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Impact of meteorological factors on lower respiratory tract infections in children

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Abstract

Objective: To evaluate retrospectively the relationship between meteorological factors in Shenmu County, Yulin City, Shaanxi Province, China and the incidence of lower respiratory tract infections in children.

Methods: Meteorological data (air temperature, atmospheric pressure, rainfall, hours of sunlight, wind speed and relative humidity) for Shenmu County and medical data from hospitalized patients aged $\leq$16 years were collected between January 2009 and December 2012. The association between meteorological factors and rate of hospitalization due to lower respiratory tract infections was investigated; the total hospitalization rate was compared with the rate of lower respiratory tract disease-related hospitalizations.

Results: The leading bacterial causes of lower respiratory tract infections were *Streptococcus pneumoniae* and *Haemophilus influenzae* type B; the main viral cause was respiratory syncytial virus. Lower respiratory tract infection hospitalization rate was significantly correlated with air temperature ($R = -0.651$), atmospheric pressure ($R = 0.560$), rainfall ($R = -0.614$) and relative humidity ($R = -0.470$), but not with hours of sunlight ($R = -0.210$) or wind speed ($R = 0.258$). Using multiple linear regression, lower respiratory tract infection hospitalization rate decreased with a gradual increase in air temperature ($F = 38.30$) and relative humidity ($F = 15.58$).

Conclusion: Air temperature and relative humidity were major influencing meteorological factors for hospital admissions in children due to lower respiratory tract infections.

Keywords

Meteorological factors, Hospitalized children, Lower respiratory tract infection, Temperature, Relative humidity, *Streptococcus pneumoniae*, Respiratory syncytial virus

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Introduction

Seasonal diseases are those that occur or worsen in close relation to changes in the weather and the seasons.[1] Changes in meteorological factors mainly affect the respiratory system and, in particular, are thought to be substantial causes of induced bronchial asthma, tracheitis, bronchitis, pneumonia and other respiratory diseases.[2] Meteorological factors are considered to affect the respiratory system via two mechanisms:[3] (i) by lowering the resistance of the human body to infection;[4] (ii) by affecting the ease with which infections spread. Factors associated with the first mechanism lower human resistance to infection by affecting the site of entrance of micro-organisms or viruses into the body, and place of settlement and further progression of disease.[5] Factors associated with the second mechanism affect general disease resistance of the body, which is determined by the specific physiochemical state of the body at a given time, and by weather and climate-related habits, e.g. crowding into rooms, shutting windows and doors (reducing ventilation), and modifying clothing and diet.[6,7]

The incidence of respiratory tract infection-based hospitalization is higher in children compared with adults, particularly in relation to lower respiratory tract infection.[8,9] An improved understanding of the relationship between meteorological factors and respiratory tract infections may facilitate measures to reduce the incidence of such infections during adverse meteorological conditions. Thus, the present study investigated the association between meteorological factors and lower rates of respiratory tract infection in children admitted to Shenmu Hospital and Shenmu Second Hospital (Shenmu County, Yulin City, Shaanxi Province, China) between January 2009 and December 2012.

Patients and methods

Study population and data collection

This retrospective observational study included medical records from children aged ≤16 years, admitted to Shenmu Hospital and Shenmu Second Hospital, and discharged between January 2009 and December 2012. Cases with a primary discharge diagnosis of lower respiratory tract infection (including pneumonia, bronchiolitis and bronchitis, in accordance with the *International Statistical Classification of Diseases and Health Related Problems-10*, version 2008[10]) and with no other associated comorbidity (e.g. obesity, physical disability, allergic conditions) were included in the study.[11] Respiratory tract infections were diagnosed according to the diagnostic standard of *Practical Pediatrics,* 7th edition.[12]

Records included chest X-radiographs obtained according to clinical indication (which included all children with a suspected lower respiratory tract infection). All chest X-radiographs were retrospectively evaluated by an expert radiologist. Sputum culture data were obtained for cases in which sputum had been produced.

Hospitalization records for all children aged ≤16 years, including those admitted with respiratory tract infection, were collected each week of the year over the study period, to represent all seasons and extremes of meteorological factors. During the corresponding time-period, data from daily monitoring of atmospheric meteorological factors were collected from Shenmu County Meteorological Bureau, Shenmu County, Yulin City, China, including daily mean air temperature, atmospheric pressure, rainfall, hours of sunlight, wind speed and relative humidity. All of the meteorological monitoring sites for Shenmu County provided hourly measurement data of meteorological factors. Methodology described by the American Heart Association was used for data selection and analyses, according to which measurements were taken at monitoring sites using a HOBO® RX3002 weather station kit (including thermometer, barometer, rain gauge, anemometer and hygrometer [Onset Computer Corporation, Bourne, MA, USA]).[13] All sensors were integrated into an Onset HOBO® RX3002 data logger, which controlled the sensors and stored the raw data using HOBOware® Pro software (Onset Computer Corporation). Hourly mean values were used to calculate the 24-h mean of each factor, from which weekly 24-h mean values were computed. Weekly 24-h mean value was subtracted from each 24-h value for that week; each subtracted value was then squared and the sum of the squares calculated for each given week. The sum was divided by 6 (7 days of week minus 1) to obtain the variance and the SD was calculated.

The Shenmu Hospital Institutional Review Board waived the requirement for ethical approval, as the study did not directly involve patients or clinical samples. A written request from the authors to collect inpatient data was approved by the head of the Paediatrics Department and the executive director of Shenmu Hospital.

Statistical analyses

Data are presented as *n* patient incidence and mean $\pm$ SD for lower respiratory tract infection hospitalization rate and meteorological factors (air temperature, atmospheric pressure, rainfall, hours of sunlight, wind speed and relative humidity), respectively. Pearson's correlation coefficient was used to assess the correlation between meteorological factors and lower respiratory tract infection hospitalization rate. Stepwise multiple linear regression was performed, with main meteorological factors as independent variables, to investigate the regression relationship between the independent variables and respiratory tract infection hospitalization rate. Shapiro–Wilk test was applied to assess distribution of the population. SAS® software version 9.3 (SAS Institute, Cary, NC, USA) was used for the statistical analyses. *P*-values < 0.05 indicated statistical significance.

Results

Epidemiology and pathophysiology

A total of 19 772 children aged $\leq$16 years were admitted to the Paediatrics Departments of Shenmu Hospital and Shenmu Second Hospital between 1 January 2009 and 31 December 2012. Of these admissions, 4449 (22.5%) were diagnosed with a lower respiratory tract infection; there were 2980 (67%) male cases.

All patients with a lower respiratory tract infection exhibited fever (temperature $>38°$C) and clinical signs such as dyspnoea, rapid breathing (children aged $<$2 months, $>$60 breaths per min; children aged 2–12 months, $>$50 breaths per min; children aged 12–59 months, $>$40 breaths per min; children aged 5–12 years, $>$30 breaths per min; children aged 12–16 years, $>$25 breaths per min), chest in-drawing and other life-endangering signs (exhaustion, inability to feed, seizures or vomiting).

In patients diagnosed with a lower respiratory tract infection, 36% of cases (1601) were found among those aged 29 days to 12 months, 33.5% of cases (1490) among those aged 1–4 years and 25% of cases (1112) among those aged 5–16 years. The lowest incidence of lower respiratory tract infection (5.5% [246 cases]) was found in neonates (aged $\leq$28 days).

The leading causative bacteria found in lower respiratory tract infections were *Streptococcus pneumoniae* (confirmed in 756 cases [17%]) and *Haemophilus influenzae* type B (400 cases [9%]). The main causative virus was found to be respiratory syncytial virus (diagnosed in 667 cases [15%]), followed

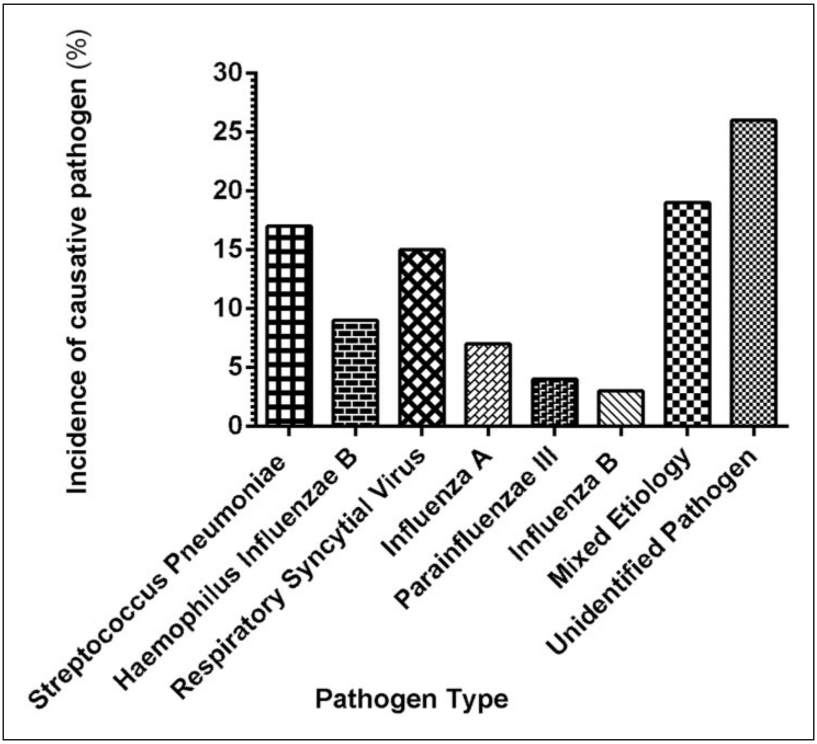

Figure 1. Micro-organisms identified in children aged ≤16 years (from Shenmu County, Yulin City, Shaanxi Province, China) admitted to hospital with lower respiratory tract infections.

by influenza A virus (311 cases [7%]), parainfluenza III (178 cases [4%]) and influenza B virus (133 cases [3%]). In total, 845 cases (19%) were of mixed aetiology, and the pathogen was unidentified in 1159 cases (26%) of lower respiratory tract infection (Figure 1).

Overall paediatric hospital admissions and admissions due to lower respiratory tract infection according to variations in air temperature, atmospheric pressure, rainfall, hours of sunlight, wind speed and humidity are shown in Table 1.

Correlation between hospitalization rate and meteorological factors

The total number of hospital admissions in children aged ≤16 years diagnosed with a lower respiratory tract infection was significantly correlated with mean values of air temperature, atmospheric pressure, rainfall and relative humidity (Table 2). There was no statistically significant correlation between mean values of hours of sunlight and wind speed (Table 2).

Regression analysis

Using Pearson's correlation coefficient, air temperature, atmospheric pressure, rainfall and relative humidity were kept as independent variables and fitted into a linear regression model against the number of lower respiratory tract infection-related hospital admissions. First, the variance inflation factor was used as a reference value for the independent variables to comprehend

Table 1. Lower respiratory tract infection (LRTI)-related hospital admissions and total hospital admissions in children aged ≤16 years (from Shenmu County, Yulin City, Shaanxi Province, China), and meteorological factors according to each week of the year.

	Hospital admissions			Meteorological factor					
Week no.	LRTI	All	% LRTI[a]	Air temperature, °C	Atmospheric pressure, Pa	Rainfall, mm	Hours of sunlight	Wind speed, m/s	Relative humidity, %
1	90	419	21.5	−8.8 ± 3.0	918.0 ± 5.1	0.0 ± 0.2	6.2 ± 2.3	1.6 ± 0.6	53.2 ± 10.1
2	97	412	23.5	−9.3 ± 2.4	919.3 ± 4.7	0.0 ± 0.0	7.4 ± 1.4	1.7 ± 0.5	46.9 ± 5.7
3	88	357	24.6	−7.9 ± 4.2	916.0 ± 5.8	0.0 ± 0.1	6.2 ± 2.9	1.9 ± 1.0	45.1 ± 9.9
4	84	339	24.8	−7.9 ± 3.8	915.9 ± 5.4	0.0 ± 0.0	7.6 ± 1.7	1.5 ± 0.4	39.5 ± 5.8
5	83	344	24.1	−4.2 ± 4.2	913.4 ± 4.7	0.0 ± 0.0	6.8 ± 3.0	1.7 ± 0.5	43.1 ± 15.8
6	70	333	21.0	−3.2 ± 4.8	910.5 ± 7.5	0.4 ± 0.8	5.9 ± 3.7	1.8 ± 0.6	49.8 ± 18.9
7	76	344	22.1	−3.8 ± 3.3	913.8 ± 4.9	0.0 ± 0.0	7.5 ± 3.0	2.0 ± 0.6	44.0 ± 13.0
8	91	370	24.6	2.1 ± 4.0	907.7 ± 5.5	0.2 ± 0.8	6.9 ± 3.2	1.8 ± 0.4	41.3 ± 14.6
9	113	384	29.4	0.2 ± 2.5	910.9 ± 4.3	0.6 ± 1.7	5.9 ± 4.0	1.9 ± 0.5	55.3 ± 17.3
10	112	403	27.8	1.2 ± 4.1	912.2 ± 6.3	0.7 ± 1.8	7.3 ± 4.2	2.1 ± 0.5	44.7 ± 16.1
11	123	401	30.7	5.5 ± 4.7	908.8 ± 6.8	0.4 ± 2.1	7.3 ± 3.6	2.4 ± 0.9	36.8 ± 15.0
12	125	386	32.4	4.0 ± 2.7	912.7 ± 4.5	0.2 ± 0.9	8.8 ± 3.1	2.3 ± 0.8	31.5 ± 10.9
13	121	394	30.7	6.6 ± 2.7	912.6 ± 3.9	0.8 ± 3.1	8.5 ± 4.1	2.1 ± 0.5	35.7 ± 16.8
14	123	411	29.9	10.3 ± 3.2	909.3 ± 4.5	0.3 ± 0.9	9.0 ± 3.3	2.2 ± 0.5	33.5 ± 17.0
15	106	377	28.1	12.6 ± 5.1	906.7 ± 5.1	0.2 ± 0.8	9.4 ± 2.9	2.1 ± 0.7	34.0 ± 9.9
16	86	356	24.2	13.6 ± 2.8	907.0 ± 4.0	0.6 ± 2.1	9.5 ± 3.1	2.5 ± 1.1	36.2 ± 14.8
17	100	371	27.0	14.6 ± 4.7	904.5 ± 5.8	0.4 ± 1.0	9.8 ± 2.8	2.6 ± 1.0	28.4 ± 10.3
18	95	373	25.5	18.6 ± 3.6	902.5 ± 3.6	0.8 ± 2.7	8.4 ± 4.2	2.0 ± 0.6	38.1 ± 16.0
19	90	386	23.3	16.8 ± 3.3	905.7 ± 3.4	2.6 ± 8.0	7.4 ± 5.0	2.1 ± 0.7	50.6 ± 20.1
20	93	387	24.0	18.0 ± 3.1	904.5 ± 3.6	0.9 ± 2.3	9.3 ± 4.1	2.0 ± 0.7	37.5 ± 16.8
21	82	371	22.1	19.2 ± 2.7	905.6 ± 2.8	1.8 ± 4.8	9.3 ± 4.5	2.1 ± 0.6	41.0 ± 16.8
22	72	410	17.6	21.7 ± 2.1	903.5 ± 4.3	0.7 ± 2.5	11.3 ± 2	2.0 ± 0.6	38.1 ± 9.4
23	50	377	13.3	22.0 ± 2.3	901.5 ± 3.1	1.3 ± 3.8	9.8 ± 3.7	2.0 ± 0.6	45.5 ± 12.2
24	64	381	16.8	24.1 ± 2.4	900.1 ± 2.6	0.6 ± 1.9	9.8 ± 4.0	2.2 ± 0.5	37.1 ± 10.2
25	57	387	14.7	25.7 ± 1.8	899.6 ± 2.2	1.6 ± 3.8	9.2 ± 3.8	2.0 ± 0.5	38.6 ± 11.4
26	77	410	18.8	24.4 ± 2.9	899.8 ± 1.9	4.3 ± 8.0	7.8 ± 5.0	1.9 ± 0.5	51.9 ± 22.0
27	69	390	17.7	25.1 ± 2.4	899.7 ± 1.9	3.5 ± 10.9	8.1 ± 4.8	1.9 ± 0.5	53.3 ± 14.3

(continued)

Table 1. Continued.

Week no.	Hospital admissions			Meteorological factor					
	LRTI	All	% LRTI[a]	Air temperature, °C	Atmospheric pressure, Pa	Rainfall, mm	Hours of sunlight	Wind speed, m/s	Relative humidity, %
28	71	381	18.6	24.8 ± 1.9	900.2 ± 2.5	2.0 ± 3.4	8.3 ± 4.0	1.8 ± 0.5	58.0 ± 12.8
29	66	368	17.9	25.6 ± 2.1	900.9 ± 2.2	4.3 ± 14.2	9.0 ± 3.8	1.8 ± 0.4	54.6 ± 11.3
30	55	360	15.3	25.4 ± 3.0	900.8 ± 2.6	3.4 ± 5.9	8.1 ± 4.1	1.9 ± 0.4	61.3 ± 12.3
31	42	325	12.9	24.5 ± 2.0	902.6 ± 2.0	3.1 ± 8.1	7.5 ± 4.7	1.8 ± 0.6	62.7 ± 11.6
32	57	364	15.7	24.8 ± 1.7	902.5 ± 2.0	2.4 ± 10.7	7.9 ± 4.5	1.7 ± 0.4	59.5 ± 10.9
33	46	307	15.0	21.5 ± 2.2	904.8 ± 2.6	5.3 ± 7.6	5.8 ± 4.2	1.8 ± 0.6	71.0 ± 9.8
34	52	338	15.4	20.6 ± 1.6	907.6 ± 2.2	1.6 ± 3.9	8.8 ± 3.8	1.7 ± 0.5	63.7 ± 13.9
35	73	393	18.6	21.3 ± 1.8	905.7 ± 1.6	2.8 ± 7.7	6.8 ± 4.1	1.6 ± 0.4	65.6 ± 11.7
36	73	352	20.7	17.0 ± 2.5	908.7 ± 2.6	2.6 ± 6.1	5.9 ± 4.3	1.5 ± 0.4	71.9 ± 11.4
37	74	380	19.5	18.5 ± 3.7	907.7 ± 2.9	1.8 ± 4.2	6.9 ± 4.1	1.9 ± 0.6	64.4 ± 8.9
38	74	381	19.4	15.7 ± 2.8	910.4 ± 4.0	2.0 ± 8.0	7.2 ± 4.1	1.6 ± 0.5	60.3 ± 12.5
39	60	360	16.7	15.0 ± 2.4	912.4 ± 2.7	1.0 ± 4.2	7.7 ± 3.8	1.7 ± 0.5	57.0 ± 16.1
40	85	407	20.9	13.3 ± 2.1	911.8 ± 3.6	0.3 ± 1.2	7.9 ± 3.5	1.4 ± 0.3	56.4 ± 12.2
41	77	382	20.2	11.0 ± 2.2	912.2 ± 2.9	1.2 ± 4.2	6.8 ± 3.7	1.6 ± 0.6	62.5 ± 14.4
42	80	395	20.3	10.8 ± 2.5	911.0 ± 2.4	0.8 ± 2.7	7.4 ± 3.7	1.5 ± 0.6	54.1 ± 12.2
43	82	412	19.9	7.5 ± 2.7	914.9 ± 4.4	0.4 ± 1.0	6.2 ± 3.6	1.5 ± 0.5	60.9 ± 11.6
44	116	438	26.5	6.3 ± 3.8	914.6 ± 5.6	0.7 ± 2.0	6.7 ± 3.7	1.6 ± 0.8	54.4 ± 15.1
45	102	417	24.5	2.8 ± 3.9	913.2 ± 4.2	1.6 ± 2.8	5.6 ± 3.6	1.8 ± 0.7	61.9 ± 16.0
46	113	425	26.6	−0.6 ± 4.9	915.8 ± 5.8	0.5 ± 1.6	6.6 ± 2.8	1.6 ± 0.4	61.0 ± 12.2
47	115	442	26.0	−0.3 ± 1.8	913.7 ± 3.7	0.0 ± 0.0	6.6 ± 2.3	1.5 ± 0.5	57.7 ± 15.3
48	119	416	28.6	−1.0 ± 2.5	913.6 ± 4.1	0.4 ± 2.0	5.4 ± 3.5	1.7 ± 0.5	57.0 ± 21.8
49	96	355	27.0	−3.6 ± 3.2	914.5 ± 6.5	0.0 ± 0.1	5.3 ± 2.8	1.9 ± 0.6	54.2 ± 19.5
50	102	368	27.7	−6.7 ± 3.6	916.5 ± 6.4	0.0 ± 0.1	6.5 ± 2.2	1.6 ± 0.5	50.7 ± 14.3
51	100	377	26.5	−6.7 ± 3.5	916.4 ± 5.1	0.1 ± 0.5	5.6 ± 2.6	1.6 ± 0.5	49.6 ± 8.9
52	82	356	23.0	−8.7 ± 3.5	915.7 ± 5.6	0.0 ± 0.0	6.0 ± 2.3	1.8 ± 0.7	48.7 ± 9.9

Data presented as *n* patient incidence, or 24-h mean ± SD.
[a]Percentage of total admissions in children aged ≤16 years.

Table 2. Correlation between lower respiratory tract infection-related hospital admission rate in children aged ≤16 years (from Shenmu County, Yulin City, Shaanxi Province, China) and meteorological factors.

	Air temperature	Atmospheric pressure	Rainfall	Hours of sunlight	Wind speed	Relative humidity
Correlation coefficient	−0.651	0.560	−0.614	−0.210	0.258	−0.470
Statistical significance	$P < 0.001$	$P < 0.001$	$P < 0.001$	NS	NS	$P < 0.001$

NS, no statistically significant correlation ($P \geq 0.05$); Pearson's correlation coefficient.

Table 3. Multiple linear regression analyses of meteorological factors impacting on lower respiratory tract infection-related hospital admission rate in children aged ≤16 years from Shenmu County, Yulin City, Shaanxi Province, China.

Variable	Partial regression coefficient	Standard error	*F* value	Statistical significance	Adjusted R^2
Intercepts	33.574	2.219	229.04	$P < 0.001$	0.545
Mean air temperature	−0.253	0.041	38.30	$P < 0.001$	0.545
Mean relative humidity	−0.173	0.044	15.58	$P < 0.001$	0.545

collinearity. The variance inflation factor for each independent variable (air temperature, 7.7; atmospheric pressure, 8.9; rainfall, 3.8; relative humidity, 2.4) was <10, suggesting that collinearity between the independent variables had little effect on parameter estimation results.

The stepwise linear regression model showed that the ratio of lower respiratory tract infection-related hospital admissions to total hospital admissions gradually decreased with the increase in mean air temperature. The same decline was observed with a rise in mean relative humidity (test optimization fitting model, $P < 0.001$ confirms the statistical significance, while adjusted $R^2 = 0.545$ shows that the regression line fits the data; Table 3). According to the normal distribution of residuals, the normality plot (Shapiro–Wilk test, $W = 0.964$; $P = 0.121$) and the rate of lower respiratory tract infection-related hospital admissions (standardized predicted values versus standardized residuals; Figure 2), the data tested were from a normally distributed population.

Discussion

Since the implementation of free healthcare for all residents of Shenmu County in March 2009, healthcare has become available to >99% of the total population of Shenmu.[14] Shenmu Hospital and Shenmu Second Hospital serve ~80% of the child population in Shenmu County. In addition, Shenmu County Meteorological Bureau holds comprehensive meteorological records for Shenmu County from 1997 onwards.[15] The present study was able to use these extensive, representative data to investigate the relationship between meteorological factors and the prevalence of respiratory tract infections in children in Shenmu County.

Respiratory tract infection is a disease caused by multiple external factors,[16,17] one

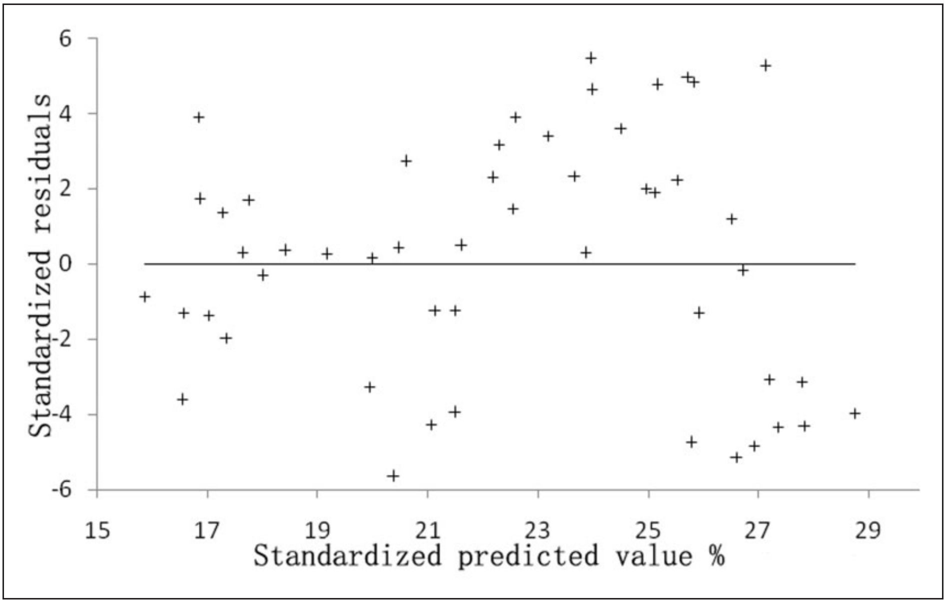

Figure 2. Scatter plot showing standardized predicted values versus standardized residuals for lower respiratory tract infection-related hospital admissions in children aged ≤16 years (from Shenmu County, Yulin City, Shaanxi Province, China).

of the most critical being meteorological. Various meteorological factors affect the respiratory tract to differing degrees[18,19], but air temperature and humidity have the most substantial impact.[20]

Meteorological factors affect the respiratory system through lowering local resistance of the human body to infection, and by affecting the general resistance of the body through influencing the spread of infections.[3,4] Local resistance may be affected in different ways: (i) the effect of thermal stress on permeability and capillary resistance of membranes, whereby resistance increases following cold stress; (ii) all meteorological factors affecting the rate of sweating and evaporation influence the acid coating produced by the eccrine sweat glands, which protects the skin against infections. Cold and low humidity favour spots of low acidity in skinfolds, resulting in the growth of micro-organisms and their penetration into the skin; (iii) low humidity causes removal of water vapour from the body cells, which in turn leads to microfissures in the nasal mucosa during cold weather and in centrally heated rooms; (iv) cold causes constriction of peripheral blood vessels and reduces blood flow, resulting in drying and cracking of nasal mucosa; it also depresses ciliary movements in the respiratory tract, thus increasing vulnerability to infections.[4]

Factors that affect general resistance of the body through influence on spread of infections include: (i) the impact of weather and climate on social habits, such as crowding in rooms, shutting windows and doors (i.e. reducing ventilation), and changing clothing and diet;[3] (ii) the influence on the survival of micro-organisms and viruses; (iii) the effect of meteorological factors on spread of infectious agents through the atmosphere. For example, Gram-positive bacteria and influenza viruses have been shown to die more quickly with high humidity and air movement.[3,21] Studies of school-age children mostly confined within classrooms have found that the degree of air circulation in the classrooms greatly affects the incidence of respiratory disease.[22] Thus, low humidity and reduced air movement in winter appears to favour the development of infectious respiratory diseases.

Studies have suggested that air temperature has the most notable influence on the incidence of respiratory tract infections; however, different views exist regarding this relationship. Some scholars believe that air temperature and respiratory tract infection rate are negatively correlated,[23] while some scientists report a positive correlation between them.[24]

A study into the correlation between climatic factors, including humidity, and clinical illnesses found that upper and lower respiratory tract infections were negatively correlated with relative humidity.[25] These data concur with the present study, which found an increased incidence of lower respiratory tract infection with decreased humidity, resulting in increased numbers of paediatric hospital admissions.

Incidence of acute respiratory tract infection is reported to be correlated with crowding; exposure to crowded conditions has led to an increased risk of acute respiratory tract infection.[26] During winter in Shenmu the temperature falls to around $-20^{\circ}C$ to $-25^{\circ}C$, which means the children are confined indoors either at home or in classrooms and outdoor activities are markedly reduced. This may make it easier for infection to spread, leading to high numbers of hospital admissions during winter.

The spread of viruses is thought to be directly related to human mobility through transportation.[27] The fact that human travel is a cause of infection spread confirms that infected humans are a source of pathogens. Thus, human confinement to a specific area due to travel-hindering weather conditions can lead to increased disease incidence in that area. The confinement indoors of the children of Shenmu during winter may thus be the cause of increased incidence of lower respiratory tract infections in the county.

The influenza virus has been shown to transmit through the air most readily in cold, dry conditions, whereas higher temperatures of $\sim 30^{\circ}C$ tend to block aerosol transmission.[21] Viruses with lipid envelopes generally tend to survive longer at lower (20–30%) humidity. This applies to most lipid-enveloped respiratory viruses, including influenza. Minimal survival for both lipid-enveloped and nonlipid-enveloped viruses occurs at an intermediate relative humidity of $50-70\%$.[21] The present study also demonstrated a high incidence of the lipid-enveloped respiratory syncytial virus followed by influenza A virus.

Gram-positive cocci are most prevalent in indoor and outdoor air, followed by Gram-positive rods (e.g. *Bacillus* and *Actinomycetes* species), Gram-negative rods and, lastly, Gram-negative cocci. For some airborne Gram-positive bacteria (*Staphylococcus albus*, *Streptococcus haemolyticus*, *Bacillus subtilis* and *S. pneumoniae* [type 1]), death rates are lower at lower relative humidity levels.[28] In the present study, the primary causative bacteria for lower respiratory tract infection in children aged ≤ 16 years were *S. pneumoniae* and *H. influenzae* type B.

Studies on aerosolized *Mycoplasma* species have shown that survival is optimal at low (<25%) and high (>80%) relative humidity, and worst between these two extremes; this reveals that mycoplasma survives well at lower humidity.[28] There is a strong association between ventilation and control of airflow direction in buildings and transmission and spread of infectious diseases. Reduced ventilation and crowding may contribute to the observed excess of lower respiratory tract infections among young children.[29] The present study also suggests an association between reduced ventilation and crowding and lower respiratory tract infections among young children, as a large number of children affected were of kindergarten age (1–4 years; 1490 cases [33.5%]) and others were of school age (5–16 years; 1112 cases [25%]).

In the present study, mean values of lower respiratory tract infection-related hospital admissions and meteorological factors were calculated per week, annually. Following Pearson's correlation coefficient analysis of meteorological factors, the multivariate linear regression model was fitted. The multivariate linear regression model, multicollinearity of the independent variables, residual normality and homogeneity of variance observed in the present study support the reliability of the results.

The present study found that the rate of lower respiratory tract infection-related hospital admissions was significantly correlated with air temperature, atmospheric pressure, rainfall and relative humidity, but was not statistically correlated with sunlight intensity and wind speed. In addition, the rate of lower respiratory tract infection-related hospital admissions was found to decrease with gradual increase in temperature and relative humidity. This information is essential from a public health perspective when planning appropriate cold risk-management strategies. Information regarding the trends and seasonality of respiratory viral infections in the community is a first step in enabling healthcare providers to implement strategies to prevent and minimize infection, and to apply early therapeutic options to high-risk patients. A limitation of this study is that the sample size and power were not predetermined.

In conclusion, the results obtained in the present study show that seasonal variations in meteorological factors are correlated with rates of respiratory tract infection-related hospital admissions in children. To the best of the authors' knowledge, this is the first published report showing seasonal patterns of respiratory infections in Shenmu County. The results demonstrate the importance of epidemiological surveillance of respiratory infections in all regions of China, and suggest that future studies are necessary to correlate clinical aspects with climatic variations.

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Declaration of conflicting interest

The authors declare that there are no conflicts of interest.

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