

The association between ambient air pollution and scarlet fever in Qingdao, China, 2014-2018: a quantitative analysis

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Abstract

Background: We conducted a distributed lag non-linear time series analysis to quantify the association between air pollution and scarlet fever in Qingdao city during 2014-2018.

Methods: A generalized additive Mixed Model (GAMM) combined with a distributed lag non-linear model (DLNM) was applied to quantify the distributed lag effects of air pollutions on scarlet fever, with daily incidence of scarlet fever as the dependent variable and air pollutions as the independent variable adjusted for potential confounders.

Results: A total of 6,316 cases of scarlet fever were notified, and there were 376 days occurring air pollution during the study period. Scarlet fever was significantly associated with air pollutions at lag 7 days with different RRs of air pollution degrees (1.172, 95%CI: 1.038-1.323 in mild air pollution; 1.374, 95%CI: 1.078-1.749 in moderate air pollution; 1.610, 95%CI: 1.163-2.314 in severe air pollution; 1.887, 95%CI: 1.163-3.061 in most severe air pollution).

Conclusions: Our findings show that air pollution is positively associated with scarlet fever in Qingdao. Moreover, the risk of scarlet fever could be increased along with the degrees of air pollution. It contributes to developing strategies to prevent and reduce health impact from scarlet fever and other non-vaccine-preventable respiratory infectious diseases in air polluted areas.

Introduction

Scarlet fever is an infectious disease caused by toxin-producing strains of the bacteria *Streptococcus pyogenes* (group A *Streptococcus*), which occurs most commonly in association with pharyngitis [1,2]. Although the effective antibiotics, hygiene and nutrition has been improved in the past decade, there were a sudden increase in the incidence of the scarlet fever in Asia [3–7]. After implementation of two-child policy from 2011, scarlet fever is an increasing threat to the growing child population in China, which had a sudden increase in the number of susceptible children [8]. Moreover, its reports of scarlet fever, which does not have a vaccine, have shown a substantial increase in the past 7 years [9]. It is considered that the reasons for this increase could include microbial, host and meteorological factors [8].

Air pollution is a complex environmental problem, which can cause adverse effects on the health of exposure population. Due to the rapid economic development and urbanization in China, the frequency and severity of air pollution episodes increased over the last few decades [10–12]. As such, a risk of health impacts on an unprecedented scale has been concerned widespread in this situation [13,14]. In eastern China, more air pollution events were observed compared with other areas [15]. Qingdao, as an important economical center and a seaport in eastern China, has suffered from air pollution frequently and been presented as a region with high PM_{2.5} and PM₁₀ mass concentrations [16].

In the past years, the incidence of scarlet fever increased continuously in Qingdao, which was considered to be related to environmental factors potentially [17]. At present, most of previous studies considered the meteorological factors, such as rainfall, temperature, air pressure and humidity, and rarely focused on the air pollution, which was suggested a link with severity of illness associated with respiratory infection [18]. Moreover, few relevant studies have reported the association between air pollution and scarlet fever. In our study, we conducted a distributed lag non-linear time series analysis to quantify the association between air pollution and scarlet fever in Qingdao city during 2014–2018.

Materials And Methods

Study area

As shown in Figure 1, Qingdao is a coastal city of Shandong province, which is situated in the eastern of China between longitude 119°30'-121°00' E and latitude 35°35'-37°09' N. The city has a mid-temperate continental monsoon climate with an annual average of 12.7°C and annual cumulative precipitation of 662.1 mm. Additionally, as a harbor city, Qingdao is the economic center of Shandong province with a population density of 801 persons per km² (in 2014: population=9,046,200; land size=11282 km²).

Data collection and management

Disease surveillance data

Daily disease surveillance data on scarlet fever from 2014 to 2018 in Qingdao were obtained from the Notifiable Disease Surveillance System (NDSS). The Chinese Government established an internet-based NDSS in 2003. 39 notifiable infectious diseases are monitored by use of this surveillance system and they are divided into three categories—classes A, B, and C—all of which must be reported within a specified timeframe. All class A infectious diseases and the class B diseases pulmonary anthrax and severe acute respiratory syndrome should be reported to the surveillance system within 2 h of diagnosis, whereas the other class B and the class C infectious diseases should be reported within 24 h. Scarlet fever is a class B notifiable infectious disease in China. All cases of scarlet fever including probable, clinical, and laboratory-confirmed infections were diagnosed according to the diagnostic criteria for scarlet fever issued by the Ministry of Health of the People's Republic of China in 2008 [19].

According to the 2004 Chinese Infectious Diseases Law, clinicians must complete a standardized infectious diseases card and report to the NDSS when they identify any probable, clinical, or laboratory-confirmed case of scarlet fever within 24 h of diagnosis. The local epidemiologist will do a field investigation once they have received the disease card using a standardized form, which includes basic demographic information (sex, date of birth, occupation, and living address); case classification; date of symptom onset, diagnosis, and death (if applicable); and clinical outcome. The epidemiologist then records their investigational data in the NDSS once they have finished their field investigation.

Air pollution data

Air pollution data during 2014-2018 in Qingdao were obtained from China National Environmental Monitoring Center, which issues daily air quality index and concentrations of major air pollutants to the public, including PM_{2.5}, PM₁₀, sulfur dioxide (SO₂), carbon monoxide (CO), nitrogen dioxide (NO₂) and ozone (O₃) for each city. According to Ambient Air Quality Standards issued by Ministry of Ecology and Environment of the People's Republic of China in December 2012, the standard limits of PM_{2.5}, PM₁₀, SO₂, CO and NO₂ concentrations, equivalently to the 24-hour means, are 75 µg/m³, 150 µg/m³, 150 µg/m³, 4 mg/m³ and 80 µg/m³, respectively, followed by the O₃ concentration limit with 200 µg/m³ on eight hours average.

Air pollution is defined as the phenomenon or event that the content of any substance in atmospheric are varied harmfully for ecological stability and the condition of human survival, causing hazards for human, animals, vegetation or material. Air quality index (AQI) is a number used by government agencies to communicate to the public how polluted the air is currently. Individual Air Quality Index (IAQI) represents the state of individual contaminant. The IAQI was calculated as follows according to the Technical Regulation on Ambient Air Quality Index (on trial):

[Due to technical limitations, the formula could not be displayed here. Please see the supplementary files section to access the formulas.]

IAQI_P represents the Individual Air Quality Index of P contaminant. C_P represents the mass concentration of P contaminant. BP_{Hi} and BP_{Lo} represent the highest and lowest value of concentration limit like C_P, respectively. IAQI_{Hi} and IAQI_{Lo} represent the Individual Air Quality Index of BP_{Hi} and BP_{Lo}, respectively.

The AQI was calculated as followed :

[See supp. files]

IAQI represents the Individual Air Quality Index of contaminants. n represents the specific contaminant.

AQI values are divided into ranges, and each range is assigned a descriptor. According to the Technical Regulation on Ambient Air Quality Index (on trial), air pollution are divided into 4 levels on the basis of AQI, which are mild pollution (AQI:101-150), moderate pollution (AQI:151-200), severe pollution (AQI:201-300) and most severe pollution (AQI:≥300).

Meteorological data

Meteorological data from 2014 to 2018 were collected from the China Meteorological Data Sharing Service System (<http://cdc.cma.gov.cn/>), which includes daily data such as cumulative precipitation, average temperature and average air pressure, etc.

Statistical analysis

First, the distribution of scarlet fever morbidity and air pollution variables were described between during the study period. Second, a generalized additive Mixed Model (GAMM) combined with a distributed lag non-linear model (DLNM) was applied to quantify the distributed lag effects of air pollutions on scarlet fever, with daily incidence of scarlet fever as the dependent variable and air pollutions as the independent variable adjusted for potential confounders. A quasi-Poisson regression was used to deal with the over dispersion of Poisson distribution. In order to control the potential confounds, the weather factors, long-term and seasonal trend, day of the week (DOW) and public holidays were introduced into the model simultaneously. The model is as follows:

[See supp. files]

Where t referred to the day of the observation. Y_t denoted the daily morbidity of scarlet fever on day t . α was the intercept. $\text{Pollution}_{t,l}$ and $\text{Pollutant}_{t,l}$ were matrixes obtained by applying the DLNM to air pollution and air pollutants over a lag of 0 to l days. γ and δ were the vectors of corresponding air pollution and pollutants variables. $NS()$ represents the natural spline function. DF was the degree of freedom of the nonparametric smoothing spline function. Prec_t , Temp_t and Pressure_t referred to cumulative precipitation, average temperature and average air pressure on day t , respectively. Time was used to control for long-term trend and seasonality confounding. DOW_t was day of the week on day t , which was a categorical variable. Holiday was a binary variable that the value was "1" if day t was a public holiday.

Air pollutants usually have a highly interaction effect, which may result in collinearity in the model. In order to avoid the collinearity, the pairwise correlation was applied by spearman correlation in all air pollutants. Among the six air pollutants, there were two pollutants such as $\text{PM}_{2.5}$ and O_3 with no correlation ($P < 0.05$), therefore $\text{PM}_{2.5}$ and O_3 were included in the model. In order to completely capture the effects of air pollution and air pollutant concentrations on daily morbidity of scarlet fever, the DLNM was applied for air pollution and air pollutants in our study with both 3 degrees of freedom (DF) [20-22]. Using a natural cubic spline, we chose DF as 7 per year for time to remove long term trends and seasonality [22]. Additionally, we used smooth function of natural cubic splines with 3 DF in the model for cumulative precipitation, average temperature and air pressure. Choices for all degrees of freedom in the model were according to previous studies and the lowest Akaike information criterion (AIC).

Previous studies have shown that the lagged effect of air pollutants on respiratory diseases were usually short [23,24]. The incubation period of scarlet fever is usually between 1 and 3 days [25]. However, considering the delayed environmental transport of pathogens and delayed onset of clinical symptoms, morbidity of scarlet fever was expected to peak several days after the exposure of air pollution. Therefore, a lag effect at a maximum of 7 days were applied in the DLNM.

Sensitive analysis was performed by altering DF (6-9 per year) for time, DF (2-5) for cumulative precipitation, average temperature and air pressure. R software (version 3.2.2, R Development Core Team 2015) was used to perform all statistical analyses. The "dlnm" package was used to create the DLNM model. All statistical tests were two-sided, and p values with less than 0.05 were considered statistically significant.

Results

Description of disease and air pollution

A total of 6,316 cases of scarlet fever were notified in the study area over no air pollution and air pollution periods from 2014 to 2018. Descriptive statistics of the scarlet fever morbidity, air pollution and meteorological factors are presented in Table 1, which are significantly different between no air pollution and air pollution periods. During the study period, there were 376 days occurring air pollution, including 278 days with mild air pollution, 58 days with moderate air pollution, 37 days with severe air pollution and 3 days with most severe air pollution.

Association between air pollution and scarlet fever

The risk ratios (RRs) of air pollution on the risk of scarlet fever from the DLNM model were presented in Table 2. Results showed that scarlet fever was significantly associated with air pollutions at lag 7 days with different RRs of air pollution degrees (1.172, 95%CI: 1.038-1.323 in mild air pollution; 1.374, 95%CI: 1.078-1.749 in moderate air pollution; 1.610, 95%CI: 1.163-2.314 in severe air pollution; 1.887, 95%CI: 1.163-3.061 in most severe air pollution), but there was no significant association between scarlet fever and air pollution at other lag periods. The cumulative effects of air pollutions were presented in Figure 2. After controlling for precipitation, temperature, air pressure, seasonality and long-term trends, air pollutions were associated with scarlet fever significantly with cumulative RR values at lag 0-7 days equal to 1.454 in mild air pollution (95%CI:1.015-2.082), 2.114 in moderate air pollution (95%CI:1.031-4.334), 3.073 in severe air pollution (95%CI:1.046-9.023) and 4.467 in most air pollution (95%CI:1.062-18.785). Table 3 listed the RRs of air pollutants, such as PM_{2.5} and Q₃ with specific concentrations at lag 0-7 days.

Sensitivity analyses

Sensitivity analyses were conducted to check whether our coefficient estimates were robust. The effects changed little when changing DF (2-5) for cumulative precipitation, average temperature, and average air pressure, we found that the effects estimated at lag 7 days did not change substantially (Figure 3). Similar effects of air pollutions on scarlet fever were observed when changing DF (6-9 per year) for time (Figure 4).

Discussion

In recent years, scarlet fever has been recognized as a significant infectious disease related to meteorological factors [26,27], however, the potential risk environmental factors have been considered to be more. Our study has quantified the lagged and cumulative effects of air pollutions on the risk of scarlet fever in Qingdao, China using a distributed lag non-linear model. After controlling for the meteorological factors, day of the week, holiday, seasonality and long-term trend, results indicate that air pollutions may play an important role in the epidemic of scarlet fever. Although this study is based on Qingdao city only, the real impact of scarlet fever due to air pollutions might be much greater, given the large population at risk and frequent air pollutions in China. Results from this study might be applicable to most cities in eastern coastal areas of north China, because air quality and climates in those places were similar with that in Qingdao.

Air pollution is the fifth leading global risk factor for public health, which contributes substantially to disease burden [28,29]. Due to the implementation of policies and plans to reduce air pollution and its adverse effects on public health in China, the air quality of most regions has been improving since 2013 and the national annual mean concentrations of air pollutants decreased between 2004 and 2018 [30]. However, air pollution remains severe and its subsequent health effects still persist. In Qingdao, there were 376 days occurring air pollution between 2014 and 2018, accounting for one fifth of the study period. During the days of air pollution, the mean concentrations of pollutants were significantly higher than no air pollution days, and the mean concentrations of different degrees of air pollution days increase with air pollution levels.

To our knowledge, it is the first time that a study has evaluated the risk of air pollutions on scarlet fever based on air pollution levels not only pollutant concentrations. Previous studies mainly focused on the air pollutant concentrations to evaluate the association with diseases [22–24]. Although using the concentration could accurately present the impact of health by certain concentrations or concentration ranges, it just stays in a single pollutant, which seems to be far from adequate for assessing the impact of air pollutions. Air pollution is a complex environmental problem, and it depends on the conditions of various pollutants. Therefore, it should consider the status of various air pollutants at certain moments to analyze the association between air pollutions and diseases. AQI is considered a summary assessment of ambient air pollutants, aiming at expressing the concentration of pollutants on a common scale where effects human health. According to the AQI, air pollution is classified into four levels, including mild pollution, moderate pollution, severe pollution and most severe pollution. Compared with concentrations of air pollutants, the degrees of air pollution might be more interesting in estimating the association between air pollutions and scarlet fever, which could present the impacts of overall situation of air pollution on health.

In our study, results of the DLNM show that air pollutions were associated with increased risks of scarlet fever with 7 days' effects after adjustment for meteorological factors, day of the week, holiday, seasonality and long-term trend. Moreover, it suggests that

the risk of air pollutions on scarlet fever could increase along with the degrees of air pollution. Compared with good air quality, the worse air quality may increase the risk of scarlet fever. This could be significant for local government to advance policies to protect population health. Due to the explosion of the child population under the two-child policy in China, the non-vaccine-preventable childhood disease such as scarlet fever might be a potential risk [8,31]. In the recent years of China, the awareness of air pollution and its health implications have been increased significantly, and a series of corresponding measures have been implemented including substantial investments in the improvement of air quality and a multidimensional control strategy aimed at reducing emissions from vehicles and fuels [32–34]. All these actions are very important to decrease the threat of scarlet fever merging scarlet fever and other non-vaccine-preventable respiratory infectious diseases in China.

We suppose that the impact of air pollution on scarlet fever is most depended on the effects of air pollutants. Our results reveal a positive association between daily average concentrations of air pollutants and scarlet fever morbidity, and the increased risks of scarlet fever are detected by $PM_{2.5}$ (50 $\mu g/m^3$, 70 $\mu g/m^3$, 100 $\mu g/m^3$, 150 $\mu g/m^3$) at lag 1 and 2 day, and NO_2 (60 $\mu g/m^3$, 80 $\mu g/m^3$) at lag 7 day. The risk estimate for $PM_{2.5}$ and NO_2 found in our study was consistent with earlier findings for Beijing [35]. However, the effects between $PM_{2.5}$ and NO_2 were a little different, such as the positive association of $PM_{2.5}$ with concentrations below or exceed standard limit, but the positive association of NO_2 with concentrations below standard limit, which may be related to different geographical distribution, population size and density, etc. Previous studies tried to investigate the mechanisms of the damage effects of air pollutants, such as $PM_{2.5}$ and NO_2 , but the biological mechanisms underlying the association between air pollutants and scarlet fever remain elusive. One of the reasons was such exposures over short periods, and longer exposures to elevated concentrations of $PM_{2.5}$ and NO_2 may irritate airways in the human respiratory system and potentially increase susceptibility to respiratory infections [36]. Studies suggested that there were three pathways which may promote this possible situation, including injury from free radical peroxidation, imbalanced intracellular calcium homeostasis and inflammatory injury [36]. However, future patient-level and mechanistic research should be done to prove the findings.

Compared with other studies researching the association between air pollution and scarlet fever, a significant feature in our study is that we use daily data to analysis this association. Different from weekly and monthly data, daily data is more accurate to assess the impact of air pollution. Applying weekly or monthly data would have to face a fact that this would underestimate the effect of extreme pollution events by averaging its impact on the long temporal scale. It may even occur that air pollution associates with one disease at weekly or monthly scale because of averaging the impacts of extreme pollution events. Using daily data to analyze the association could avoids this situation, and it could identify the degrees of air pollution to assess the impact of air pollution precisely.

Limitations of our study should be acknowledged. Firstly, due to lack of case data, we just evaluated the effect of air pollution on overall population, and cannot analyze the effects among different gender and age groups. Secondly, the effects of many factors, such as population, available health services and hygiene, social and economic status, were not included in this analysis due to unavailable data. Thirdly, we did not analyze the effect pf air pollutions on scarlet fever cases by GAS emm types. In addition, under-reporting is an inevitable issue, which could lead to an underestimation of the impact of air pollutions on scarlet fever.

Conclusion

In conclusion, our findings show that air pollution is positively associated with scarlet fever in Qingdao. Moreover, the risk of scarlet fever could be increased along with the degrees of air pollution. Our findings contribute to developing local strategies to prevent and reduce health impact from scarlet fever and other non-vaccine-preventable respiratory infectious diseases in air polluted areas.

Declarations

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Availability of data and material

The complete dataset is included in this manuscript.

Authors' contribution

Wei Ni, Xiaowen Hu, Fachuan Jiang and Tao Wei: They conducted the literature review and analyses and drafted the manuscript, and approved the final manuscript as submitted. Yalin Han, Jing Jia and Bei Pan: They conducted the data collection and analysis, and critically reviewed the manuscript, and approved the final manuscript as submitted.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

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Tables

Table 1 Description of scarlet fever incidence, air pollution and meteorological factors from 2014 to 2018 in Qingdao city

Variables	period	Mean±SD	Min	P ₂₅	Median	P ₇₅	Max
Daily morbidity of scarlet fever(1*10 ⁸)	No air pollution period	3.7±3.7	0	1.1	2.2	5.4	23.9
	Air pollution period*	4.3±4.2	0	1.1	3.3	6.5	22.6
PM _{2.5} (µg/m ³)	No air pollution period	32.6±16.9	0	19.8	29.0	43.0	95.0
	Air pollution period*	89.0±44.5	0	58.0	83.5	107.0	304.0
PM ₁₀ (µg/m ³)	No air pollution period	70.0±66.0	0	48.0	66.0	90.0	165.0
	Air pollution period*	156.0±63.1	0	119.0	150.0	186.0	455.0
SO ₂ (µg/m ³)	No air pollution period	17.9±12.4	2.0	9.0	15.5	23.0	79.0
	Air pollution period*	33.8±22.2	2.0	18.0	28.0	43.0	132.0
CO (mg/m ³)	No air pollution period	0.7±0.6	0.2	0.5	0.6	0.8	8.6
	Air pollution period*	1.3±0.8	0.4	0.9	1.1	1.5	12.6
NO ₂ (µg/m ³)	No air pollution period	31.9±14.4	3.0	21.0	30.0	40.0	107.0
	Air pollution period*	48.7±18.9	9.0	34.0	46.0	62.8	111.0
O ₃ (µg/m ³)	No air pollution period	94.5±32.2	0	68.0	95.0	119.0	161.0
	Air pollution period*	113.0±60.7	0	58.3	99.0	168.8	254.0
Cumulative precipitation (mm)	No air pollution period	1.9±7.7	0	0	0	0	121.4
	Air pollution period*	0.3±2.6	0	0	0	0	39.2
Average temperature (°C)	No air pollution period	14.3±9.6	-12.9	6.4	15.7	22.6	30.5
	Air pollution period*	11.9±9.4	-4.4	3.7	9.9	20.1	30.6
Average air pressure (KPa)	No air pollution period	1000.8±9.2	988.3	1000.4	1008.4	1015.8	1032.3
	Air pollution period*	1009.3±8.7	987.8	1001.9	1010.4	1016.0	1027.6

SD: standard deviation; Min, minimum; P₂₅, the 25th percentile; P₇₅, the 75th percentile; Max, maximum.

*p < 0.05 vs. non-flooded month.

Table 2 The RRs of air pollution on the risk of scarlet fever from the DLNM model

Lags	Mild	Moderate	Severe	Most severe
Lag0	1.034(0.912-1.174)	1.071(0.831-1.379)	1.108(0.758-1.619)	1.147(0.691-1.902)
Lag1	1.077(0.994-1.168)	1.161(0.987-1.363)	1.251(0.983-1.592)	1.348(0.977-1.859)
Lag2	1.066 (0.980-1.159)	1.137(0.961-1.344)	1.212(0.943-1.558)	1.292(0.924-1.806)
Lag3	1.029 (0.957-1.106)	1.058(0.916-1.224)	1.089(0.877-1.353)	1.121(0.839-1.497)
Lag4	0.994 (0.925-1.068)	0.988(0.856-1.141)	0.982(0.792-1.219)	0.977(0.732-1.303)
Lag5	0.987 (0.908-1.073)	0.974(0.825-1.151)	0.962(0.749-1.235)	0.949(0.680-1.325)
Lag6	1.034(0.954-1.120)	1.069(0.910-1.254)	1.105(0.869-1.405)	1.142(0.829-1.573)
Lag7	1.172(1.038-1.323)*	1.374(1.078-1.749)*	1.610(1.163-2.314)*	1.887(1.163-3.061)*

Mild: mild air pollution; Moderate: moderate air pollution; Severe: severe air pollution; Most severe: most severe air pollution.

* p < 0.05.

Table 3 the RRs of air pollutant with specific concentrations at lag 0-7 days from the DLNM model

Concentrations	Lag0	Lag1	Lag2	Lag3	Lag4	Lag5	Lag6	Lag7
PM _{2.5} ($\mu\text{g}/\text{m}^3$)								
50	1.065(0.592-1.916)	1.622(1.048-2.510)*	1.497(1.078-2.081)*	1.176(0.840-1.645)	0.986(0.699-1.390)	0.993(0.709-1.391)	1.210(0.782-1.872)	1.607(0.914-2.822)
75	0.897(0.486-1.656)	1.652(1.050-2.600)*	1.478(1.050-2.076)*	1.053(0.777-1.555)	0.920(0.661-1.343)	1.092(0.736-1.469)	1.447(0.847-2.090)	1.374(0.803-2.574)
100	0.803(0.418-1.543)	1.702(1.051-2.756)*	1.478(1.027-2.123)*	1.053(0.729-1.522)	0.920(0.632-1.339)	1.092(0.757-1.575)	1.447(0.895-2.339)	1.610(0.706-2.426)
150	0.752(0.351-1.611)	1.863(1.065-3.257)*	1.530(1.003-2.334)*	1.029(0.671-1.578)	0.926(0.600-1.430)	1.212(0.792-1.853)	1.658(0.948-2.899)	1.887(0.557-2.308)
NO ₂ ($\mu\text{g}/\text{m}^3$)								
60	1.922(0.930-3.972)	0.913(0.536-1.557)	0.830(0.552-1.247)	0.941(0.620-1.427)	1.052(0.695-1.592)	1.109(0.733-1.677)	1.272(0.731-2.212)	2.219(1.066-4.617)*
80	2.081(0.973-4.451)	0.892(0.509-1.562)	0.764(0.499-1.172)	0.856(0.554-1.323)	0.981(0.636-1.514)	1.077(0.698-1.663)	1.273(0.712-2.277)	2.181(1.015-4.685)*
100	2.174(0.926-5.102)	0.831(0.437-1.582)	0.649(0.398-1.060)	0.719(0.436-1.187)	0.891(0.540-1.471)	1.106(0.669-1.828)	1.395(0.714-2.724)	2.065(0.866-4.924)
120	0.614(0.126-2.986)	0.870(0.311-2.431)	1.167(0.570-2.388)	1.267(0.630-2.550)	1.096(0.520-2.308)	0.855(0.424-1.723)	0.785(0.289-2.141)	1.275(0.381-4.275)

Figures

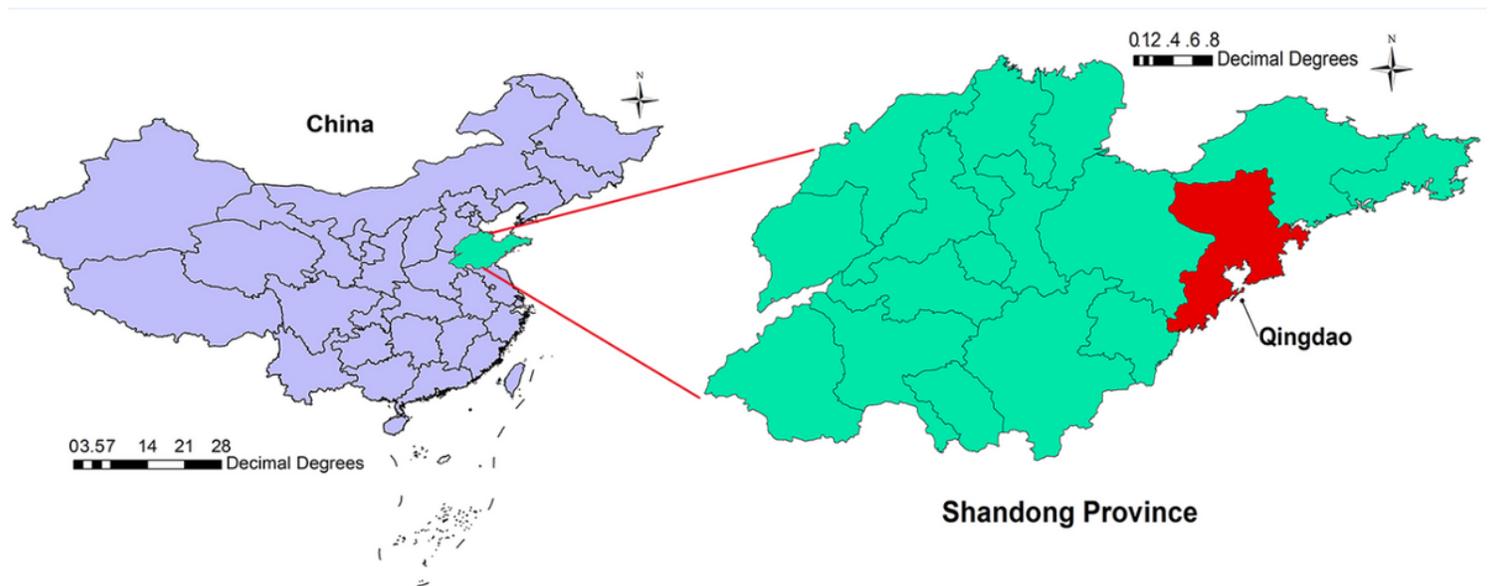


Figure 1

Location of Qingdao in Shandong Province, China. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

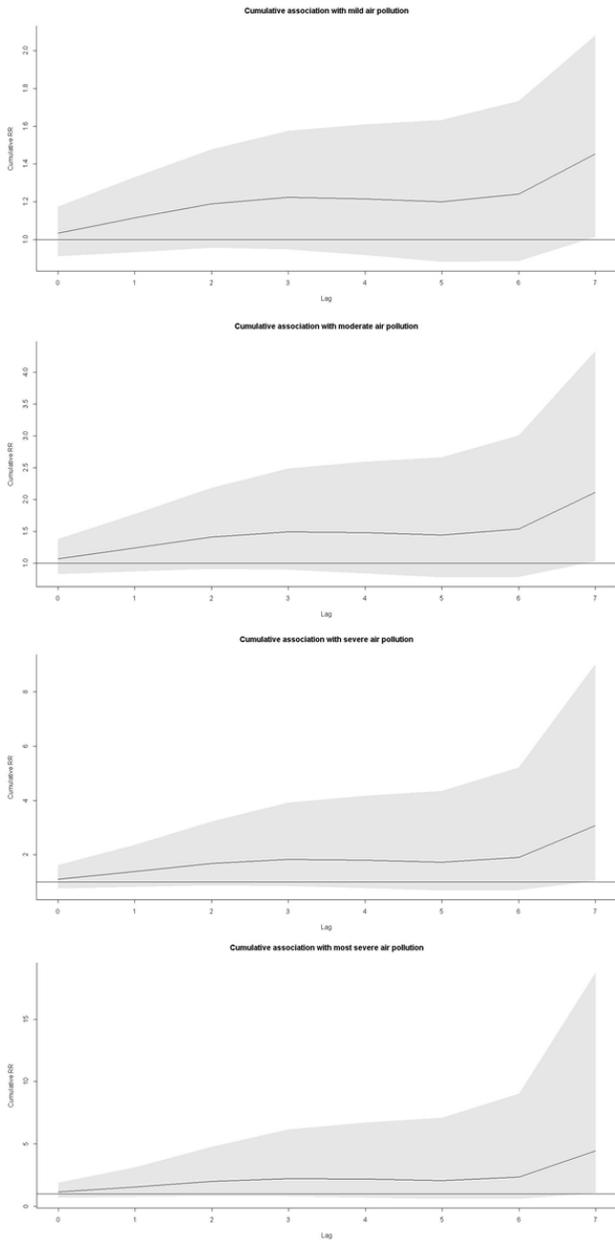


Figure 2

The cumulative relative risks (RRs) of different degrees of air pollution at lag 0-7 days.

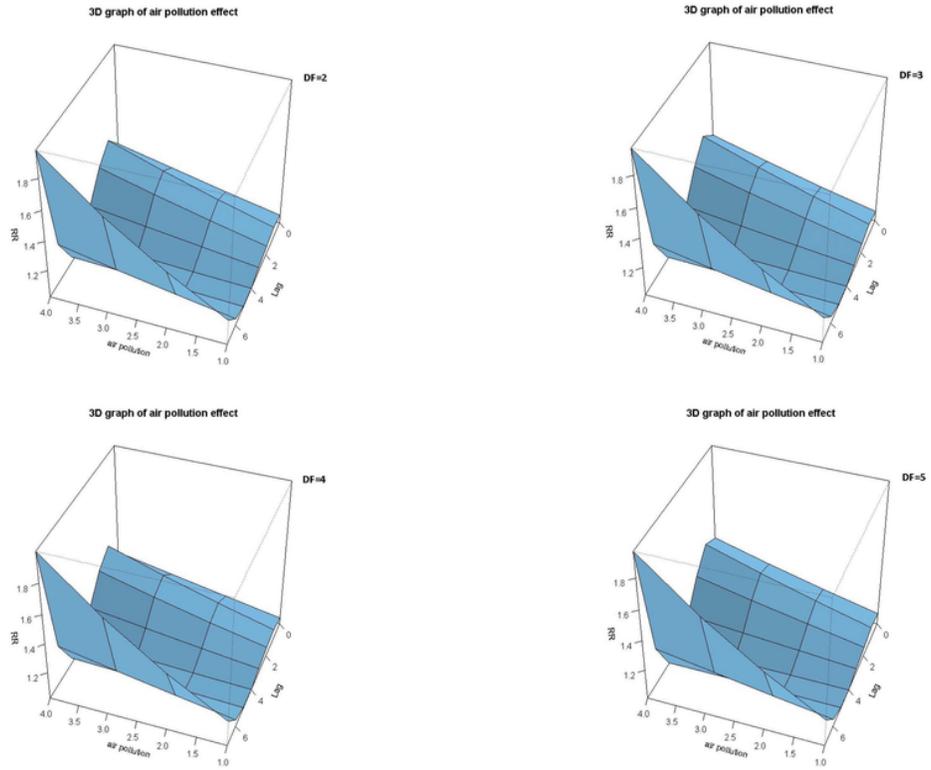


Figure 3

The 3D graphs of air pollution effect with DF 2-5 of meteorological factors.

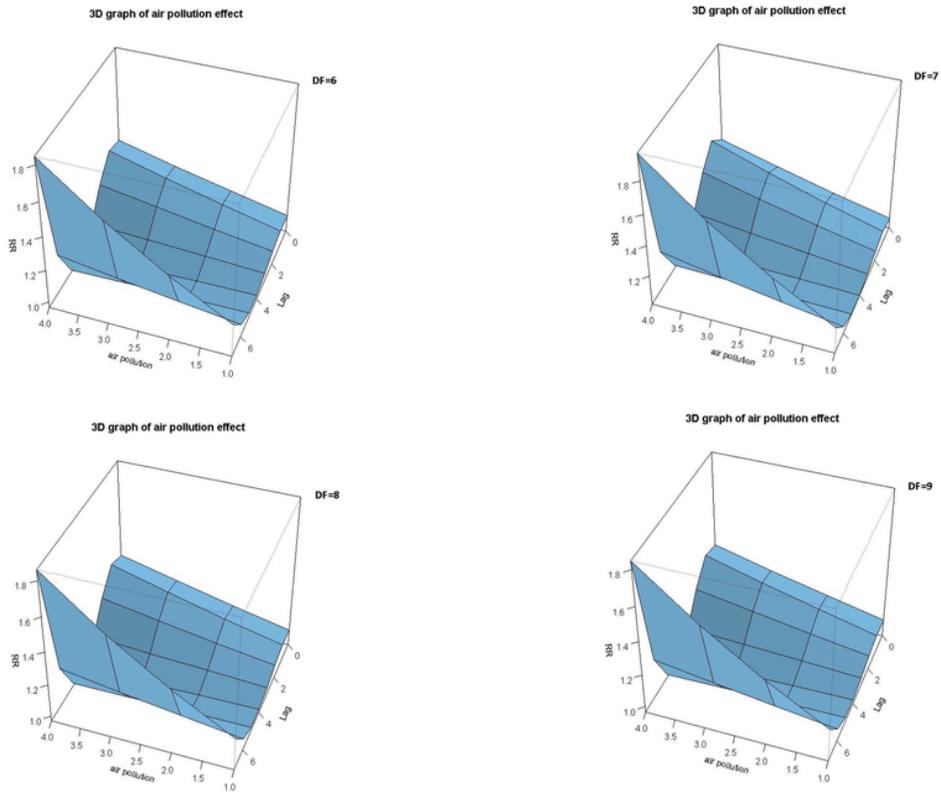


Figure 4

The 3D graphs of air pollution effect with DF 6-9 of Time.

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- [Methodsformulas.docx](#)