The Impact of Ambient Temperature on Pulmonary Morbidity among a Chinese Urban Population

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Abstract

Zunyi is a city seriously polluted by acid rain in southwest China. Few studies have been performed in the region to investigate the respiratory health impact of meteorological conditions. In this study, we did an ecological time-series study to examine the association between climatic parameters (mainly of temperature) and daily numbers of hospital outpatient visits for respiratory diseases in Zunyi. Daily pulmonary morbidity and meteorological data from 1 January 2007 to 1 January 2010 in Zunyi were obtained. A generalized additive model (GAM) in a Poisson regression was used to model the relationship between air temperature and pulmonary morbidity.

For respiratory admissions, there was a linear association. For a 1ºC increase in daily average temperature below a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity increased by 1.05009331-fold, whereas for a 1ºC increase in daily average temperature above a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity decreased by 0.99032897-fold over the past year.

Our study offers the first statistically significant evidence in an acid rain-plagued region of China that ambient air temperature has an adverse effect on population respiratory health. The effects should be considered in planning health actions to prevent respiratory diseases and minimize the established health risks.

Keywords: temperature, respiratory disease, number of hospital outpatient visits

Introduction

Respiratory morbidity is a major public health problem in many developing countries [1, 2] and the mortality, for example, from lower respiratory tract infections among elderly people and children still maintains a high level [3, 4].

Weather and climate is known to influence human health. Seasonal changes of temperature promote alterations in respiratory morbidity and in total and cause-specific mortality. WHO estimated diseases affected by the changing climate contributed to more than 150,000 deaths together with 5 million "disability-adjusted life years" (DALYs) in the last three decades [5]. The effect of extreme climatic conditions (and also of the poor air quality in general), on human health has been studied by numerous scientists [6-10].

Ambient air temperature is a significant cause of respiratory morbidity and mortality worldwide. An association between minimum temperatures during winter and an increases in respiratory hospital admissions in the eldery

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(14-64, 65+) for total respiratory infections or inflammations, bronchitis and asthma, and whooping cough and acute bronchitis was observed in Auckland, New Zealand over a 10-year period (1994-2004) [8]. A noticeable correlation between incidence of respiratory syncytial virus (RSV) disease with climatic parameters also had been revealed on Lombok Island, Indonesia. Occurrence of rain was associated with 64% higher incidence of RSV (incidence rate ratio (IRR) 1.64). A 1% rise in mean relative humidity and 1ºC increase in mean air temperature was associated with a 6% (IRR 1.06) and 44% (IRR 1.44) increase in RSV cases, respectively [11].

In China, there is increasing epidemiological evidence that weather is associated with significant pulmonary morbidity and mortality [12, 13], and air pollution problems may exacerbate other conditions [14, 15], such as asthma and respiratory distress, being more prominent among vulnerable populations. One study looked at weather and severe acute respiratory syndrome (SARS) transmission in Beijing and Hong Kong in the 2003 epidemic, and found significant inverse association between the number of daily cases and maximum and/or minimum temperatures, whereas air pressure was found to be positively associated with SARS transmission [16].

Numerous prior heat-related epidemiological studies focus their study locations on economically developed metropolitans [17] or coastal regions [18] in China. However, very few studies had paid attention to the influence of climatic conditions on heath in inland western regions, which occupy nearly 71% of China's mainland area with the region's lowest gross domestic product (GDP) [19]. Zunyi is a typical commercial city lying in the western region, which is known as the city most seriously polluted by acid rain in China (Fig. 1): the acid rain area was 2,658.27 km^2 in Zunyi in 2001. The frequency of acid precipitation in Zunyi was above 80%, and the lowest pH value of acid precipitation ever had reached 3.2 [20].

Climate changes such as elevated air temperature due to greenhouse gas emissions from human activities or extreme weather conditions (e.g. heat waves) could cause adverse effects on human respiratory health. An estimate of the effect on climatic seasonality or specified thresholds of meteorological variables on human respiratory health seems to be very important. This study aimed to examine whether climatic conditions (mainly of temperature) might be a potential risk factor for pulmonary morbidity in a densely populated area in China. The assessment of the association between global warming and respiratory health as far as describing and quantifying the impact of these changes is concerned can help identify vulnerable populations and public health officials in formulating preventive actions.

Materials and Methods

Data

Study Design

We performed a cross-sectional study in Zunyi, Guizhou province, China. The epidemiological study is designed as retrospective research, which was conducted to investigate the relationship between meteorological factors and the number of hospital outpatient visits for respiratory diseases.

Study Location and Population

Zunyi is one of the most populous cities in southwest China. The altitude of the city is approximately 900 meters. The city comprises urban/suburban districts and counties, with a total area of 30,763 km^2, and had a population of 795,000 by the end of 2009. Our study area was limited to the traditional two urban districts of Zunyi (1,304 km^2): Honghuagang and Huichuan. The target population includes all permanent residents living more than three years in these areas.

Meteorological Data

Air temperature, relative humidity, atmospheric pressure, and rainfall were routinely measured at the meteorological fixed-site stations in Honghuagang and Huichuan districts, of the Zunyi County Meteorological Bureau. The climate data were available for the period from January 2007 through January 2010. We extracted 24-hour average, minimum and maximum air temperature, relative humidity, and average, and minimum, and maximum atmospheric pressure. We used only the actual collected data, and did not fill in the missing data of the meteorological indexes.
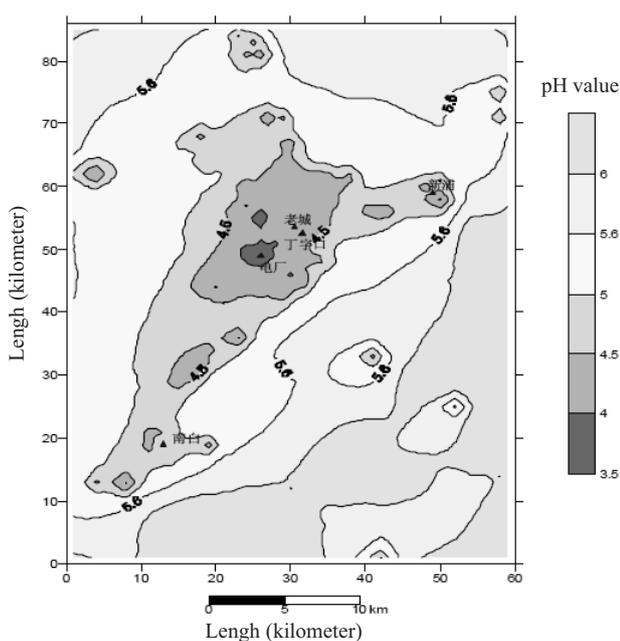
Fig. 1. Acid rain status chart in Zunyi in 2000.

The daily counts of hospital outpatient admission for respiratory disease from January 2007 to January 2010 were obtained from the database of the Outpatient Department of Affiliated Hospital of Zunyi Medical College. The completeness of the register, the quality of patient diagnosis, and certificated cause of respiratory diseases has been examined. The register is both complete and reliable, i.e. all respiratory diseases are confirmed by physicians. The disease diagnosis was classified according to the International Classification of Disease, Tenth Revision (ICD 10). Eight outcomes were considered based on ICD-10 codes for respiratory outcomes (acute upper respiratory tract infections (J00-J06), influenza (J10-J11), pneumonia (J12-J18), rhinitis and sinusitis (J30-J32), bronchitis (J40-J42), emphysema (J43), other chronic obstructive pulmonary diseases (J44), and asthma (J45-J46)).

Statistical Methods

Time-series methodologies are needed to examine associations between urban climatic parameters and health outcomes (e.g. respiratory morbidity). Poisson regression model was used to model the daily count data for each respiratory morbidity outcome as the dependent variable; and daily average, minimum, and maximum air temperature; relative humidity; and average, minimum, and maximum atmospheric pressure as the independent variables.

In the current study, we investigated associations between climatic conditions and health outcomes using a generalized additive model (GAM) [21] with penalized splines. We analyzed the meteorological parameters, number of hospital outpatient visits for respiratory diseases, and covariate data, while controlling for seasonal and long-term trends and day of the week. Because the daily counts of hospital outpatient visits for respiratory disease data typically follow a Poisson distribution, the core analysis was a generalized additive model.

We incorporated smoothed spline functions of time and weather conditions, which can accommodate nonlinear and nonmonotonic patterns between the number of hospital outpatient visits for respiratory diseases and weather or time conditions. The partial autocorrelation function (PACF) was used to select the degrees of freedom for time trend. 4 *df* (degree of freedom) for time trend (for our research period) was selected in our analyses for the number of hospital outpatient visits for respiratory diseases. After we established the basic models, we introduced the weather variable (daily mean average, minimum and maximum air temperature, relative humidity, and average, minimum and maximum atmospheric pressure), and analyzed their effects on pulmonary morbidity. 5 *df* for daily mean temperature, 6 *df* for daily relative humidity and 3 for daily pressure could control their effects on the daily counts of hospital outpatient visits for respiratory diseases and was used in the model.

Briefly, we fit the following log-linear generalized additive model:

$$Y_{t|temp,humidity,pressure} \sim Poisson(\mu_{t|temp,humidity,pressure})$$

$$\ln(\mu_{t|temp_t,humidity_t,pressue_t}) = \beta_0 + ns(temp_t,df_1) + ns(humidity_t,df_2) + ns(pressue_t,df_3) + ns(t,df_4)$$

...where the subscript t denotes the time of the observation; $t|temp$, *humidity,* and *pressure* signifies expected daily cardiovascular disease hospital outpatient admissions on time t; $ns(.)$ refers to natural cubic spline; β_0 is the intercept term; $temp_t$ refers to daily average temperature at time t; $humidity_t$ reflects daily relative humility at time t; $pressure_t$ reflects daily average pressure at time t; df refers to degrees of freedom; $ns(t, df)$ explains expressing the change of hospital outpatient amount with time in a time trend.

Because air temperature, relative humidity, and atmospheric pressure variables in this study belong to time series, from the perspective of forecasting, air temperature, relative humidity and atmospheric pressure can be explained and forecasted by high-degrees-of-freedom time trend function, therefore, if the degree of freedom of time trend function was chosen too high, variations of air temperature, relative humidity and atmospheric pressure could be absorbed. When the degree of freedom of time trend function is 200, the variations of air temperature, relative humidity and atmospheric pressure curves were almost horizontal. The principle of our study is to smooth the time trend curve without the existing curve's disturbance. Under the premise of no obvious effects on other factors, we tried to fit the model better.

We used air temperature, relative humidity, and atmospheric pressure as original variables. All model analyses were performed using R, version 2.5.0 [22].

Result

Data Description

Air Temperature, Relative Humidity, Atmospheric Pressure, and Hospital Outpatient Admission for Respiratory Diseases

The descriptive analysis of the variables (daily average air temperature, relative humidity, daily average atmospheric pressure, and number of hospital outpatient visits for respiratory diseases) used in the study are shown in Table 1.

Figs. 2 and 3 show the distribution of the number of hospital outpatient visits for respiratory diseases for our target population. Among Zunyi residents (aged 0-95 years), a total of 104,597 hospital outpatient visits for respiratory diseases were observed for the study period, and its average of daily figures was 98.21±62.00. The number of hospital outpatient visits for respiratory diseases followed a long-term and seasonal pattern for residents. The pattern of daily figures for hospital outpatient visits for respiratory diseases increased gradually; however, the seasonal pattern was not noticeable during the study years (2007-10).

Table 1. Frequency distribution of daily air temperature, relative humidity and atmospheric pressure and the number of hospital outpatient visits for respiratory diseases from 2007.1.1 to 2010.1.1 in Zunyi.

Variable	$\bar{x}\pm s$	Minimum	P25	P50	P75	Maximum
Daily average temperature (°C)	15.66±7.73	-4.50	9.95	16.70	22.40	28.1
Daily minimum temperature (°C)	13.10±9.10	-5.20	7.45	13.90	19.30	25.70
Daily maximum temperature (°C)	19.97±12.26	-3.80	13.40	20.60	27.50	33.80
Relative humidity (%)	75.05±12.47	16.00	68.00	76.00	85.00	96.00
Daily average pressure (hPa)	905.70±6.42	886.30	900.50	905.50	910.45	921.30
Daily minimum pressure (hPa)	902.82±6.85	881.90	897.70	902.30	907.45	917.90
Daily maximum pressure (hPa)	907.86± 6.58	891.70	902.60	907.70	912.70	924.00
Respiratory Diseases	98.21±62.00	0	59	90	146	282
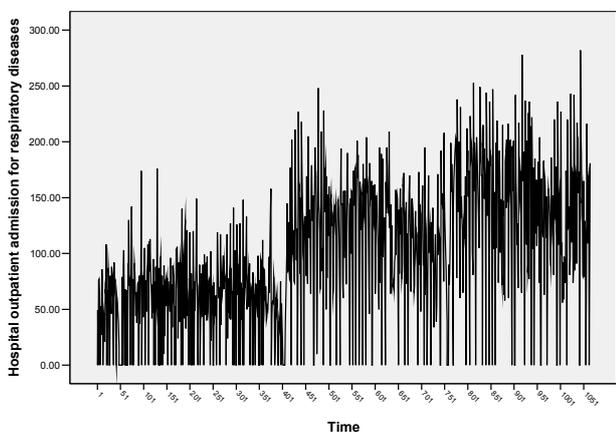
Fig. 2. Daily number of hospital outpatient visits for respiratory diseases versus time (2007.1-2010.1).
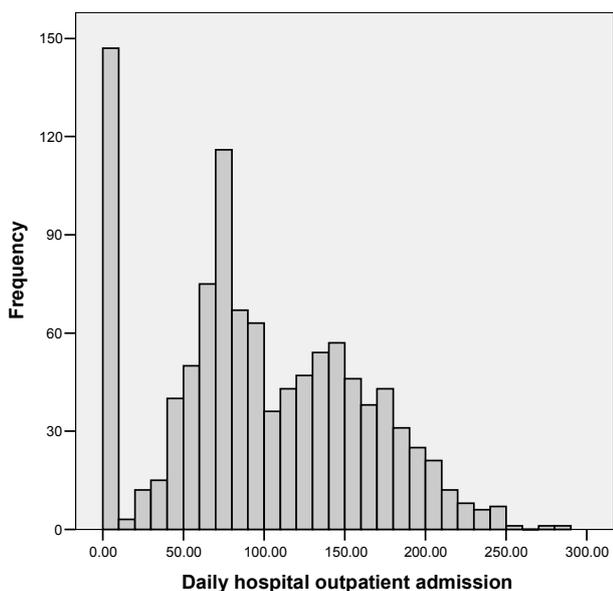
Fig. 3. Distribution of pulmonary hospital outpatient admissions in Zunyi (2007.1-2010.1) among residents.

Meteorological data were measured on 1,065 days for the respiratory disease patients. The daily average air temperature during study period was15.66±7.73ºC. Mean relative humidity was 75.05±12.47% and daily average atmospheric pressure was 905.70±6.42 hPa. Daily average values for air temperature were plotted for the entire period 2007.1.1 through 2010.1.1 to graphically display trends in ambient temperature levels over time. As expected, a distinctive cyclic pattern is readily seen with higher values occurring in the summer/fall months and lower values in the winter/spring (Fig. 4).

Regression Results

Temperature, Humidity, Air Pressure and the Number of Hospital Outpatient Visits for Respiratory Diseases

Time Trend Function

Comparing degrees of freedom of time trend function 3 with 4, we considered the variations of air temperature,
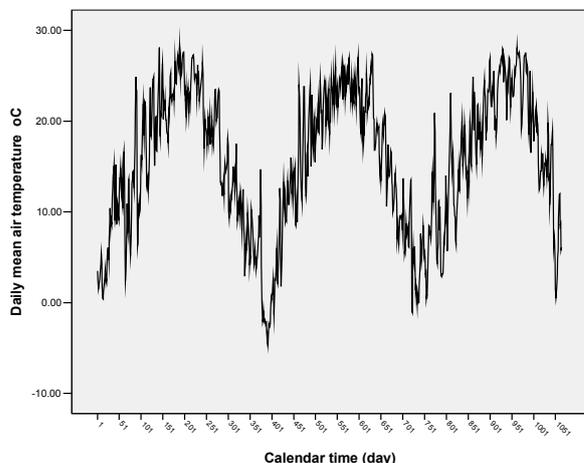
Fig. 4. Daily mean air temperature values in Zunyi (2007.1-2010.1).

relative humidity and atmospheric pressure of both degree of freedom is small. Hence, we selected 4 as degree freedom of time trend function after a first exploratory analysis (Fig. 5).

Temperature Trend Function

It is hard to explain how the curve became obviously disturbing when air temperature ranges from 15 to 25ºC (Fig. 6A). Curve became bounce when air temperature ranged from 15 to 25ºC, the change of curve may result from the reason that it is comparatively easy for patients to visit hospital outpatient rooms and rainfall reduction in the air temperature variation range. According to trend curve's variation and disturbance, when *df* was chosen as 5, the variation of the trend function didn't present obvious disturbance, therefore we considered 5 as the *df* of temperature trend function (Fig. 6B).
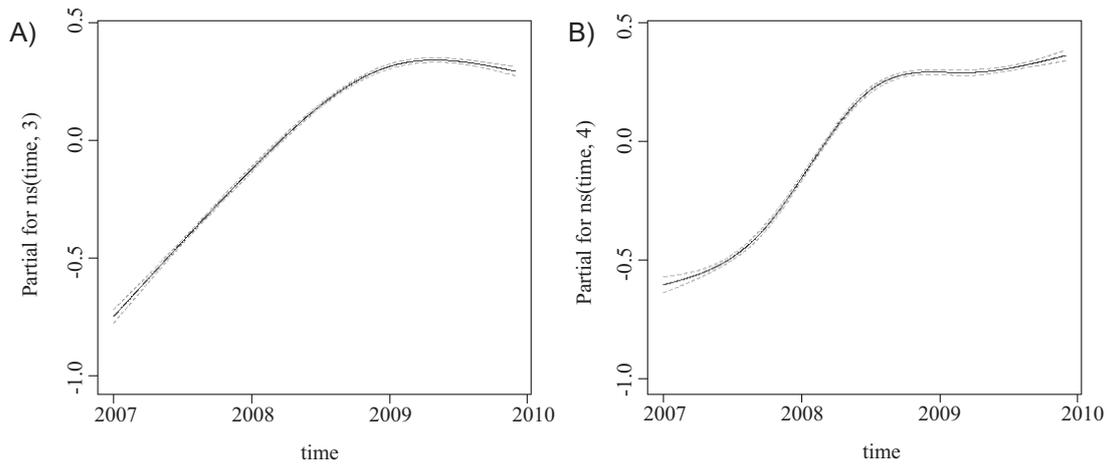
Fig. 5. Time trend curve's variation and disturbance. A: df = 3, B: df = 4.
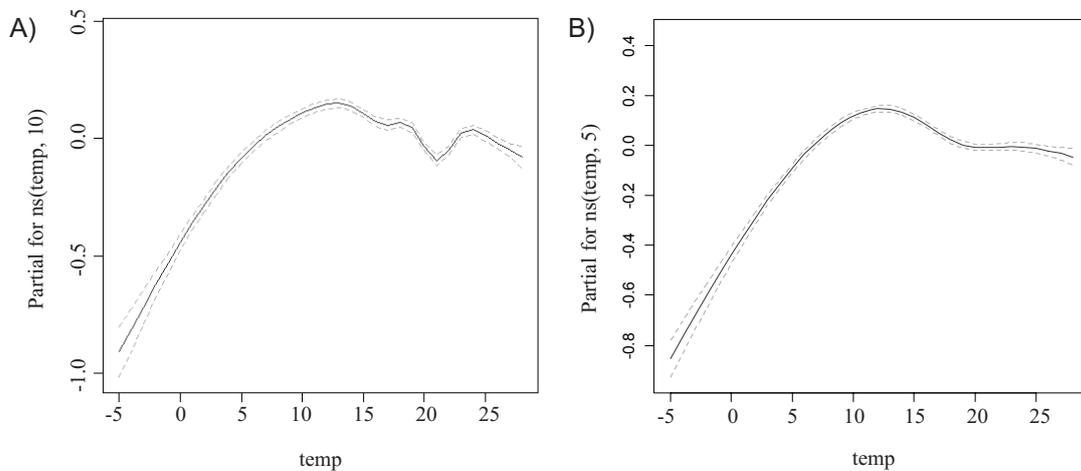
Fig. 6. Temperature trend curve's variation and disturbance. A: df = 10, B: df = 5.
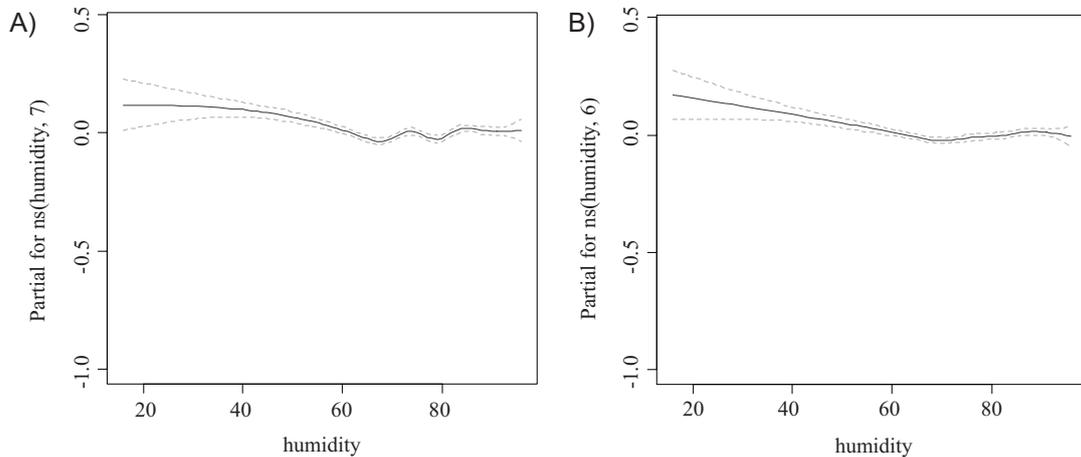
Fig. 7. Humidity spline curve's variation and disturbance. A: df = 7, B: df = 6.
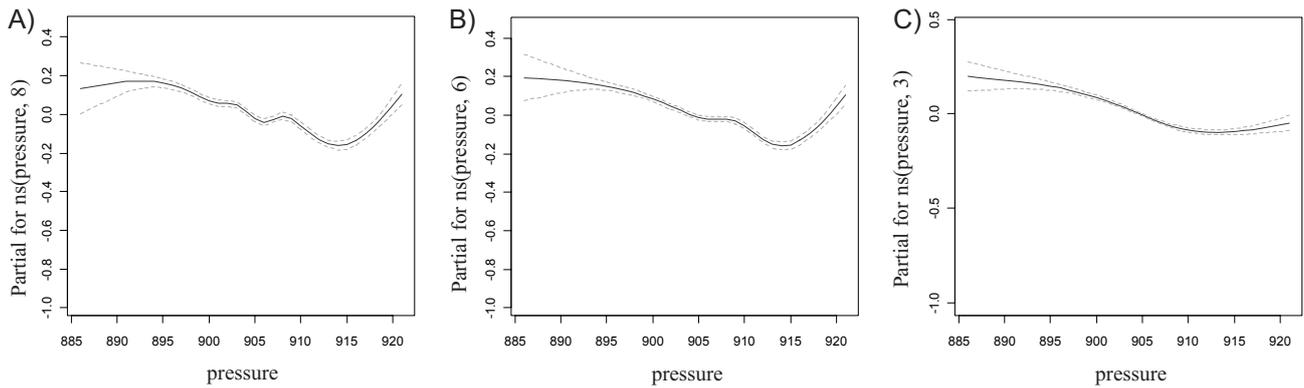
Fig. 8. Air pressure spline curve's variation and disturbance. A: df = 8, B: df = 6, C: df=3.

Humidity Spline Function

When we chose 7 or 8 as the *df* of humidity spline function, humidity spline curve presented a disturbance; when *df* 5 and 6 were chosen, the curve indicated no disturbance, hence, we selected 6 as the *df* of humidity spline function (Fig. 7).

Air Pressure Spine Function

When we considered 8 or 6 as the *df* of air pressure spine function, air pressure spine curve presented either a noticeable disturbance or no noticeable disturbance. But the right tail of air pressure spine curve occurred with a slight tilt. When *df* was 3, the air pressure spine curve appeared with an unobvious disturbance, and the right tail of air pressure spine curve occurred with a slight tilt, but not noticeable. We selected 3 as the *df* of air pressure spine function (Fig. 8).

Day-of-the-Week Effect

Day-of-the-week effect is obvious, the number of hospital outpatient room visits for respiratory diseases was
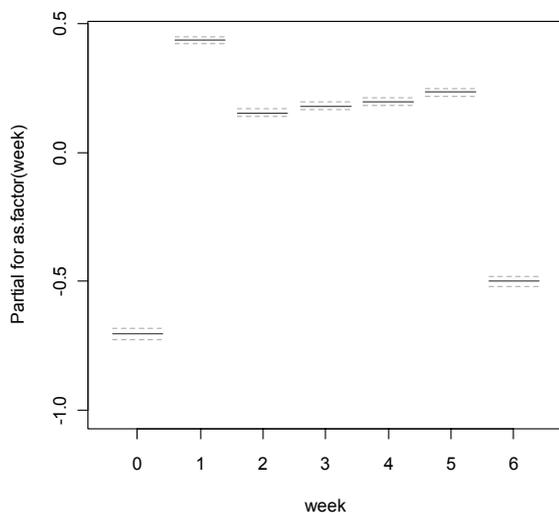
Fig. 9. Day-of-the-week effect (0 – Sunday, 1 – Monday, 2 – Tuesday, 3 – Wednesday, 4 – Thursday, 5 – Friday, 6 – Saturday).

reduced distinctly on Saturday and Sunday compared to other days, and the number was least on Saturday (Fig. 9).

In order to facilitate interpreting the regression results, we defined:

$$temp1 = \begin{cases} temp & if\ temp<10 \\ 10 & if\ temp \geq 10 \end{cases}$$

$$temp2 = \begin{cases} 0 & if\ temp<10 \\ temp-10 & if\ temp \geq 10 \end{cases}$$

From Tables 2 and 3, above, we inferred for a 1ºC increase in daily average temperature below a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity increased by exp(0.0488790) = 1.0500933-fold, whereas for a 1ºC increase in daily average temperature above a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity decreased by exp(-0.0097181) = 0.99032897-fold over the past year.

Discussions

We found that seasonal changes of temperature in the acid rain-plagued city of Zunyi, China, were associated with residents' respiratory morbidity. Moreover, this exploratory study has revealed a linear relationship between respiratory outcomes and daily mean air temperature. For a 1ºC increase in daily average temperature below a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity increased by 1.05009331-fold, whereas for a 1ºC increase in daily average temperature above a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity decreased by 0.99032897-fold over the past year. To the best of our knowledge, this is the first study to examine potential effect modifiers of meteorological conditions on the daily number of hospital outpatient visits for respiratory disease in an acid rain-plagued area, and our results should contribute to the understanding of climatic seasonality of temperature and climate-related health effects in China.

The rate of admissions to hospitals [23-25] and mortality [12, 17, 26] are broadly used as measures of health impact with climatic factors in previous studies. In the present investigation, we reported exposure to different climatic

Table 2. Coefficient parameter estimates in generalized additive model.

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.69572	0.07639	35.287	< 2e-16 ***
as.factor(week)1	1.14141	0.01388	82.226	< 2e-16 ***
as.factor(week)2	0.85646	0.01443	59.354	< 2e-16 ***
as.factor(week)3	0.88085	0.01438	61.245	< 2e-16 ***
as.factor(week)4	0.90134	0.01432	62.964	< 2e-16 ***
as.factor(week)5	0.94293	0.01424	66.203	< 2e-16 ***
as.factor(week)6	0.20848	0.01622	12.855	< 2e-16 ***
ns(temp, 5)1	1.05692	0.03499	30.203	< 2e-16 ***
ns(temp, 5)2	0.82606	0.04326	19.095	< 2e-16 ***
ns(temp, 5)3	0.58401	0.02861	20.411	< 2e-16 ***
ns(temp, 5)4	1.62265	0.08465	19.169	< 2e-16 ***
ns(temp, 5)5	0.29595	0.02477	11.946	< 2e-16 ***
ns(humidity, 6)1	-0.24471	0.04998	-4.896	9.80e-07 ***
ns(humidity, 6)2	-0.22129	0.05552	-3.985	6.74e-05 ***
ns(humidity, 6)3	-0.23386	0.05327	-4.390	1.13e-05 ***
ns(humidity, 6)4	-0.12704	0.03469	-3.663	0.000250 ***
ns(humidity, 6)5	-0.38471	0.11263	-3.416	0.000636 ***
ns(humidity, 6)6	-0.13048	0.03008	-4.338	1.44e-05 ***
ns(pressure, 3)1	-0.32436	0.02401	-13.507	< 2e-16 ***
ns(pressure, 3)2	-0.31857	0.08207	-3.882	0.000104 ***
ns(pressure, 3)3	-0.21454	0.02715	-7.901	2.78e-15 ***
ns(time, 4)1	0.95923	0.01904	50.389	< 2e-16 ***
ns(time, 4)2	0.82804	0.01710	48.424	< 2e-16 ***
ns(time, 4)3	1.01516	0.04222	24.043	< 2e-16 ***
ns(time, 4)4	0.90750	0.01474	61.579	< 2e-16 ***

*** p<0.001

Table 3. Coefficient parameter estimates in generalized additive model.

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	13.7702928	0.7330375	18.785	<2e-16 ***
temp1	0.0488790	0.0016046	30.462	<2e-16 ***
temp2	-0.0097181	0.0008910 -10.907	<2e-16 ***	
humidity	-0.0001921	0.0002794	-0.688	0.492
pressure	-0.0112323	0.0007970	-14.094	<2e-16 ***
ns(time, 4)1	0.9164377	0.0185376	49.437	<2e-16 ***
ns(time, 4)2	0.8213615	0.0167830	48.940	<2e-16 ***
ns(time, 4)3	0.9633490	0.0416664	23.121	<2e-16 ***
ns(time, 4)4	0.8964516	0.0144847	61.890	<2e-16 ***

*** p<0.001

conditions on health effects using the number of hospital outpatient admission visits as respiratory outcome because we deemed the outpatient visit data might be a more sensitive indicator for the acute health effects of climatic conditions than inpatient data.

Environmental impacts on Health have been an area of continuing research interest [27-30]. Many studies reported in literature considered low temperature as a risk factor to trigger pulmonary morbidity. Our findings in Zunyi are in agreement with two investigations performed in Auckland, New Zealand, where increases in respiratory admissions were strongly linked to minimum temperatures during winter over the 1994 to 2004 period [8], and in Lahore, Pakistan, in 1984 through 1987 [31]. Erling et al. deemed a low monthly average minimum day temperature to be associated with the prevalence of upper respiratory tract infections and lower respiratory tract infections, especially among boys.

The absence of a positive correlation between temperature and number of hospital outpatient visits under a threshold in the current study is not consistent with previous reports [32, 33]. Regarding temperature, Gasparrini et al. estimated that an overall increase in all-cause mortality of 2.1% (95% CI 1.6% to 2.6%) for a 1ºC rise above the regional heat threshold, the steepest increase in risk was for respiratory mortality (+4.1% (3.5% to 4.8%) per 1ºC). When analyzing data for Finland, Harju et al. [33] observed that the prevalence of cold-related respiratory symptoms were even higher in asthmatics (69% in males, 78% in females) and patients with chronic bronchitis (65%/76%) than in healthy persons (18%/21%), started to emerge at relatively low (threshold) temperatures: -14ºC for males and -15ºC for females. Compared with the prior results above, lower exposure-response relationships may exist in this Chinese meteorological condition study. The discrepancy may stem from the different characteristics of the study contexts, such as geographic locations (e.g. latitude), climatic characteristics (e.g. sudden weather changes, often occurring in spring and fall, triging people to be attacked by respiratory morbidity), urban population (e.g. particular matter), demographic characteristics (e.g. vulnerable populations, population disease profile) and statistical techniques used, etc. In addition, cold weather with snow could have prevented patients from reporting to physicians. This might be among the reasons for the association between cold weather and low admission numbers.

In the current analysis we found no non-linear relation (J-, V-, or U-shaped) between the meteorological parameters and the number of hospital outpatient visits, but an opposite correlation between meteorological and health variables above/below the threshold of 10ºC observed. However, this result was not entirely with other studies in China [34] and worldwide [35-37]. In Madrid, Spain, Alberdi et al [36], using a Poisson regression statistical approach to model outdoor temperature, relative humidity, and daily mortality, reported a J-shaped relationship. Mortality was inversely related to cold temperature (4- to 11-day lag) and directly related to warm temperature (1-day lag). A large-scale multi-city time-series analyses in

ISOTHURM' project estimated a U-shaped temperature-mortality relationship, with increasing death rates at colder temperatures and with increasing heat in most cities. The threshold for cold-related mortality ranged from 15ºC to 29ºC; and for heat-related deaths ranged from 16ºC to 31ºC [35]. Disparity of the analyzing results may also be explained by the difference in health outcome variables in data analysis and a statistical approach, as well as local air pollution. Prior climatic change time-series studies indicated climatic seasonality of temperature showed a greater impact on mortality than hospital admissions for respiratory morbidity [38, 39]. These studies implied, during periods of weather in the extreme, that many deaths took place rapidly before the patient receives medical treatment or is admitted to a hospital.

Numerous prior temperature-related time series studies have been based on the generalized additive model in S-PLUS [23, 40, 41] or R software [26, 42]. In accordance with privous reports, we conducted our time series analysis using GAM with penalized splines in R software. Prior studies had indicated that diverse regression models and parameter setting in the models (e.g. *df* selection) might influence the regression coefficients.

The air pollution level in China, compared with developed countries, is much higher. Chinese western regions have been most affected by acidic deposition in the past three decades. Zunyi is a notable acid rain-plagued area with frequent acid precipitation and acidity, a result of excessive coal consumption by local industries and households. Meteorological and environmental conditions may contribute to our season-specific observation in Zunyi, which has a basic humid subtropical climate with a monsoon season. Unseasonably warm or cold spells are common, though temperatures rarely reach extremes. Rain falls throughout the year. It also is one of China's least sunny cities. In addition, topography, climatic factors, and air pollution have exacerbated ambient air quality conditions of Zunyi. Mountains surrounding Zunyi (up to 1,250 meters high) inhibit dispersion of air pollutants.

We are aware of some limitations in this study. Because of the ecological design, we confined our analyses to the evaluation of meteorological parameters, and did not control for air pollution, which might contribute significantly to the prevalence of pulmonary morbidity. Another limitation is the inability to control completely for the confounding of concomitant cardio-cerebral-vascular diseases, which might aggravate a respiratory event. In addition, we were unable to control for the possible confounding effect how the temperature-morbidity relationship modified by age, gender, race, and socioeconomic status as well as cause of morbidity, et al.

Conclusion

In summary, in this epidemiologic study of interactions between meteorological parameters and pulmonary morbidity, we have observed a linear relationship between daily mean air temperature and the number of hospital outpatient

visits for respiratory diseases. For a 1ºC increase in daily average temperature below a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity increased by 1.05009331-fold, whereas for a 1ºC increase in daily average temperature above a threshold (10ºC), the number of hospital outpatient visits for respiratory morbidity decreased by 0.99032897-fold over the past year. Our findings emphasize not only the need for further in-depth analyses on the synergistic effects of the climatic conditions on respiratory health, together with ambient air pollution, but aid policy makers with convincing evidence of the need to minimize the established health risks.

Acknowledgements

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