Relationship between air pollution and outpatient visits for nonspecific conjunctivitis in Taiwan: an application of Bayesian regression model

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Abstract. As a direct exposed part of the human body, the eyes are susceptible to external stimuli of air pollution. The adverse effects of air pollution on the human eye are mainly stimulation and inflammation, and conjunctivitis is a major problem. This study investigated the effects of air pollution on non-specific conjunctivitis based on data from a Taiwanese outpatient clinic. The study focused on the importance of air pollution to eye health. Data for ophthalmology outpatient visits were obtained from the National Health Insurance Research Database of Taiwan. Ambient air monitoring data were obtained from the Taiwan Environmental Protection Administration air pollution monitoring stations. The study included five regulated air pollutants. This study used Bayesian linear regression to investigate the association between daily air pollutant concentrations and the number of outpatient visits for non-specific conjunctivitis. The results of this study indicate that air pollutants SO$_2$, CO and PM$_{10}$ are significantly associated with non-specific conjunctivitis. Air pollutants, SO$_2$, CO and PM$_{10}$ can increase the chances of outpatient visits, suggesting that this may be the cause of non-specific conjunctivitis.

1. Introduction
Air pollution is associated with many adverse health effects and diseases, and many studies are well aware of this. [1, 2, 3, 4, 5] WHO defines air pollution as “the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. [6]” Although recent legislation on air pollutant standards is more stringent than before, air pollution remains a major problem and its health effects remain. The more developed countries attach great importance to the regulation of air pollution, and the organization and government departments have conducted comprehensive review and guidance.

Previous studies were carried out on the correlation between air pollutants and health using a wide spectrum of mathematical and statistical methods. Findings from most of the previous studies showed that air pollutants have negative influence on health. Studies on lung cancer [1, 2], acute respiratory infection [3], liver cancer [4], and menstrual cycle [5] showed a significant correlation between health and air pollutants. Dense innervations in the ocular surface are extremely sensitive to environmental agents. [7] Furthermore, the eyes are protected only by a thin layer of tear film from potentially damaging exterior influences. [8] Thus, human eyes are very susceptible to ill effects of air pollution.

The ill effects of air pollution on human eyes are mostly irritation and inflammation, with conjunctivitis being a significant problem. [9, 12-15] Many research investigations have attempted to...
discover the effects of environmental toxins on the ocular surface. Among persons living in high-polluted areas, a considerable portion suffers from subclinical ocular surface changes. [12]

Conjunctivitis is one of the most commonly diagnosed conditions in ophthalmologic outpatient and emergency room visits. [14] More than 40% of ophthalmologic outpatient visits are diagnosed with conjunctivitis annually, according to data from the Bureau of Taiwan National Health Insurance. Conjunctival disorders induced by air pollution can be subclinical ocular surface changes [12], but on many occasions with serious discomforts such as burning and irritation require clinical visits. Furthermore, chronic exposure to air pollution can induce cellular change, such as goblet-cell hyperplasia in the ocular surface. [10] The discomforts of ocular diseases manifested in burning, irritation, itching, and tearing interfere with people’s daily activities, including work efficiency and road safety. Treating ocular diseases by steroid eye drops occasionally results in cataracts, glaucoma, and other severe side effects, which can lead to permanent vision loss. [11]

Bourcier, Viboud, Cohen, Thomas, Bury, Cadiot, Mestre, Flahault, Borderie, and Laroche investigated short-term associations between ophthalmologic emergency room visits and air pollution in Paris, and they concluded a relation between NO$\textsubscript{2}$, O$\textsubscript{3}$, SO$\textsubscript{2}$, and PM$\textsubscript{10}$ and conjunctivitis. [9] Chang, Yang, Chang, and Tsai investigates the relationship between air pollution and outpatient visits for nonspecific conjunctivitis in Taiwan, and they found that the air pollutants, NO$\textsubscript{2}$, SO$\textsubscript{2}$, O$\textsubscript{3}$, and PM$\textsubscript{10}$ increase the chances of outpatient visits for nonspecific conjunctivitis and have no evident lag effects. [12] Mimura, Ichinose, Yamagami, Fujishima, Kamei, Goto, Takada, and Matsubara examined the association of airborne pollutants with allergic conjunctivitis in Tokyo. Their findings suggest a possible role of PM$\textsubscript{2.5}$ in the development of allergic conjunctivitis during the non-pollen season. This association between PM$\textsubscript{2.5}$ and allergic conjunctivitis may have broad public health implications in relation to allergic diseases. [13] Szyszkowicz, Kousha, and Castner examine the associations between emergency department visits for conjunctivitis and ambient air pollution levels in urban regions across the province of Ontario, Canada and they suggest that there are associations between these two, with different temporal trends. [14] Based on the database of the Shanghai Health Insurance System (SHIS), Hong, Zhong, Li, Xu, Ye, Mu, Lu, Mashaghi, Zhou, Tan, Li, Sun, Liu, and Xu assess the relationship between air pollutants with outpatient visits for allergic conjunctivitis. They found that higher levels of ambient NO$\textsubscript{2}$, O$\textsubscript{3}$, and temperature increase the chances of outpatient visits for allergic conjunctivitis. Ambient air pollution may contribute to the worsening of allergic conjunctivitis. [15]

2. Materials and research method

This study used Bayesian linear regression to investigate the relationship between air pollution concentrations and outpatient visits for nonspecific conjunctivitis (Figure 1). In the Bayesian linear regression of the cases of nonspecific conjunctivitis, the SO$\textsubscript{2}$, NO$\textsubscript{2}$, O$\textsubscript{3}$, CO, and PM$\textsubscript{10}$ are regarded as air pollutants.

![Figure 1. The research framework](image)

2.1. Study area

Taiwan has made efforts on air pollution monitoring and control. The Environmental Protection Administration (EPA) of Taiwan started to set up the Taiwan Air Quality Monitoring Network (TAQMN) in 1990. In September 1993, there were 66 air quality monitoring stations in TAQMN, replacing the original 19. Up until 1998, there were 72 air quality monitoring stations, including four traffic pattern stations, four background pattern stations, three industrial pattern stations and two
national park pattern stations. These five types of air quality monitoring stations serve different purposes.

In Taiwan, the priority pollutants that can be monitored through continuous emission monitoring systems (CEMS) of the monitoring network include sulfur dioxides (SO$_2$), nitrogen dioxide (NO$_2$), oxygen (O$_2$), carbon monoxide (CO), and particulate matter (PM$_{10}$).

2.2. Data collection
The research focuses on the significance of air pollution’s impact on ocular health. Data for ophthalmology outpatient visits were obtained from the National Health Insurance Research Database of Taiwan. Nonspecific conjunctivitis was defined and filtered according to the diagnostic codes in the International Classification of Diseases, 9th revision (ICD-9). Ambient air monitoring data were obtained from the Taiwan Environmental Protection Administration air pollution monitoring stations. Six regulated air pollutants were included in this study.

Though many air pollutants are monitored in Taiwan, not every air monitoring station monitors all kinds of the air pollutants because different kind of monitoring stations has its own purpose. This study only concerns about SO$_2$, NO$_2$, O$_2$, CO, and PM$_{10}$. These air pollutants are regarded as criteria pollutants because the pollutant standard index (PSI) is based on them. Only the monitoring stations that contained data with all these six pollutants were considered for this study.

The clinic visit counts of non-specific conjunctivitis were obtained from the data of National Health Insurance database. This database is originated from the Bureau of National Health Insurance (BNHI) and cleaned by National Health Research Institute (NHRI) of Taiwan. Data from ophthalmologic outpatient visits between 1997 and 2010 were obtained from the National Health Insurance Database. In ICD-9-CM, acute conjunctivitis is coded 372.00; chronic conjunctivitis is coded 372.10; simple chronic conjunctivitis is coded 372.11; other chronic allergic conjunctivitis is coded 372.14; blepharoconjunctivitis is coded 372.20, other and unspecified conjunctivitis is coded 372.30; and conjunctival hemorrhage is coded 372.72. To protect privacy, the data on patient identities and institutions had been scrambled cryptographically.

2.3. Data analysis: Bayesian regression model
The cases of nonspecific conjunctivitis of Taiwan from January 1997 to December 2010 were analyzed with Bayesian linear regression with Julia. [16] The Bayesian linear regression model plots the nonspecific conjunctivitis incidence (cases) versus SO$_2$, NO$_2$, O$_2$, CO, and PM$_{10}$ in the following equation:

\[
\text{nonspecific conjunctivitis incidence} = \beta_0 + \beta_1 \cdot \text{SO}_2 + \beta_2 \cdot \text{NO}_2 + \beta_3 \cdot \text{O}_2 + \beta_4 \cdot \text{CO} + \beta_5 \cdot \text{PM}_{10}
\]

This study introduced the Bayesian regression model by Martin, Quinn, and Park. The main advantages of the Bayesian approach is that using Markov chain Monte Carlo (MCMC) to output backward reasoning is very simple, as these methods provide a direct sample of the parameters of interest. [17-19] In purpose of to detect the significance of air pollution’s impact on ocular health, Bayesian regression model be applied to insurance data. This model [17-19] simulates from the posterior distribution using standard Gibbs sampling which is a multivariate Normal draw for the betas, and an inverse Gamma draw for the conditional error variance. The model to be estimated is as:

\[
Y_i = x_i' \beta + e_i
\]

Where the errors are assumed to be Gaussian as $e_i \sim \mathcal{N}(0, \sigma^2)$. It can be assumed standard, semi-conjugate priors as $\beta \sim \mathcal{N}(b_0, B_0^{-1})$, and $\sigma^2 \sim \mathcal{G}(c_0/2, d_0/2)$.

Where $\beta$ and $\sigma^2$ are assumed a priori independent. Note that only the starting value of $\beta$ is allowed because the Gibbs sample with the conditional error variance is used for the simulation as the first block in the sampler.

3. Results
Using monthly aggregated data, outpatient visit data of nonspecific conjunctivitis of Taiwan from 1997 to 2010 were analyzed with Bayesian linear regression analysis for the interval-valued data in this study. The air pollutants data in this study includes SO$_2$, NO$_2$, O$_2$, CO, and PM$_{10}$. Details of the non-specific conjunctivitis incidence in Taiwan, SO$_2$, NO$_2$, O$_2$, CO, and PM$_{10}$ measurements are presented in Table 1.

### Table 1. The Summary of the research data.

|       | N    | Min  | Max  | Average | S.E.   |
|-------|------|------|------|---------|--------|
| SO$_2$| 168  | 2.41 | 7.14 | 4.563   | 0.895  |
| NO$_2$| 168  | 11.51| 27.81| 19.295  | 4.277  |
| O$_2$ | 168  | 16.20| 43.80| 27.568  | 5.478  |
| CO    | 168  | 0.32 | 0.92 | 0.614   | 0.142  |
| PM$_{10}$ | 168 | 32.00| 96.00| 57.790  | 15.130 |

The Cases of Nonspecific Conjunctivitis 168 888.00 59725.00 29778.200 14016.945

### Table 2. The result of Bayesian linear regression analysis of air pollutants affecting nonspecific conjunctivitis cases in Taiwan.

|                | Mean   | St. Dev | Naive SE | Lower | Upper |
|----------------|--------|---------|----------|-------|-------|
| (Intercept)    | 73461.7| 6187.4  | 61.874   | 61451.7| 85566.5|
| SO$_2$         | 6716.7 | 1064.5  | 10.645   | 4631.5| 8798.5|
| NO$_2$         | 257.7  | 507.6   | 5.076    | -730.8| 1243.5|
| O$_2$          | 125.9  | 171.6   | 1.716    | -212.0| 463.6 |
| CO             | 67757.4| 1106.2  | 110.621  | 46386.4| 89271.9|
| PM$_{10}$      | 347.6  | 102.7   | 1.027    | 148.4 | 551.4 |
| $\sigma^2$     | 71913692.0| 8106157.7| 8106157.7| 57613085.1| 89527014.2|

The result of Bayesian linear regression analysis is as Table 2. Lower and Upper indicate central (IC) 95 percent Bayesian credible intervals in Table2. SO2 (95% IC: 4631.5~8798.5), CO (95% IC: 46386.4~89271.9), and PM10 (95% IC: 148.4~551.4) are positively correlated with nonspecific conjunctivitis cases. The relationship between nonspecific conjunctivitis cases and NO2 (95% IC: -730.8~1243.5) and O2 (95% IC: -212.0~463.6) are not statistically significant.

### 4. Discussion and conclusions

Previous studies examining the relationship between air pollution and respiratory diseases have shown that air pollution can induce and aggravate respiratory diseases. [20] Some studies suggest that the response of the conjunctival and respiratory mucosa is similar to exogenous stimuli. [21] The results of this study show some similar patterns consistent with respiratory disease investigations.

In this study, the results showed that air pollutants, SO$_2$, CO and PM$_{10}$ were significantly associated with non-specific conjunctivitis. The more the increase of the level of SO$_2$, CO, and PM$_{10}$, the more nonspecific conjunctivitis cases occur. This result is similar with the studies of Bourcier, Viboud, Cohen, Thomas, Bury, Cadiot, Mestre, Flahault, Borderie, and Laroche [9], Chang, Yang, Chang, and Tsai [12], Szyszkwicz, Kousha, and Castner [14], and Hong, Zhong, Li, Xu, Ye, Mu, Lu, Mashaghi, Zhou, Tan, Li, Sun, Liu, and Xu. [15]

The study combines and integrates air pollution and ophthalmology data to investigate the association between non-specific conjunctivitis clinic visits and air pollution levels. It has found that the air pollutant, SO$_2$, CO, and PM$_{10}$ can increase chances of outpatient visits, suggesting that it is a possible cause for nonspecific conjunctivitis. Furthermore, this paper has also shown that a favourable air-pollution-monitoring infrastructure combined with established public health data can provide valuable information for an examination of adverse health effects related to air pollution.

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