitations in transportation and atmospheric pollutants have reduced the surface temperature especially in urban areas (by 1-2°C).[14] Similar to previous studies, we found a significant reduction in asthma-related ED visits during and after the COVID-19 pandemic.[15] Postulated reasons include healthcare avoidance by the patients, improved awareness about hygiene and mask wearing, and reduced transmission of respiratory pathogens with the pandemic lockdown from 2020 to 2021.[15, 16]

In many countries similar to ours, asthma-related emergency department (ED) visits surged shortly after the relaxation of COVID-19 restrictions, likely due to increased social interactions and the transmission of respiratory infections.[17] The COVID-19 pandemic demonstrates that population-level policies are highly effective in mandating behavioral changes and reducing asthma exacerbations, independent of other trigger exposure and indoor pollutant. The delayed rebound in ED visits to pre-COVID levels suggests persisting behavioral changes, perhaps due to sustained medication adherence and habitual changes in some individuals. It would be insightful to follow the trend and understand the long-term impact of such policies.

Transboundary haze and ED visits in the region

Singapore resides within one of the most severely polluted regions in the world, exposed to emissions from local and regional transport, industrial activities, with exacerbation of pollution during haze events.

Every year, the region experiences spikes in ambient pollution due to the transboundary haze aggravated by the Southwest monsoon winds. Occurring during the warmer Southwest

monsoon seasons, regional peatland fires can trigger haze events and contribute to as much as 50-85% of the regional PM2.5 levels.[18] Our study showed similar spikes in August and November in 2015, 2016, 2019, and 2023. Despite the incrimination of unlawful slash-and-burn practices, the issue persists due to peatland fires caused by the drier weather.[18] Haze exposure can cause ED visits in a 'dose-dependent' relationship, for instance, a 50-150μ/m3 rise in PM10 was associated with a 12% increase in upper respiratory tract conditions.[19]

Importantly, the haze effects extend beyond respiratory conditions, including myocardial infarction, overall ED visits and hospitalisations.[20] An earlier study in Singapore showed that between 2010 and 2015, for every 30-unit increase in PSI, there is a significant rise in all ED visits (RR 1.023, $p<0.005$).[21] Another study in Malaysia also reported a 31% rise in inpatient admissions during haze periods which amounted to an annual inpatient costs of USD 91,000.[19] To mitigate the detrimental effect of regional haze, we can adopt similar risk-avoidance measures during the COVID-19, such as limiting non-urgent travel and wearing N95 mask.[22] In anticipation of increased indoor dwelling, it is crucial to raise public awareness about indoor pollution sources, such as stove cooking, cigarette smoking, and incense burning.

Limitations

There are several study limitations: there were incomplete meteorological data in some weather stations (i.e. Newton station in September-November 2016 and Chao Chu Kang station in May 2015). The average of the country's weather stations was used in our analysis, and we imputed the missing data based on the other stations. Second, the correlation between air quality and ED visits did not account for indoor air quality which may affect the cumulative pollutant exposure. This may bias the associations, especially during the COVID-19 lockdown periods where indoor pollution sources predominate. Third, our study focused on asthma-related ED visits, which capture only a portion of adverse asthma outcomes. Poor symptom

control and reduced quality of life are also key asthma outcomes that may be among the first to be impacted by environmental changes.

Conclusion

This study examines the impact of climate and air quality on asthma-related ED visits in Singapore from 2015 to 2024. While ED visits generally declined, significant spikes were observed during haze events. Air quality, particularly PSI, and temperature were identified as key determinants of ED visits, with the strongest correlations found at the monthly scale. Notably, a lagged effect was observed, with the impact on ED visits most pronounced on day 4. Our findings suggest that environmental factors, even in Singapore's stable tropical climate, influence asthma exacerbations, highlighting the need for ongoing monitoring and targeted health interventions to mitigate these effects.

Table 1. Clinical characteristics of the study population

Variable		Number of patients (%)
Total number of patients		
Mean age, years (± SD)		
Race (%)	Chinese	
	Malay	
	Indian	
	Others	
Gender	Male	
	Female	
Comorbidities	Allergic conjunctivitis	
	Allergic rhinitis	
	Anxiety disorder	
	Atopic dermatitis	
	COPD	
	Depressive disorder	
	GERD	
	Heart failure	
	Hypertension	
	Obstructive sleep apnoea	
	Pneumonia	
Site of care	SC	
	PC	
	Both SC and PC	
	ED defaulters	
GINA step at first visit	1	
	2	
	3	
	4	
	5	
Number of ED visits	2015	
	2016	
	2017	
	2018	
	2019	
	2020	
	2021	
	2022	
	2023	
	2024	

Table 2. ED visit, air quality and climate pre- and post-COVID-19 pandemic

Variable	Pre-COVID (Mean ± standard deviation)	Post-COVID (Mean ± standard deviation)	p-value
ED Visits	2.67	1.84	<0.005
PSI	55.63	47.74	<0.005
PM2.5 (μg/m³)	17.52	14.66	<0.005
Mean Temperature (°C)	28.13	27.94	<0.005
Daily Rainfall Total (mm)	5.66	7.85	<0.005
Mean Wind Speed (km/h)	7.80	8.70	<0.005

Table 3. Climate and air quality predictors of ED visit using Poisson regression.

Variable	Mean ± standard deviation	Coefficient (β)	Standard Error	Risk ratio	p-value	95% confidence interval
Temperature (°C)	27.99 ± 0.97	-0.0471	0.015	0.954	0.002	-0.076, -0.018
Rainfall (mm)	7.11 ± 14.46	-0.0037	0.002	0.996	0.017	-0.007, -0.001
Wind speed (km/h)	8.37 ± 3.64	-0.0083	0.007	0.992	0.230	-0.022, 0.005
PSI	52.36 ± 11.47	0.0080	0.001	1.008	<0.005	0.006, 0.010
Intercept	—	1.8382	0.426	—	<0.005	1.003, 2.673

Figure 1. Daily trends of ED visits, air quality, temperature, rainfall, windspeed between 2015 and 2024. A notable decrease in ED visits was observed after 2020, corresponding to the onset of COVID-19 pandemic and isolation measures.

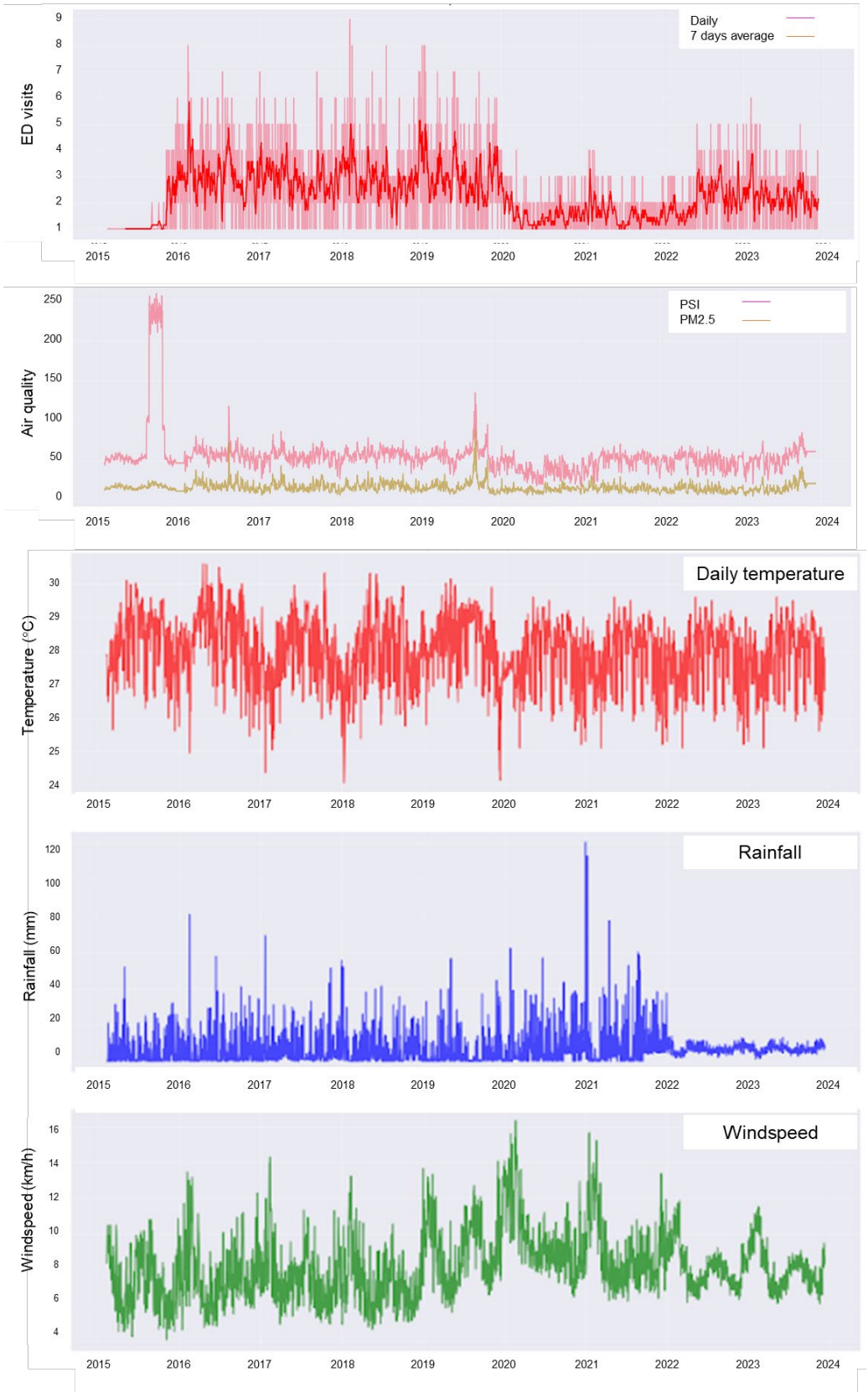


Figure 2. Correlation matrix between ED visit, PSI and climate variables using daily (left), weekly (middle), monthly (right) trends. ED visit was positively correlated with PSI, PM2.5 and negatively correlated with rainfall and temperature.

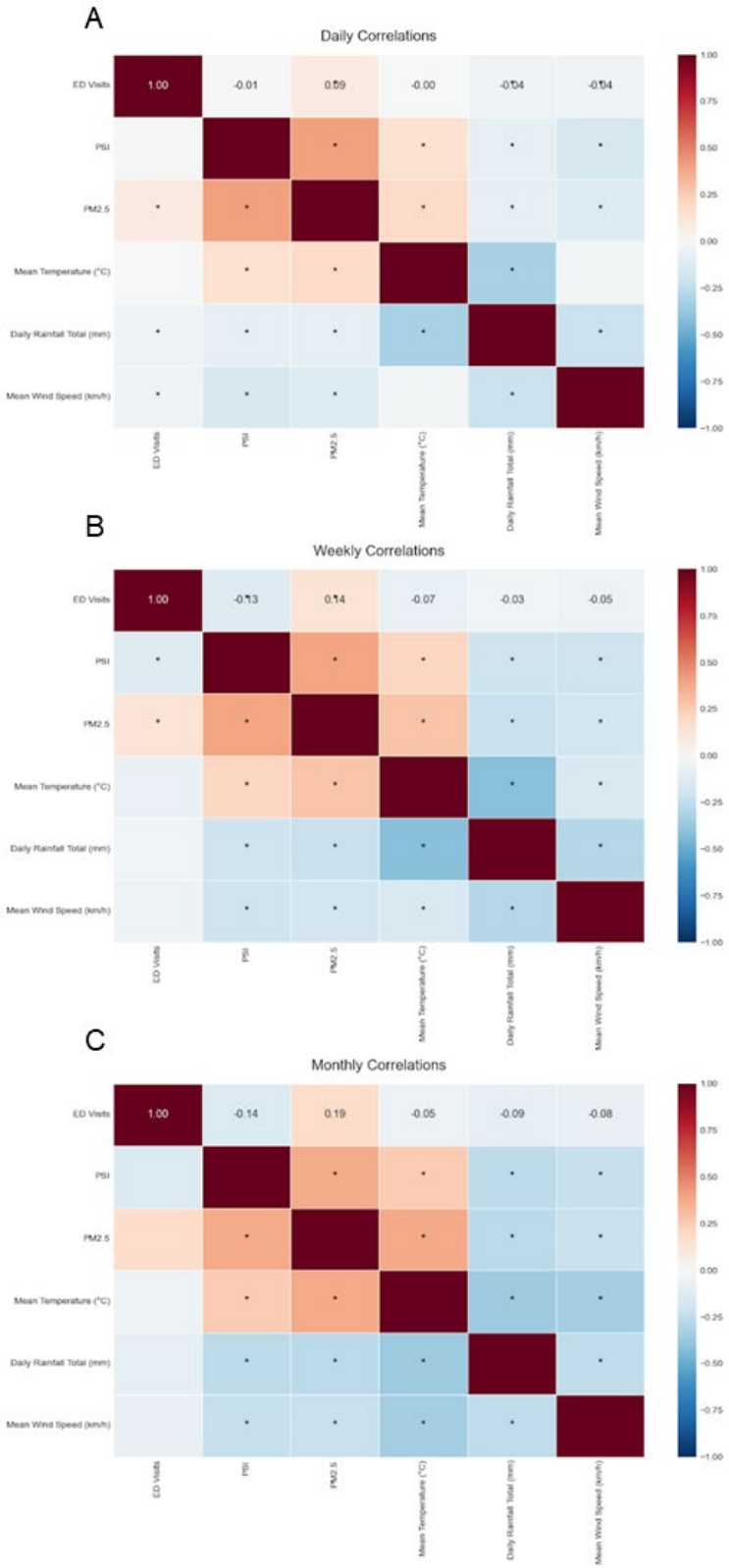


Figure 3. Time-lag correlation between ED visits, air quality and climate (lag 0 to 7).

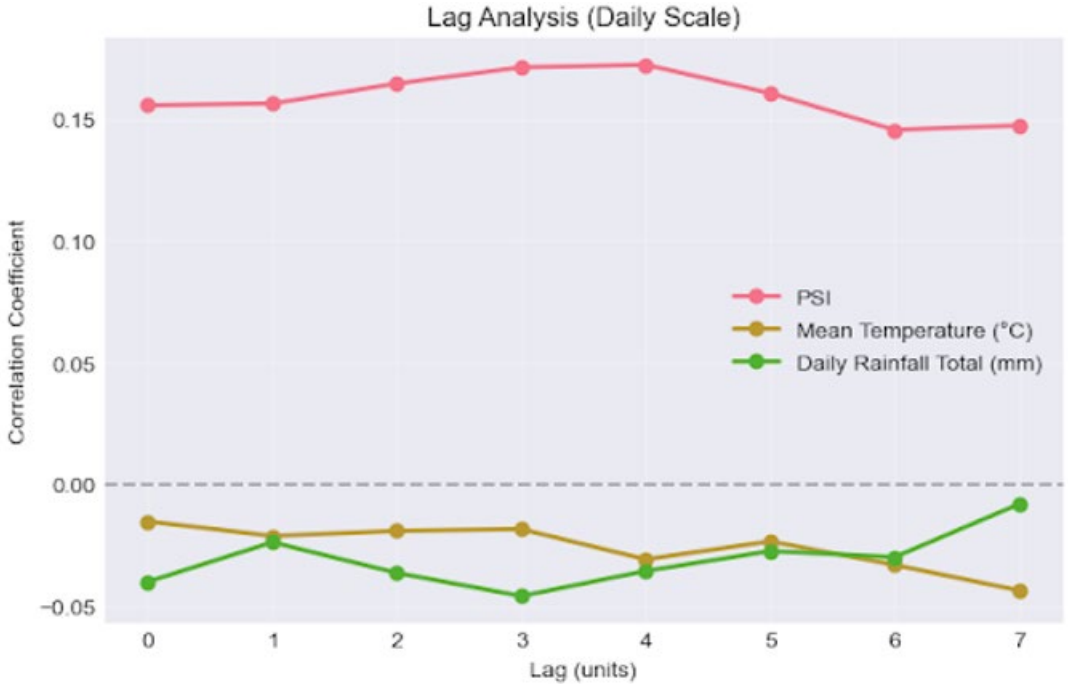
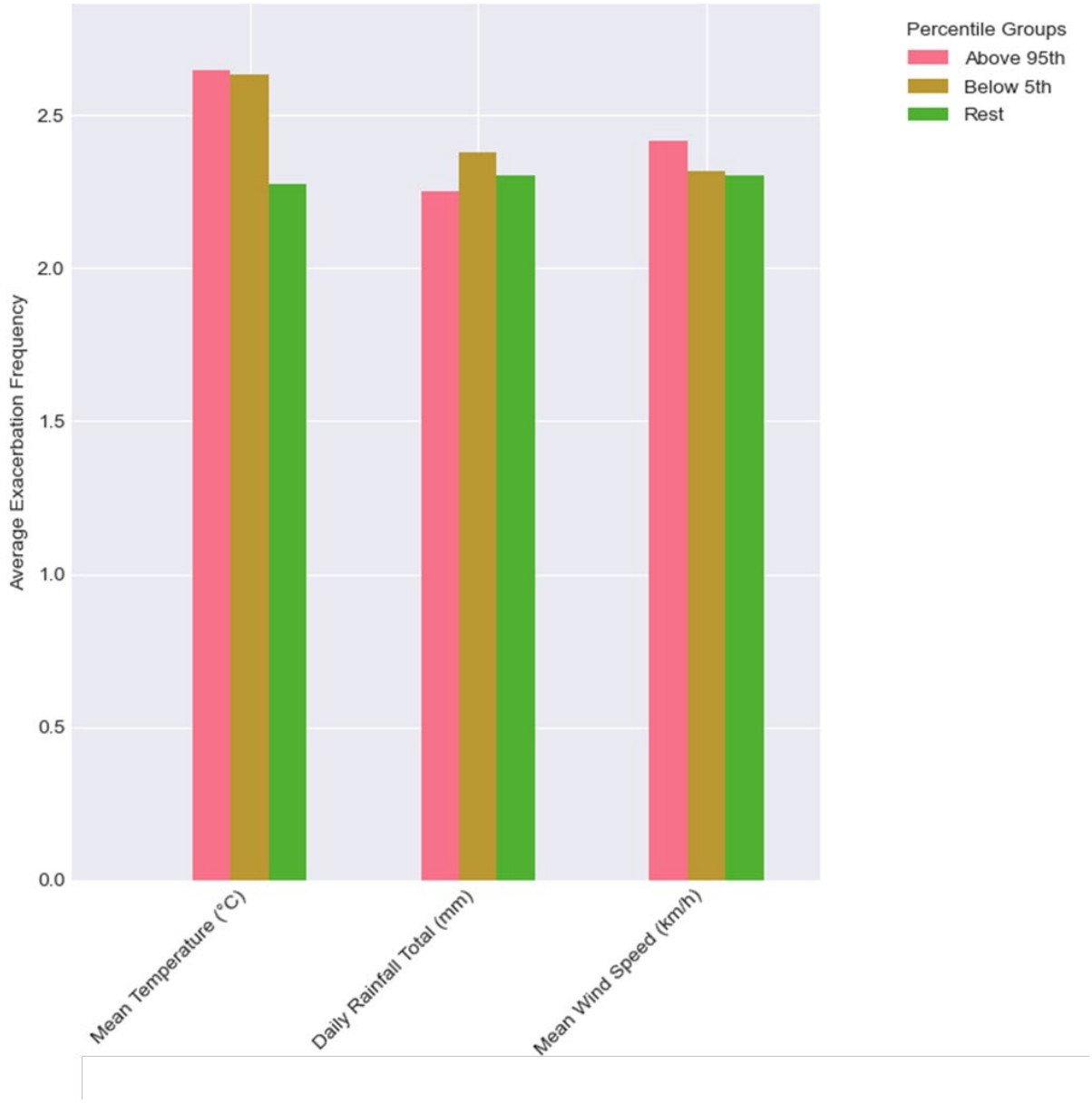


Figure 4. Comparing the frequency of ED visit between extremes of climate (5^{th}, 95^{th} percentiles) and the rest of the study period.



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