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Air Quality, Patterns and Otolaryngology Health Effects of Air Pollutants in Beijing in 2013

Fengying Zhang[1,2,3*], Jin Xu[4], Li Wang[2], Jinmei Lu[5], Yonghua Li[3], Yong Ni[1], Wuyi Wang[3], Thomas Krafft[2,6]**

[1] *China National Environmental Monitoring Centre, Beijing 100012, China*
[2] *CAPHRI School of Public Health and Primary Care, Maastricht University, Netherlands*
[3] *Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[4] *Department of Otolaryngology-Head and Neck Surgery, Beijing Hospital, Ministry of Public Health, Beijing 100730, China*
[5] *Department of Engineering and Safety, University of Tromsø, N-9037 Tromsø, Norway*
[6] *Institute of Environment Education and Research, Bharati Vidyapeeth University, Pune 411043, India*

ABSTRACT

We carried out a time-series analysis on daily/hourly ambient air pollutant concentrations and daily number of outpatient consultations for otolaryngology during the first year (2013) of implementation of the National Ambient Air Quality Standards in Beijing. Daily patterns of SO_2, NO_2, CO, O_3, PM_{10} and $PM_{2.5}$ were determined and hourly characteristics of air pollutants from Dongsi are discussed. Health effects of air pollutants on ear, nose and throat (ENT) were evaluated. The results show that daily air pollutant concentrations had obvious seasonal differences. O_3 levels in the warm season were higher than in the cold season, whereas other pollutants showed opposite trends. All pollutants had different seasonal patterns for hourly concentrations. Hours with peak concentrations also had seasonal differences, and hourly time trends of $PM_{2.5}$ and PM_{10} (particulate matter with an aerodynamic diameters less than 2.5 µm and 10 µm, respectively) were different. In contrast with other air pollutants, hourly O_3 concentrations in warm season were higher than cold season. Dongcheng District had high PM_{10} and $PM_{2.5}$ levels and Beijing experienced heavy $PM_{2.5}$ pollution in 2013. Ozone became the second main air pollutant in Beijing. All pollutants had health effects on ENT, and lag effects were found for some pollutants. Relative risks in the warm season were higher than in the cold season for O_3 and lower than the cold season for the other five air pollutants.

Keywords: Air pollutants; Air quality; Temporal pattern; Otolaryngology; Beijing.

INTRODUCTION

Air pollution has serious direct effects on public health in China (Dong *et al.*, 2013; Shang *et al.*, 2013; Tang *et al.*, 2014; Zhou *et al.*, 2014). Particulate matter with aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) has become the fourth greatest threat to the health of the Chinese people (Chen *et al.*, 2013).

Extremely polluted weather related to $PM_{2.5}$ pollution, such as haze and fog, has impacted China severely and frequently over the past few years (Schatz, 2007; Ma *et al.*, 2010; Liu *et al.*, 2014). In January 2013, a hazardous continuous massive haze emerged in the central and eastern regions. This haze covered nearly 2.7 million km^2, more than 40 major cities in 17 provinces, and affected more than 800 million people. During the most haze-polluted period, hourly concentrations of $PM_{2.5}$ reached 680 µg m^{-3} in Beijing, and the real-time Air Quality Index (AQI) exceeded 500 many times. In winter 2013, northern China experienced an intense haze (Liu *et al.*, 2014). Action should be taken to solve the air pollution problem in the country (Demoly *et al.*, 2008). Owing to the health effects of air pollutants, the government issued a new National Ambient Air Quality Standard (GB3095-2012) in February 2012, which is to be implemented incrementally. All cities should implement this standard from 1 January 2016 (Ministry of Environmental Protection of the People's Republic of China and Administration of Quality Supervision Inspection and Quarantine 2012). As one of the first-stage cities, Beijing has released real-time hourly monitoring concentration data of air pollutants to the general public since 1 January 2013.

[*] Corresponding author.
Tel.: 86-10-84943245; Fax: 86-10-84949045
E-mail address: zhangfy@cnemc.cn
[**] Corresponding author.
Tel.: 86-10-64889286; Fax: 86-10-64856504
E-mail address: wangwy@igsnrr.ac.cn

Beijing is the capital of China and its air quality is of widespread concern (Wu *et al.*, 2010; Zhang *et al.*, 2011; Wu *et al.*, 2014). Therefore, it is necessary to comprehensively investigate temporal fluctuations and health effects of its air pollution, and to provide a reliable research basis for more valid means of control, especially for $PM_{2.5}$, O_3 and CO. Given a lack of reliable data, few systematic studies have focused on temporal patterns of air pollutants, air quality assessment based on GB3095-2012, and related health effects of those pollutants during 2013 in Beijing.

Many studies have shown the relationship between air pollutants and mortality and morbidity of many diseases (Brunekreef and Holgate, 2002; Brook *et al.*, 2010; Zhang *et al.*, 2011; Dong *et al.*, 2013; Tang *et al.*, 2014; Wu *et al.*, 2014; Zhou *et al.*, 2014). Air pollution has been specifically evaluated as a risk factor for both otitis media and respiratory illness in several studies (Brauer *et al.*, 2007; Zhang *et al.*, 2011). An association between ear, nose and throat (ENT) infections at an early age was made based on increased exposure to air pollution in the Netherlands (Brauer *et al.*, 2002). However, studies related to health effects of air pollutants on ENT represent a small sample size over a relatively short period. Most such studies focused on children (Brauer *et al.*, 2007; Bhattacharyya and Shapiro, 2010), with few dealing with adults (Zhang *et al.*, 2011). Relevant studies in China are rare.

We carried out a time-series analysis of daily/hourly concentration of air pollutants and daily number of outpatient consultations for otolaryngology during the first year (2013) of GB3095-2012 implementation in Beijing. The object of the study was to: 1) characterize temporal variations of air pollutants (SO_2, NO_2, CO, O_3, PM_{10} (particulate matter with aerodynamic diameter less than 10 µm) and $PM_{2.5}$) and evaluate air quality in Beijing in 2013; 2) find possible health effects of air pollutants on ENT.

METHODS

Air Pollutant Monitoring and Meteorological Data

Daily air quality data was provided by the Beijing Municipal Environmental Protection Monitoring Center for daily PM_{10}, SO_2, NO_2, CO, maximum 8-hour average O_3 (O_3-8h), and $PM_{2.5}$ concentrations. The data were available as averages derived from the monitoring data of 11 state-controlled monitoring stations across Beijing. For the calculation of daily means, at least 75% hourly concentrations had to be available in a single day. If more than 25% of the data in a monitoring station was missing in the whole study period, the entire station would be excluded. According to technical guidelines of the Ministry of Environmental Protection (MEP) of China, these locations must not be in the immediate vicinity of traffic intersections or major industrial polluters, and should be sufficiently distant from any other emission sources. Thus, the monitoring data reflect the general background urban air pollution level in Beijing.

To find hourly patterns of air pollutants, hourly monitoring data from one of the aforementioned stations were obtained. These data are found at the National Real-Time Air Quality Monitoring Data Publishing Platform, developed by the China National Environmental Monitoring Center, publicly accessible via the website http://113.108.142.147:20035/emcpublish/.

Daily temperatures, humidity and other meteorological variables for Beijing were obtained from the Beijing Meteorological Bureau.

Ambient Air Quality Assessment

In February 2012, China released GB3095-2012, which set $PM_{2.5}$ limits for the first time. The standards will take effect nationwide in 2016, and many cities and regions in the country are required to implement the standards earlier than the national timeline. Beijing was included in the first-step cities. Accompanying GB3095-2012, the Ministry of Environmental Protection issued the Technical Regulation on Ambient Air Quality Index (on trial) (HJ633-2012), which regulates the class of Air Quality Index (AQI), calculation method, and ambient air quality classes.

Outpatient Visits for Otolaryngology

The daily number consulting outpatients for otolaryngology during 2013 was obtained from the Department of Otolaryngology - Head and Neck Surgery, Beijing Hospital, Ministry of Public Health. Beijing Hospital is a leading Class-Three, Grade A level hospital, located in Dongcheng District and serving a large area within central Beijing. The hospital is open to the general public and provides large-scale comprehensive integrated health services including medical treatment, teaching and education, scientific research and disease prevention.

Only one daily visit per individual patient was included in the tabulation of daily visit counts. Subsequent follow-up visits within 30 days of the initial consultation were not included.

This study was approved by Ethics Review Boards of Beijing Hospital and the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. Our study did not involve any patient personal information.

Data Analysis

Temporal Patterns of Air Pollutants

Statistical analyses were conducted to find temporal patterns of six air pollutants in Beijing. To reflect air quality and pollution level in the urban area, hourly pollutant concentrations from 1 January 2013 to 31 December 2013 at Dongsi monitoring station were selected. Dongsi is downtown, within Dongcheng District and near Beijing Hospital.

Health Effect of Six Air Pollutants on ENT

The objective of the data analysis was to quantify the health effects of air pollutants on daily number of outpatients, while adjusting for weather and temporal factors in the multivariable modelling. Because the daily number of otolaryngology outpatients was small and typically follow a Poisson distribution (Wood 2006; Box *et al.*, 2013), Because daily number of outpatient visit was small and typically followed a Poisson distribution, the core analysis was a generalized additive model (GAM) with log link and Poisson error that accounted for fluctuations in daily outpatient numbers. Consistent with previous time-series studies (Zhang *et al.*, 2011; Bhaskaran *et al.*, 2013), we used the generalized additive model (GAM) with penalized splines to analyze outpatient visits, air pollutants, and covariates (meteorological factors, temporal trend, and day of the week).

Before conducting the model analyses, there were two steps in the procedure of the model building and model fit: development of the best base model (without a pollutant) and development of the main model (with a pollutant). The latter is achieved by adding the air pollution variables to the final cause-specific best base model, assuming a linear relationship between the logarithmic outpatient visit count and air pollutant concentration.

First, we constructed the basic pattern of outpatient excluding the air pollution variables. We incorporated smoothed spline functions of time and weather conditions, which can include non-linear and non-monotonic links between outpatient visit and time/weather conditions, offering a flexible modelling tool. Other covariates, such as day of the week (DOW), were also included in the basic models.

After we established the basic models, we introduced the pollutant variables and analyzed their effects on human's ear, nose and throat. To compare the relative quality of the outpatient predictions across these non-nested models, Akaike's Information Criterion (AIC) was used as a measure of how well the model fitted the data. Smaller AIC values indicate the preferred model. Briefly, we fitted the following log-linear generalized additive models to obtain the estimated pollution log-relative rate β in the study district:

$$\log\left[E\left(Y_t\right)\right]=\alpha+\sum_{i=1}^{q}\beta_i\left(X_i\right)+\sum_{j=1}^{p}f_j\left(Z_j,df\right)+W_t\left(week\right) \quad (1)$$

Here $E(Y_t)$ represents the expected number of outpatient visit at day t; β represents the log-relative rate of outpatient visit associated with an unit increase of air pollutants; X_i indicates the concentrations of pollutants at day t; $W_t(week)$ is the dummy variable for day of the week. $\sum_{j=1}^{p}f_j\left(Z_j,df\right)$ is the non-parametric spline function of calendar time, temperature and humidity. A detailed introduction to GAM was described in Wood's book (Wood 2006).

Sensitivity analysis was conducted with basic models following Welty's method (Welty and Zeger, 2005). We initialized the df as 7 df year^{-1} for time, 3 df for temperature and barometric pressure, 5 df for humidity. We fitted both single-pollutants models and multi-pollutant models (models with a different combination of two or three pollutants per model) to assess the stability of pollutants' effect.

In a lag effects model, effects of air pollutants with different lag (L) structures of single-day (from L0 to L3) and multi-day (L01 to L03) lags were examined. Here, a lag of 0 day (L0) corresponds to current-day pollution, and a lag of 1 day to the previous-day concentration. In multi-day lag models, L03 corresponds to a 4-day moving average of pollutant concentration of the current and previous 3 days (Gasparrini *et al.*, 2010; Zhang *et al.*, 2013). Meteorological factors used in the lag models were current-day data.

Seasonality was differentiated on the basis of heating/non-heating periods between the Beijing cold season (heating) from October through March and warm season (non-heating) from April through September. Because major portions of Beijing are still provided with central heating from coal-burning power plants, air pollution load during the heating period increases significantly. Our seasonal analysis followed the method introduced in Peng (Peng *et al.*, 2005).

Temporal changes of the air pollutants were summarized by Origin 9.0 software. All other statistical analyses were conducted in R3.1.0 using the MGCV package. The results were expressed as relative risk (RR) percentage changes (RRs) in number of patient otolaryngology consultations per 10 µg m^{-3} increments of air pollutant concentration (RR = $e^{\beta x \Delta C}$, RRs = (RR – 1) × 100, where ΔC is the increase of air pollutants; we used 10 µg m^{-3} for comparison with similar studies in other Chinese locales).

RESULTS

General Descriptions and Statistical Results

Table 1 summarizes statistical distributions of daily number of outpatient otolaryngology visits, air pollutant concentrations, and meteorological factors in Beijing for 2013.

Concentrations of all air pollutants showed obvious seasonal differences. O_3-8h levels in the warm season were higher than in the cold season, and the other five air pollutant concentrations in were higher in the cold season. Annual values of these pollutants were larger than median values.

Pearson correlation coefficients of air pollutants are shown in Table 2. SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO had significant positive correlations with each other, whereas O_3 had significant negative correlation with the other five pollutants.

Temporal Patterns of Air Pollutants and Assessment of Air Quality

Hourly Patterns and Assessment

The 11 state-controlled air quality monitoring stations in Beijing are mainly used to assess regional air quality and its overall variation. To describe the distribution of hourly air pollutant concentrations in the Dongcheng District and central Beijing, we show monitoring data at Dongsi station in Fig. 1.

The six air pollutants showed different hourly concentration patterns. Hourly average concentrations of each pollutant had differing hourly trends in both warm and cold seasons, and hours with maximum and minimum concentrations also had seasonal differences. All hourly average SO_2, NO_2, CO and $PM_{2.5}$ concentrations in the cold season were higher than in the warm season. Maximum hourly PM_{10} levels in the cold season were higher than in the warm season, with the opposite seasonal distinction for minimum PM_{10}. Hourly O_3 concentrations in the warm season were higher than in the cold season. Maximum hourly O_3 was around 16:00 and the minimum around 6:00.

Table 1. Statistical characteristics of air pollutants, meteorological factors, and number of patients.

Items	Annual average	SD	Percentage				
			min	25%	50%	75%	max
Daily number of patients	202	37	36	180	201	227	305
Air Pollutants μg m^{-3}							
SO_2	26	26	3	7	16	36	148
NO_2	56	25	9	40	49	69	157
PM_{10}	109	76	10	56	93	140	506
CO	1459	1103	300	782	1185	1700	6873
O_3-8h	90	62	4	44	74	123	267
$PM_{2.5}$	90	71	6	41	68	122	390
Temperature °C							
Average	13.4	11	–9.7	4.2	12.8	23.4	31.7
max	18.6	11	–6.3	10.2	19.4	28.1	38.2
min	8.7	11.1	–14.1	–1.4	7.9	19.2	27
Barometric Pressure hPa							
Average	1009	54	10	1004	1012	1020	1039
max	1012	54	11	1006	1015	1023	1042
min	1006	53	10	1000	1009	1017	1037
Humidity %							
Average	55.8	19.8	14	41.3	56	72	97
min	34.2	19.5	4	18	29	47	84
Wind speed m s^{-1}							
Average	2.1	0.9	0.7	1.5	2	2.5	6.6
max	4.8	1.7	1.7	3.6	4.4	5.9	11.3

Table 2. Correlation coefficients among air pollutants.

	SO_2	NO_2	PM_{10}	CO	O_3-8h	$PM_{2.5}$
SO_2	1					
NO_2	0.769**	1				
PM_{10}	0.661**	0.804**	1			
CO	0.825**	0.835**	0.788**	1		
O_3-8h	–0.351**	–0.395**	–0.106*	–0.418**	1	
$PM_{2.5}$	0.651**	0.807**	0.937**	0.846**	–0.203**	1

** Correlation significant at 0.01 level (2-tailed test).

Hourly SO_2, NO_2, O_3-8h, CO, PM_{10} and $PM_{2.5}$ concentration ranges were 1–225 μg m^{-3}, 0–258 μg m^{-3}, 1–1071 μg m^{-3}, 0–20 mg m^{-3}, 6–1000 μg m^{-3}, and 3–584 μg m^{-3}, respectively. According to GB3095-2012, the maximum hourly SO_2 met the Class 2 standard, but those of the other five air pollutants failed to do so.

Annual average air pollutant concentrations at Dongsi were 30 μg m^{-3}, 63 μg m^{-3}, 59 μg m^{-3}, 1.6 mg m^{-3}, 117 μg m^{-3}, and 97 μg m^{-3} for SO_2, NO_2, O_3-8h, CO, PM_{10} and $PM_{2.5}$. High annual PM_{10} and $PM_{2.5}$ levels reveal strong PM_{10} and $PM_{2.5}$ pollution in the Dongcheng District.

Daily/Yearly Patterns and Air Quality

Fig. 2 shows daily concentrations of air pollutants in Beijing during 2013. In accord with the statistical results, there were obvious seasonal differences for SO_2, NO_2, O_3 and CO. Although no clear temporal patterns of PM_{10} and $PM_{2.5}$ concentration are evidenced in Fig. 2, there were seasonal differences.

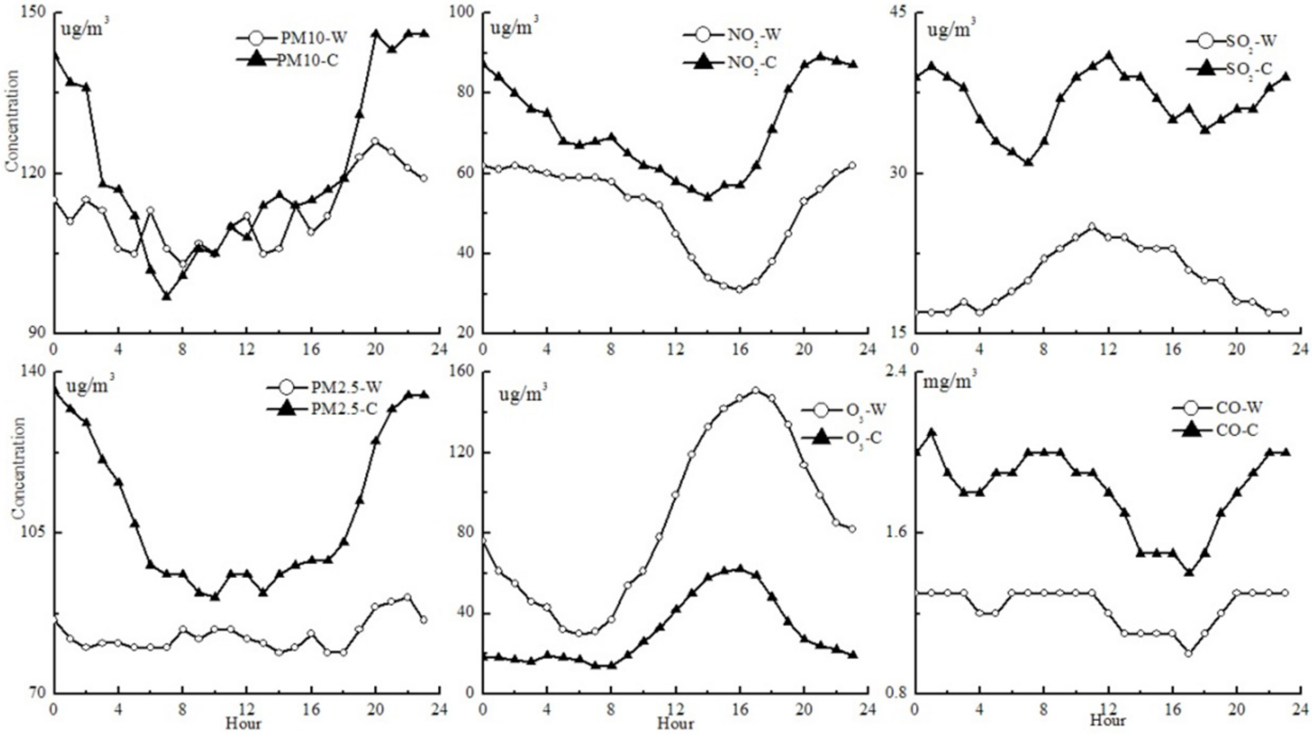
According to standards GB3095-2012 and HJ633-2012, $PM_{2.5}$ was the major air pollutant in Beijing. There were 160 days of heavy $PM_{2.5}$ pollution, with daily concentrations exceeding 75 μg m^{-3}. O_3 was the secondary air pollutant. Around 64 days had heavy O_3 pollution with daily maximum 8-hour average concentrations exceeding 160 μg m^{-3}, most which were during May–August. There were 74 days with heavy PM_{10} pollution, with daily concentrations exceeded 150 μg m^{-3}. There were no polluted days for SO_2 and CO.

NO_2 ranged from 9 to 157 μg m^{-3}, and the annual mean level was 56 μg m^{-3}. The daily 8-hour maximum concentration of O_3 was from 4 to 267 μg m^{-3}. The daily range of PM_{10} was 10 to 506 μg m^{-3}, with annual average of 109 μg m^{-3}. Concentrations of $PM_{2.5}$ were 6–390 μg m^{-3}, with annual value 90 μg m^{-3}. Ranges of NO_2, O_3, PM_{10} and $PM_{2.5}$ were wide, with maxima many times higher than the Class 2 limits of GB3095-2012.

Daily Number of Outpatients and Association with Air Pollutants

Temporal Patterns of Outpatient Otolaryngology Visits

There were 73,903 outpatients in 2013. The daily number of patients ranged from 36 to 305. The average daily number of outpatient otolaryngology visits in the warm season was higher than in the cold season. Fig. 3 shows the daily number of outpatient otolaryngology visits. Consistent with the statistical distribution, this number had obvious peaks in the warm season, especially around April and September. The number was small during January–February.



W: warm season, C: cold season.

Fig. 1. Average hourly air pollutant concentration at Dongsi.

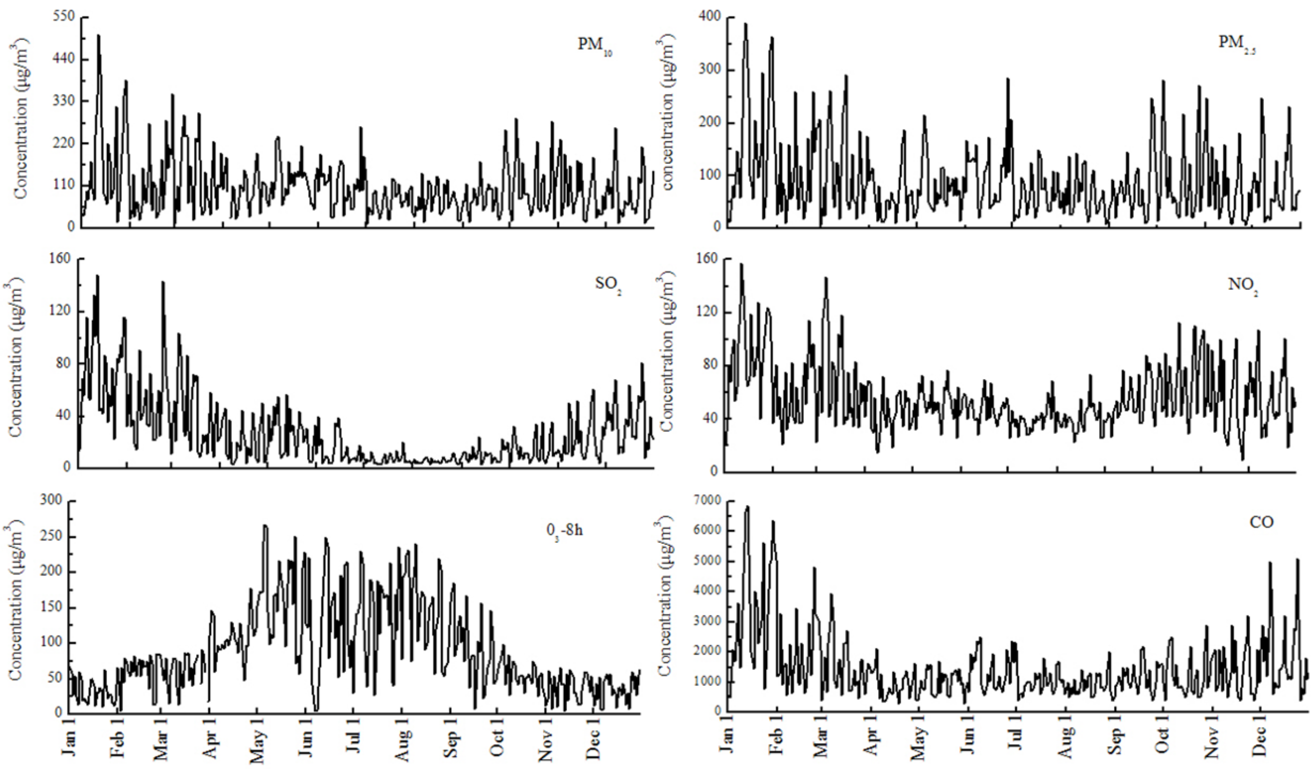


Fig. 2. Daily concentrations of air pollutants in Beijing.

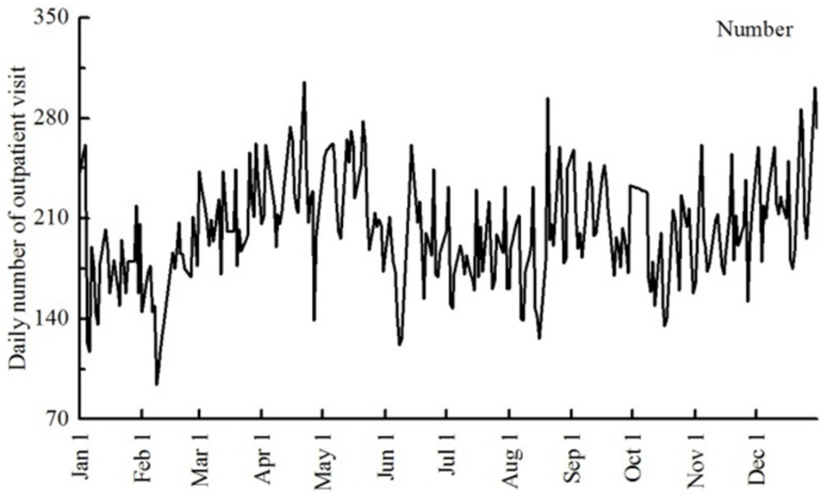


Fig. 3. Daily number of otolaryngology outpatients.

Associations between Air Pollutants and ENT

Table 3 presents RR percentage changes (RRs) of daily outpatient number for ENT for every 10 µg m^{-3} increase in air pollutants concentration. To identify possible time delays of air pollutant health effects in the clinical manifestation of symptoms, we analyzed lag effects of the pollutants on the daily number of outpatient visits. Change of RR in number of ENT outpatients with a 10 µg m^{-3} increment of pollutants in single-day measures, 1–3 days prior to the outpatient visit (L0–L3), and moving averages from day 0 and 1 to day 3 prior to the visit are listed in Table 3. When running the models, lag effects > 3 days for all six air pollutants were also considered, but little relationship was found, so results of that analysis were excluded in the study.

RR percentage changes (RRs) of SO_2 for single-day lags decreased with time, while increased with increased for moving-average lags; and the largest RRs were found for the current day (L0). RRs of NO_2 and CO had similar time trend to that of SO_2, the greatest associations were forL0. The effect magnitude of O_3 showed a decreasing trend from L0 to L3 and an increasing trend from L01 to L03. The greatest RRs were found in 2-day cumulative measures (L02). Associations of PM_{10} and $PM_{2.5}$ had decreasing trends from L0 to L3 for single lag day effects, and increasing trends for moving average day effects. The greatest RRs were for L0.

Seasonal RRs in number of ENT outpatients with a 10 µg m^{-3} increase of pollutants were also shown in Table 3. RRs of O_3 in the warm season were higher than in the cold season, while RRs of other five air pollutants were in the warm season were lower than in the cold season

Given the large correlation coefficients between air pollutants, multiple air pollutant exposure effects on ENT in one model were not considered in this study.

DISCUSSION

The present study focused on air quality and patterns and health effects of air pollutants on ENT during the first year (2013) of GB3095-2012 implementation in Beijing, especially $PM_{2.5}$, CO and O_3, which were newly added as regular monitoring pollutants in that standard. The results are unique in the following aspects: 1) Based on reliable data sources, hourly patterns of air pollutant concentrations in Beijing were determined; 2) using the National Ambient Air Quality Standard and hourly/daily air pollutant concentrations, Beijing air quality in 2013 was assessed; 3) to our knowledge, the study is the first to combine daily adult patient otolaryngology visits with daily air pollutant concentrations in Beijing; particularly for CO, O_3 and $PM_{2.5}$; 4) GAM was used to analyze the highly nonlinear or non-monotonic exposure-response relationship between air pollutants and daily outpatient clinic visits for otolaryngology. Our study provides air quality monitoring information and possible health effects of air pollutants on ENT to the general public for 2013. The study encourages health service policymakers in Beijing to consider the exacerbating effect of air pollution on ENT in outpatient resource planning and furnishes ideas for real-time public health alerts for air quality, so that those affected can be appropriately advised and treated.

The results show that daily air pollutant concentrations had clear seasonal differences. O_3 levels in the warm season were higher than that in the cold season. Concentrations of the other five pollutants were higher in cold season than warm season. Although air pollution sources in the mega-cities gradually changed from conventional coal combustion to a mixture of that combustion and motor vehicle emissions (Schatz, 2007), biomass or fuel-burning sources in and around Beijing may have had a tremendous impact in the heavy air pollution period there (Gao *et al.*, 2014). Hourly concentration trends of air pollutants varied and had different hourly trends in both the warm and cold seasons. Hours of maximum and minimum pollutant concentrations also had seasonal variations. All hourly average $PM_{2.5}$ concentrations in the cold season were higher than in the warm season. The hourly PM_{10} trend changed greatly, with maxima in the cold season higher than in the warm season; the opposite was true for minima. The different temporal trends of $PM_{2.5}$ and PM_{10} may be related to varying pollution emissions and meteorological factors (Tian *et al.*, 2014; Zhang *et al.*, 2015). In contrast with the other five air

Table 3. RR percentage changes (RRs) of outpatients for every 10 μg m^{-3} increase in air pollutant concentration.

	RRs (95% confidence interval (CI))					
	SO_2	NO_2	CO	O_3	PM_{10}	$PM_{2.5}$
L0	0.436 (0.308–0.564)	0.411 (0.213–0.609)	0.050 (0.08–0.092)	0.591 (0.407–0.775)	0.532 (0.315–0.749)	0.547 (0.318–0.776)
L1	0.267 (0.163–0.371)	0.216 (0.091–0.341)	0.006 (–0.059–0.071)	0.382 (0.112–0.652)	0.391 (0.146–0.636)	0.238 (0.072–0.404)
L2	0.215 (0.097–0.333)	0.179 (0.067–0.291)	0.007 (–0.058–0.072)	0.371 (0.103–0.639)	0.121 (0.009–0.233)	0.132 (0.020–0.244)
L3	0.207 (0.071–0.343)	0.115 (0.031–0.199)	0.001 (–0.063–0.065)	0.027 (0.001–0.053)	0.064 (0.003–0.125)	0.015 (0.001–0.039)
L01	0.262 (0.087–0.437)	0.023 (–0.091–0.137)	0.026 (0.006–0.046)	0.611 (0.413–0.809)	0.414 (0.203–0.625)	0.221 (0.069—0.373)
L02	0.272 (0.101–0.443)	0.213 (0.064–0.362)	0.014 (0.002–0.026)	0.638 (0.432–0.844)	0.434 (0.213–0.655)	0.224 (0.065–0.343)
L03	0.329 (0.143–0.515)	0.257 (0.081–0.433)	0.018 (0.003–0.033)	0.556 (0.389–0.723)	0.465 (0.243–0.687)	0.233 (0.070–0.396)
cold	0.515 (0.211–0.819)	0.451 (0.176–0.726)	0.066 (0.012–0.120)	0.485 (0.253–0.717)	0.567 (0.326–0.808)	0.578 (0.320–0.836)
warm	0.383 (0.273–0.493)	0.375 (0.129–0.621)	0.041 (0.003–0.079)	0.608 (0.425–0.791)	0.411 (0.201–0.621)	0.447 (0.216–0.678)

cold: cold season; warm: warm season.

pollutants, all hourly O_3 concentrations in the warm season were higher than in the cold season. Maximum hourly O_3 was in the afternoon and minimum in early morning.

During the study period, $PM_{2.5}$ was the main air pollutant in Beijing, with 43.7% of days having $PM_{2.5}$ pollution. O_3 was second. Many studies have reported health effects of $PM_{2.5}$ (Shang *et al.*, 2013; Xu *et al.*, 2013; Wu *et al.*, 2014). O_3 is generated when nitrogen oxides produced at fossil fuel-burning sources such as power plants and automobiles react with volatile organic compounds from sources such as gasoline and solvents. O_3 has a multitude of potential adverse health effects, and exposure is associated with various respiratory symptoms including dyspnea, upper airway irritation, coughing, and chest tightness (Chen *et al.*, 2007). Research on harmful effects of O_3 is rare in China, so further studies are needed.

Consistent with other time series studies (Brauer *et al.*, 2002; Mehta *et al.*, 2013), the present work revealed a statistically significant association between air pollution and ENT health. RR in the number of ENT outpatients increased with air pollution level. RR percentage changes (RRs) in the number of ENT outpatients with a 10 μg m^{-3} increase of air pollutants were 0.436, 0.411, 0.050, 0.591, 0.532 and 0.547 for SO_2, NO_2, CO, O_3, PM_{10} and $PM_{2.5}$, respectively. In contrast with lag effects of air pollutants in other studies (Liu *et al.*, 2013; Shang *et al.*, 2013), the highest RRs for SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$ were for the current day, and L02 for O_3. This may related to the process of ENT infection and morbidity being more rapid than cardiovascular/respiratory disease. The nature of ENT disease also caused people to go to hospitals as soon as they had disease symptoms. Compared to the results of air pollution effects on human health in other studies, RRs for outpatients with every 10 μg m^{-3} increase in air pollutant concentration were mostly less than 1. This may related to the composition and contribution of air pollutants in the ambient air of Beijing, especially PM. More in-depth studies should be done to clarify this issue.

The daily average number of outpatient otolaryngology visits was larger in the warm season (207) than in the cold season (198). Daily mean concentrations of SO_2, NO_2 CO, PM_{10} and $PM_{2.5}$ were higher in the cold season. RRs were higher in the cold season than in warm season for SO_2, NO_2 CO, PM_{10} and $PM_{2.5}$, while were lower in the cold season than in warm season for O_3. A possible explanation is that other factors (pollen, temperature, or others) may influence ENT health during the warm season, and the high O_3 levels in that period could also harm the ENT. Our previous study showed that the combination of air pollutants and pollen can increase the incidence of allergic rhinitis, and an increase in pollen was significantly associated with hospital outpatient visits for this rhinitis (Zhang *et al.*, 2012). Another reason was the influence of O_3. There was significant increase in risk of death from respiratory causes with rising O_3 concentration (Jerrett *et al.*, 2009). A study in Guangzhou had different results in which significant O_3 effects on non-accidental mortality were found in the cold season and on days with low temperature; the short-term effect of ambient O_3 on mortality was modulated by temperature (Liu *et al.*, 2013). Further investigations of this issue are therefore required.

CONCLUSIONS

During 2013, daily air pollutant concentrations had obvious seasonal differences. O_3 levels in the warm season were higher than cold season, and the other five air pollutants had the opposite variation. Hourly concentration differences were found in both warm and cold season for all air pollutants. Hours of maximum pollutant concentrations also had seasonal differences. PM of different sizes had different hourly trends. In contrast with other five air pollutants, hourly O_3 concentrations in the warm season were higher than cold season. Beijing experienced heavy $PM_{2.5}$ pollution in 2013. O_3 became the second major air pollutant, so greater attention should be given to it. All air pollutants had health effects on human's ENT. There were lag effects of some pollutants. RR percentage changes (RRs) in the warm season were higher than in the cold season for O_3, opposite to the variation of the other five air pollutants.

In conclusion, we explored air quality status, temporal characteristics of air pollutants, and ENT health effects. We gave further epidemiological and scientific evidence for informed decisions on air pollution control measures and provided information for environmental health research. The study had some limitations. We were only able to obtain data from one major hospital in Beijing. We had hourly air pollutant concentration data near the hospital, but used average values derived from monitoring data of 11 state-controlled monitoring stations across Beijing as exposure concentrations. This was done because of a lack of information on variables such as residence/work location and time-series activity of patients. Accurate exposure assessment and accurate coverage boundaries of the hospital are important in future investigation. Further in-depth studies on the relationship between meteorological factors, air pollutants, time-series human activity, personal pollutant exposure, social economy and human health at city-level are required.

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COMPETING INTERESTS

All authors declare no conflict of interest in the context of this study.

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