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Article

Temporal analysis of atmospheric nitrogen dioxide pollution and pediatric outpatient visits for respiratory illnesses in Yuexiu District, Guangzhou, China

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Abstract: Objective: The study aims to investigate the impact of atmospheric nitrogen dioxide (NO_2) levels on pediatric outpatient consultations for respiratory illnesses in the Yuexiu District of Guangzhou, China. **Methods**: Data on atmospheric NO_2 levels, weather conditions, and outpatient visits for respiratory diseases were gathered from a children's hospital in Guangzhou's Yuexiu District over the period of 2014 to 2016. Spearman rank correlation analysis and time-series analysis employing a generalized additive model were utilized to examine the association and lagged effects between NO_2 concentrations and concurrent pediatric respiratory outpatient visits. **Results**: The annual mean NO_2 concentrations in Yuexiu District during 2014, 2015, and 2016 were 6130, 6046, and 6081 μg/m^3, respectively, and the number of days exceeding national standard values was 70, 64, and 62, respectively. The time-series analysis revealed a significant impact of NO_2 on respiratory outpatient visits from day 0 to day 7, with the most pronounced effect observed on lag day 0 (lag0). An excess risk (ER) of 145% (95% CI: 93%–198%) was observed on lag day 0 (lag0). The highest cumulative lag effect and ER of 307% (95% CI: 204%–410%) were found on lag days 0 to 6(lag06 d). **Conclusion**: The rise in NO_2 levels in Guangzhou's Yuexiu District between 2014 and 2016 was associated with an increase in pediatric respiratory disease outpatient visits.

Keywords: nitrogen dioxide; time series analysis; respiratory diseases

In recent years, with the rapid development of China's economy, residents' yearning for a better life and the continuous growth of automobile demand, motor vehicles have become an important source of air pollution. The impact of air pollution on Residents' health has been paid much attention and has become a hot spot for public health scholars [1]. Studies have shown that due to urban traffic congestion and dense building clusters, the emission of automobile exhaust cannot spread as soon as possible, and the concentration of NO_2 in urban areas is high [2]. For example, Yuexiu District of Guangzhou, as a central urban area, has dense population and large traffic flow, and the automobile exhaust emission is mainly NO_2, resulting in health damage that cannot be ignored. However, due to their own physiological structure, narrow respiratory tract, high respiratory rate, underdeveloped immune system, high daily activity, and many opportunities of outdoor air exposure, children are vulnerable to air pollution [3,4].

Domestic research on the impact of air pollution on respiratory diseases shows that every 10% increase in no concentration μ G/m^3, the outpatient and emergency volume of respiratory diseases increased by 044% [1], and the mortality of respiratory diseases increased by 161% [5]; foreign studies have found that the increase of air pollution concentration (including particulate matter, so, NO, CO and O) will lead to an increase in the incidence rate of respiratory diseases in the elderly, children and adolescents [6]. Geographical environment, polluted environment and other factors (such as local pollutant concentration, composition, source and population composition differences) may also lead to differences in the impact of air pollution on people's health. Therefore, by collecting the data of daily outpatient volume of respiratory diseases and air pollutants in a children's Hospital in Yuexiu District of Guangzhou from 2014 to 2016, this paper uses the generalized additive model method to study the relationship between NO_2 concentration level and outpatient volume of respiratory diseases, and provides decision-making basis for the government to take effective measures to protect children through the health risk assessment of NO_2.

1. Object and method

1.1. Respiratory outpatient volume data

Collect the daily outpatient volume data of children's respiratory diseases in a children's Hospital in Yuexiu District of Guangzhou from 2014 to 2016, and use the international classification of diseases (ICD 10) classification. Respiratory diseases refer to diseases with ICD code of j00-j99.

1.2. Meteorological data

The meteorological data from 2014 to 2016 were collected by Guangzhou Meteorological Bureau, including daily average temperature, daily average relative humidity, etc.

1.3. Air pollutant data

The data of air pollutants monitored daily by the state environmental protection control point in Yuexiu District from 1 January 2014 to 31 December 2016 were collected by Guangzhou Environmental Protection Bureau, mainly including $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3-1 h (average value of ozone for 1 h) and O_3-8 h (average value of ozone for 8 h). The results of all indicators were determined according to the average annual standard value of pollutant concentration in class II area in the ambient air quality standard (GB 3095-2012) [7].

1.4. Generalized additive model

When analyzing the health effects of air pollution, poisson distribution regression model is usually used to evaluate the relationship between daily pollutant concentration changes and the number of visits [8]. In the total population, the incidence of respiratory diseases is a small probability event. The outpatient volume data used for time series research is approximate to the Poisson distribution. Therefore, the Poisson regression model is introduced into the semi parametric generalized additive model (GAM). The non parametric smoothing function can better control the confounding characteristics, fit the time trend, meteorology and other confounding factors, and control the "day of week (Dow)" and legal holidays

(PH), take the air pollutant NO_2 as a linear variable to build a relationship model between it and the daily outpatient volume of respiratory diseases. See Equation (1):

$$\log E(Y_t) = \beta\rho_t + ns(\mathrm{Time}, df) + ns(t, df) + ns(\mathrm{RH}, df) + \mathrm{DOW} + \mathrm{PH} + \alpha \ (1) \tag{1}$$

where: $E(Y_t)$ predictive value of outpatient volume of respiratory diseases on day t;

ρ_t: daily average mass concentration of atmospheric NO on day t, μ g/m^3;

β: Regression coefficient;

NS: nonparametric smoothing function;

Time—date variable. Selecting an appropriate DF value for the date can effectively control the long-term fluctuation trend of pollution and outpatient series data;

T—temperature, °C;

RH—relative humidity;

DF—degree of freedom;

Dow—day of week effect;

PH—legal holidays;

A—Residuals.

When the degree of freedom of date variable (time) is 8, and the degrees of freedom of temperature (*T*) and relative humidity (RH) are 6 and 3, the optimal model is obtained according to Akaike information principle (AIC).

Firstly, a single pollutant model is constructed to consider the lag effect of pollutants. The literature shows that the impact of air pollutants on the daily outpatient volume of respiratory diseases is generally 5 days [9]. The concentrations of pollutants (lag0 D, lag1 lag8 d) on that day and before the 1st to 8th days were introduced into the model one by one to determine the lag time of the strongest effect of NO_2 concentration on the daily outpatient volume of respiratory diseases, and then the double pollutant model was fitted. $PM_{2.5}$, PM_{10}, SO_2, CO, O_3-1 h and O_3-8 h were successively incorporated into the model to evaluate the robustness of the model.

Calculate when no concentration increases by 10 μg/m^3. Relative excess risk (ER) and its 95% confidence interval of daily outpatient volume of respiratory diseases at 95% CI.

1.5. Quality control

The data source of this paper is reliable. All the data are sorted and rechecked by professionals, and then used for analysis after logical error detection and missing value filling.

1.6. Statistical methods

In this paper, SPSS 210 software was used to analyze the data. Because the collected data did not obey the normal distribution, Mann Whitney U rank sum test was used to compare the difference of daily outpatient volume of respiratory diseases, and Spearman rank correlation was used to analyze the relationship between meteorological factors and air pollutants. Application r36 the mgcv software package of 3 software is used for model fitting. Two sided test, $p < 0.05$ means the difference is statistically significant.

2. Results

2.1. Basic information

From 2014 to 2016, the annual mean value (minimum and maximum) of NO_2 concentration measured at the environmental protection state control monitoring points in Yuexiu District were 6130 (90,117,604), 6046 (100,220,804) and 6081 (249,917,703) respectively μg/m^3, according to the national air quality standard (GB 3095-2012) [7] the annual average and 24 h average standard values of no concentration in class II area are 40 and 80 respectively μg/m^3, the annual average value of no concentration in Yuexiu District in three years exceeds the standard, and the days exceeding the standard are 70, 64 and 62 days respectively. In three years, the average daily outpatient volume of respiratory system in a children's Hospital in Yuexiu District was 955 (64, 2180) person times/D, 1018 person times/D for respiratory diseases on the day when NO_2 exceeded the standard, and 942 person times/D for respiratory diseases on the day when it reached the standard. The rank sum test showed that there was a significant difference in the daily outpatient volume ($z = -227$, $p < 0.05$; **Table 1**).

Table 1. Daily outpatient volume of respiratory diseases, air pollutants and meteorological factors of a children's hospital in Yuexiu District, Guangzhou from 2014 to 2016.

Index	$\bar{x} \pm s$	Min	P25	P50	P75	Max
955 ± 331 64 740 909 1123 2180						
$PM_{2.5}$ Concentration/(μg/m^3)	41.11 ± 22.82	5.02	26.00	35.01	52.00	179.02
PM_{10} Concentration/(μg/m^3)	61.32 ± 30.89	10.02	40.02	53.00	76.03	241.04
SO_2 Concentration/(μg/m^3)	12.32 ± 7.40	2.01	7.03	11.00	16.76	57.97
NO_2 Concentration/(μg/m^3)	61.12 ± 23.71	9.01	44.03	57.97	72.82	208.04
CO concentration/(μg/m^3)	1.01 ± 0.35	0.19	0.81	1.00	1.20	3.42
O_3-1 h concentration/(μg/m^3)	93.41 ± 64.75	2.02	42.21	81.00	131.03	411.02
O_3-8 h concentration/(μg/m^3)	79.62 ± 52.26	2.03	38.00	71.04	112.05	280.04
Temperature/℃	22.02 ± 6.32	3.61	17.01	23.90	27.32	31.13
Relative humidity/%	79.12 ± 9.89	31.03	74.05	80.00	86.04	97.01

2.2. Correlation analysis

Spearman rank correlation analysis results (**Table 2**) show that: Among the seven air pollutants, except that CO is negatively correlated with O_3-1 h and O_3-8 h, the other two pollutants are positively correlated ($p < 0.05$). Among them, nO_2 is strongly correlated with PM_{10} and $PM_{2.5}$, O_3-1 h is strongly correlated with O_3-8h, and PM_{10} is strongly correlated with $PM_{2.5}$. There is a correlation between air pollutants and meteorological factors. Except SO_2, there is a strong positive correlation between temperature and O_3-1 h and O_3-8 h, and a negative correlation between temperature and other pollutants, both of which have statistical significance ($p < 0.05$).

Table 2. 2014 Spearman rank correlation analysis (RS) of air pollutants and meteorological factors in Yuexiu District in 2016.

Index	NO_2	CO	O_3-1 h	O_3-8 h	PM_{10}	$PM_{2.5}$	Temperature	Humidity
SO_2	0.471*	0.142*	0.204*	0.419*	0.617*	0.590*	−0.031	−0.327*
NO_2		0.459*	0.062*	0.098*	0.716*	0.729*	−0.327*	−0.014
CO			−0.255*	−0.228*	0.436*	0.463*	−0.401*	0.115*
O_3-1 h				0.863*	0.194*	0.166*	0.520*	−0.401*
O_3-8 h					0.280*	0.291*	0.454*	−0.489*
PM_{10}						0.897*	−0.276*	−0.309*
$PM_{2.5}$							−0.237*	−0.233*
Temperature								0.127*

Note: *$p < 0.05$.

2.3. Analysis results of generalized additive model

In the single pollutant analysis, on the basis of controlling the time trend, the day of the week effect, the impact of legal holidays and visits and meteorological factors, the daily outpatient volume of children's respiratory diseases was fitted with the gam model of NO_2. The NO_2 concentration level had an impact on the daily outpatient volume of respiratory diseases from day 0 to day 7. The strongest effect period was on day 0, with a statistically significant difference ($p < 005$). The daily outpatient volume of children's respiratory diseases increased by 145% (95% CI: 093%~198%), the moving average value of NO_2 concentration at the cumulative lag (0~6) d (lag06 d) has a significant impact on the daily outpatient volume of children's respiratory diseases ($p < 0.05$; **Table 3**).

Table 3. Lag effect relationship between NO_2 and daily outpatient volume of children's respiratory diseases in Yuexiu District, Guangzhou from 2014 To 2016.

Time effect/d		ER(95% Cl)/%
Hysteresis effect	Lag0	1.45(0.93–1.98)*
	Lag1	1.18(0.63–1.73)*
	Lag2	1.24(0.69–1.78)*
	Lag3	1.02(0.48–1.56)*
	Lag4	0.77(0.24–1.31)*
	Lag5	0.55(0.01–1.08)*
	Lag6	0.78(0.26–1.32)*
	Lag7	0.67(0.15–1.20)*
	Lag8	0.48(–0.05–1.01)
Cumulative lag effect	Lag01	1.64(1.05–2.24)*
	Lag02	1.96(1.29–2.63)*
	Lag03	2.21(1.48–2.94)*
	Lag04	2.36(1.57–3.15)*
	Lag05	2.47(1.62–3.32)*
	Lag06	3.07(2.04–4.10)*
	Lag07	2.92(1.96–3.90)*
	Lag08	2.72(1.81–3.63)*

Note: *$p < 0.05$.

According to the lag effect analysis results of the single pollution model, the double pollutant model is fitted with the effect of NO_2 concentration on the 0th day (lag0d). In the two pollutant model, after introducing the other six pollutants, the influence of NO_2 concentration on the daily outpatient volume of children with respiratory diseases was still statistically significant ($P < 0.05$); after the introduction of CO, PM_{10} and $PM_{2.5}$, the concentration of NO_2 had little effect on the outpatient volume of respiratory diseases; after SO_2, O_3-1 h and O_3-8 h were introduced, the impact of NO_2 concentration on the daily outpatient volume of respiratory diseases decreased slightly (**Table 4**).

Table 4. Analysis results of double pollutant model of NO_2 strongest effect day (lag0 d) and daily outpatient volume of children's respiratory diseases in Yuexiu District, Guangzhou from 2014 to 2016.

Pollutant model	**ER(95% CZ)/%**
NO_2	1.45(0.93–1.98)*
$NO_2 + SO_2$	1.00(038–1.62)*
NO_2 + CO	1.48(089–2.07)*
$NO_2 + O_3$-1 h	1.20(0.64–1.77)*
$NO_2 + O_3$-8 h	1.28(0.72–1.84)*
$NO_2 + PM_{10}$	1.42(0.65–2.18)*
$NO_2 + PM_{2.5}$	1.54(0.78–230)*

Note: $^*p < 0.05$.

3. Discussion

By analyzing the impact of NO_2 on the daily outpatient volume of children's respiratory diseases in the central urban area of Guangzhou, this paper provides a basis for the protection of children's physical and mental health, the government's control of air pollution and the formulation of policies. Respiratory diseases caused by air pollution are common causes for children to seek medical treatment. Some literature shows that the increase in the incidence of respiratory diseases and symptoms in children is related to the increase in the concentration of air pollution [10,11]. Xiong et al. [12] and Wu et al. [13] found that the incidence of persistent cough and expectoration in children increases with the increase in the concentration of NO_2 and NO_x. This study shows that during the days when NO_2 exceeds the standard, the daily outpatient volume of children with respiratory diseases is higher than that on the days when NO_2 exceeds the standard, which confirms that when NO_2 is polluted, the probability of children seeking medical treatment for respiratory diseases increases. At present, the number of motor vehicles in Guangzhou is nearly 2.8 million, and the problem of vehicle exhaust pollution is prominent. The government should strengthen the control of vehicle exhaust pollution, such as continuing to promote the four new regulations for motor vehicles, increasing investment in new energy vehicles and strengthening the construction of public transport facilities, implementing the public transport priority policy, advocating green travel for the masses, and avoiding going out during the high pollution period/day when vehicle exhaust emissions are concentrated, to reduce the health risk caused by NO_2 pollution exposure.

This study shows that the increase of NO_2 concentration in Yuexiu District of Guangzhou will increase the daily outpatient volume of children's respiratory diseases. The results of single pollutant model show that every 10% increase in NO_2 concentration μg/m^3, the daily outpatient volume of children's respiratory diseases increased by 145% (95% CI: 093%~198%), the strongest effect period is on the same day (lag0 d), which may be related to the fact that Yuexiu District is the central urban area of Guangdong Province and the three prefectures in the urban area, and the local residents generally have a higher awareness of health. When children have health conditions, the residents are more willing to choose to seek medical treatment nearby and as soon as possible. The smoothing function analysis shows that as the lag effect time increases, the moving average concentration of NO_2 first increases and then decreases. The moving average value of NO_2 lag (0–6) d (lag06 d) has a significant impact on the daily outpatient volume of children's respiratory diseases, which is similar to the research results of Fengxian District [14] in Shanghai, Shunyi District [15] in Beijing and Zhengzhou [16] in China. The increase of no concentration will have a cumulative effect on children's respiratory system, however, some studies have concluded that the lag effect of NO_2 concentration on the daily outpatient volume of children with respiratory diseases is not statistically significant [17]. The results of this study can provide reference for the government to release air pollution health warning information, and have guiding significance in formulating measures to protect children's health and travel activities.

The results of the two pollutant model show that there is still a positive correlation between NO_2 and the daily outpatient volume of children's respiratory diseases. When other pollutants are introduced, the effect estimation increases and decreases. Although there is a correlation among the seven air pollutants, the effects of each pollutant are not completely combined, or are superposition and synergy, suggesting that each pollutant has a comprehensive impact on the daily outpatient volume of children's respiratory diseases, when considering air pollution control, the government should strengthen the comprehensive control of air pollutants.

The shortcomings of this paper are as follows: first, relying on the national monitoring platform for the impact of air pollution on people's health, this paper selects only one children's hospital within the jurisdiction, with a small sample size and limited representativeness. There is a gap in assessing the impact of NO_2 pollution on the real exposure level of the population; second, the relationship between air pollution and the health effects of different age and sex groups could not be further explored due to the fact that the outpatient volume did not distinguish between age, sex and other information; thirdly, although the time trend, holiday effect and meteorological factors are controlled in this paper, the influence of wind speed on NO_2 concentration is not considered, which should be further strengthened in the future research; fourth, due to the lack of influenza incidence data, the impact of influenza on the daily outpatient volume of respiratory diseases cannot be controlled.

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engaged in environmental health monitoring and evaluation author unit: Guangzhou Yuexiu District Center for Disease Control and Prevention.

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