Zhang et al. BMC Public Health (2024) 24:3135
https://doi.org/10.1186/s12889-024-20619-1

BMC Public Health

RESEARCH

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A study of the correlation between meteorological factors and hospitalization for acute lower respiratory infections in children

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Abstract

Background The study focuses on the effect of temperature and relative humidity on hospitalization for acute lower respiratory tract infections (LRTI) in children, respectively.

Methods In this study, the Distributed Lag Nonlinear Model (DLNM) based on quasi-Poisson distribution was used to investigate the effect of temperature and relative humidity on LRTI hospitalization in children, and subgroup analyses were conducted to identify sensitive populations by gender and age.

Results A total of 43,951 children were hospitalized for LRTI from 1 January 2014 to 31 December 2019 in Lanzhou. The mean temperature during the study period was 11.34 °C and the mean relative humidity was 51.03%. With reference to the median temperature of 12.7 °C during the study period, both low (-4.1 °C) and high (25.43 °C) temperature had a detrimental effect on LRTI hospitalization, and the maximum effect was reached at lag0-10 and lag0-9, respectively, with RR values of 1.645 (95%CI: 1.533, 1.764) and 1.098 (95%CI: 1.018, 1.184). With a reference to the median relative humidity of 51.17% during the study period, both low relative humidity (26.71%) and high relative humidity (76.70%, P95) had a detrimental effect on LRTI hospitalization, and the maximum effect was reached at lag0-21 and lag21, respectively, with RR values of 1.235 (95% CI: 1.163, 1.311) and 1.044 (95% CI: 1.036, 1.051). The results of subgroup analyses showed that changes in meteorological factors had a stronger effect on Female and children aged 5–14 years.

Conclusions The meteorological factors all have different degrees of influence on LRTI hospitalization in children. Girls and the children aged 5–14 years are more sensitive. Attention to these meteorological risks can inform targeted interventions.

Keywords Temperature, Relative humidity, Acute lower respiratory tract infections, Hospitalization, Distributional lag nonlinear model

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Introduction

The respiratory diseases are important risk factors affecting the health of the population, especially children's health, on the global scale. About more than 4 million people die from respiratory diseases every year [1]. Because respiratory diseases have a relatively high incidence, they are one of the main causes of hospitalization and death in children. Nearly 3 million children die from respiratory infections [2]. The causes of respiratory diseases are complex, for which bacterial and viral infections are the main causes [3]. However, environmental factors also have a harmful effect on the respiratory tract that cannot be ignored. Numerous studies have demonstrated the important adverse effects of air pollutants on respiratory diseases [4–7]. In recent years, some researchers have also found that meteorological factors also have an impact on diseases related to respiratory infections [8–10]. Variability in meteorological factors is often cited as an important contributor to the development of acute lower respiratory tract infections (LRTI) such as bronchitis and pneumonia [11].

There remains a lack of research on the correlation between meteorological factors and LRTI in children in China. The few studies that have been done on the subject have also focused on the economically developed regions of eastern China [12, 13]. With the huge size of China, there are huge differences between the eastern and western regions in terms of both natural and social factors. This also tends to make the applicability of research findings limited. The warm and humid ocean currents are difficult to reach the inland northwest compared to the eastern part of the country in China. This results in scanty rainfall in these areas. Sufficient hours of sunshine result in high evaporation. This leads to a dry climate in the region. In addition, the inland northwest has a weak economy, which is also closely related to the health of the population. However, fewer studies have been conducted on exploring the impact of meteorological factors on LRTI hospitalization in children in the inland northwest of China.

Lanzhou city is located in the inland area of China, with dry climate, scarce precipitation and poor natural conditions. In this study, Lanzhou, an inland city in northwest China, was used as a representative city. Information on pediatric LRTI hospitalizations in the secondary and tertiary public hospitals in the region and the major local meteorological factors were collected. The effects of ambient temperature and relative humidity on the hospitalization of children with LRTI were explored.

Methods

Study area

Lanzhou (102°36′-104°35′E, 35°34′-37°00′N) occupies a deep inland location in Northwest China and serves as an important transportation hub. Due to the inaccessibility of warm and humid ocean currents, rainfall is scarce and the climate is dry all year round. The sunshine time is sufficient and the evaporation is large. It is a typical temperate continental climate. These characteristics are similar to other inland northwestern cities. The Huanghe River passes through the city, and the population lives on its two sides. As of 2021, the resident population of Lanzhou reached 4.359 million. There are eight districts and counties under Lanzhou City. Its main urban areas are Chengguan, Anning, Xigu and Qilihe District. The four districts of the main city have convenient traffic and are densely populated. Therefore, this study chooses the above four main urban areas as the study area.

Data collection

In the present study, daily hospitalization data of local residents were collected for the last 6 years from 1 January 2014 to 31 December 2019 from all secondary and above secondary public hospitals in the four main districts of Lanzhou City. The data covered detailed information on gender, age, home address, admission time, hospitalization diagnosis and disease codes of the cases. We organized the case data according to the corresponding disease codes of the International Classification of Diseases 10th Revision (ICD-10). Codes for the corresponding LRTI diseases (ICD-10: J12-J18 and J20-J22) were extracted. We removed inpatients who did not have a permanent local residence based on patient address information. In addition, we removed patients with missing key information such as gender, age, length of hospitalization and home address.

We collected the daily data of mean temperature and relative humidity in Lanzhou during the study period on the China Meteorological Data Service (CMDS) network. These meteorological data were collected and processed in accordance with the specification requirements for surface meteorological observations of the China Meteorological Administration (CMA), and the data were complete, valid and of good quality, with no missing values in the observations during the study period.

In addition, the daily data of air pollutants in Lanzhou during the same period were obtained from the China Air Quality Monitoring website. Four pollutants with significant relationship with human health were selected as covariates, mainly including fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) [14]. These air pollutant concentration data are derived from hourly monitoring data from four national air quality monitoring stations in Lanzhou City (Biological Products Institute, Railway Design Institute, Lanzhou Refining Hotel and Provincial Staff Hospital). These stations are located far away from buildings, main traffic intersections, industrial pollution sources, and other emission sources. Therefore, these monitoring data are a good representation of the actual air pollution levels in the study area.

The meteorological data in this study were collected by professional meteorological observation instruments certified by China Metrology. And the data were reviewed and managed by professional meteorological observers. The air pollutant data were obtained from four state-controlled ambient air quality monitoring stations in Lanzhou City. The data collected from these monitoring stations are in accordance with the relevant regulations on ambient air quality sampling. And all data were reviewed by experts from the environmental protection department. This ensured the completeness and accuracy of the study data.

Statistical analysis

A statistical description of the children's LRTI hospitalizations and meteorological factors during the study period was first performed, and the main indicators included mean, standard deviation, minimum, 5th, interquartile range (IQR), 95th, and maximum values. Spearman's correlation analysis was used to observe the correlation between the main meteorological factors and air pollutants.

The daily hospitalization for LRTI is a small probability event relative to the total population. In addition, the influences of meteorological factors on human health tend to have lagged effects. In order to observe the influences of temperature and relative humidity on LRTI hospitalizations in children in more detail. The study used a distributed lag linear model (DLNM) based on a quasi-Poisson distribution [15]. The DLNM uses cross-basis functions to assess the lagged effects of temperature, relative humidity and LRTI hospitalization. Related studies indicated that the influence of temperature on health lasts for 2 to 3 weeks [16]. Referring to previous related studies, the number of lag days in this study was chosen as 21 days [17]. The df used to adjust the meteorological factors and air pollutants was chosen as 4. The df for the time variables was chosen as 7/year to control for long-term trends and seasonality. Referring to previous related studies, the model constructed in this study is as follows:

$$\mathrm{Log}(\mathrm{E}(Y_t)) = \alpha + \Sigma cb(\mathrm{temperature}, lag = 21, df = 4) + ns(relativehumidity, df = 4) + ns(PM_{2.5}, df = 4) + ns(PM_{10}, df = 4) + ns(SO_2, df = 4) + ns(NO_2, df = 4) + ns(Time, df = 7 * year) + as.factor(Dow) + as.factor(Holiday)$$

$$\mathrm{Log}(\mathrm{E}(Y_t)) = \alpha + \Sigma cb(\mathrm{relative\ humidity}, lag = 21, df = 4) + ns(temperature, df = 4) + ns(PM_{2.5}, df = 4) + ns(PM_{10}, df = 4) + ns(SO_2, df = 4) + ns(NO_2, df = 4) + ns(Time, df = 7 * year) + as.factor(Dow) + as.factor(Holiday)$$

where, t is the observation day. Y_t is the dependent variable, indicating the number of LRTI admissions on day t. $E(Y_t)$ is the anticipated value of LRTI admission on that date. α is the intercept. $\Sigma cb()$ is a two-dimensional cross-base function of the meteorological factors temperature and relative humidity. *temperature* is the temperature. relative humidity is relative humidity. *lag* is the number of lag days. *df* is the degrees of freedom. *ns* is the natural cubic spline function. *Time* is the time variable. *as.factor*() is the function used to control the categorical variables. *Dow* is a multicategorical variable representing the day of the week effect. *Holiday* is a binary categorical variable to represent the holiday effect.

This study focused on the cumulative influences of low (5th) and high (95th) levels of temperature and relative humidity relative to mean temperature and mean relative humidity, respectively, on the amount of LRTI hospitalizations in children. The effect results were expressed as the magnitude of the cumulative relative risk (RR) values and their 95% confidence interval (CI) ranges. In addition, further subgroup analyses were conducted in this study to identify sensitive populations according to gender (boy and girl) and age (<5 years and 5–14 years).

We then further assessed the significant differences between the effect estimates of the stratified analyses by calculating 95% CIs using the following equation:

$$\mathrm{Z} = (\widehat{\mathrm{Q}}_1 - \widehat{\mathrm{Q}}_2) \pm 1.96\sqrt{\widehat{\mathrm{SE}}_1^{\,2} + \widehat{\mathrm{SE}}_2^{\,2}}$$

where $\widehat{\mathrm{Q}}_1$ and $\widehat{\mathrm{Q}}_2$ indicate the estimates for two subgroups (e.g., boy and girl), $\widehat{\mathrm{SE}}_1$ and $\widehat{\mathrm{SE}}_2$ are their appropriate standard errors.

Sensitivity analyses

In order to assess the stability of the model, this study performed sensitivity analyses by varying the df of the time variables (df=6, 7, 8), the maximum number of lagged days (max lag=14, 21, 28), and the df of the atmospheric pollutants (df=3, 4, 5) in the model.

All results in this study were considered statistically significant correlations at a two-tailed *p*-value less than 0.05. All statistical analyses in this study were analyzed using the software R 4.4.1.

Results

Table 1 shows the general characteristics of childhood LRTI hospitalizations, meteorological factors, and air pollutants from 2014 to 2019.A total of 43,951 children were hospitalized for LRTI during the study period, with

Table 1 The ALRI hospitalization and meteorological factors in Lanzhou, 2014–2019

Variables	Mean	SD	Min	5th	IQR	95th	Max
Number of ALRI hospitalizations							
Total	20.06	13.45	0	5	15	49	91
Male	11.78	8.00	0	2	22	28	53
Female	8.28	6.17	0	1	17	21	42
< 5 years	15.63	10.64	0	3	29	37	67
5–14 years	4.43	3.93	0	0	4	12	32
Meteorological factors							
Temperature (℃)	11.34	9.83	-12.30	-4.10	17.50	25.43	30.40
Relative humidity (%)	51.03	15.08	11.71	26.70	22.5	76.80	96.09
Air pollutants							
$PM_{2.5}$ (μg/m^3)	49.90	26.79	8.86	19.93	28	101.41	275.08
PM_{10} (μg/m^3)	117.05	83.70	16.76	41.42	65.45	229.15	1484.54
SO_2 (μg/m^3)	21.42	14.00	3.54	6.08	18.05	51.02	80.48
NO_2 (μg/m^3)	48.13	17.55	12.58	24.10	18.50	84.66	151.10

an average of 20 hospitalizations per day. There were 25,800 total hospitalizations for boys. There were 18,151 total hospitalizations for girls. There were 34,235 total hospitalizations in children aged < 5 years and 9,716 total hospitalizations in children aged 5–14 years. The mean temperature was 11.34 °C with a range of -12.3 to 30.4 °C. The mean relative humidity was 51.03% with a range of 15.08 to 96.09%. The IQR concentrations of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 were 28.00, 65.45, 18.05 and 18.50 μg/m^3, respectively, during the study period.

Table S1 shows the Spearman's correlations between mean daily air temperature, relative humidity and with air pollutants during the study period. The correlation coefficient between temperature and relative humidity was -0.01. There was a low negative correlation. There is a low to moderate negative correlation between temperature and each air pollutant. There is a low negative correlation between relative humidity and each air pollutant.

Figure 1 shows the exposure–response relationships of temperatures and relative humidity to the risk of LRTI hospitalization at lag 0–21 days. The cumulative exposure–response curve of temperatures to the risk of LRTI hospitalization showed an inverted "U" shape. The temperatures was deleterious to childhood LRTI hospitalization at -2.3 to 11.7 °C. The cumulative exposure–response curves for relative humidity on the risk of LRTI hospitalization showed a generally decreasing trend. The relative humidity was deleterious to childhood LRTI hospitalization at 0–30%.

Table 2 demonstrates the results of the cumulative lagged effects of extreme temperatures on LRTI hospitalization in children, using the median temperature of 12.7 °C during the study period as a reference. At

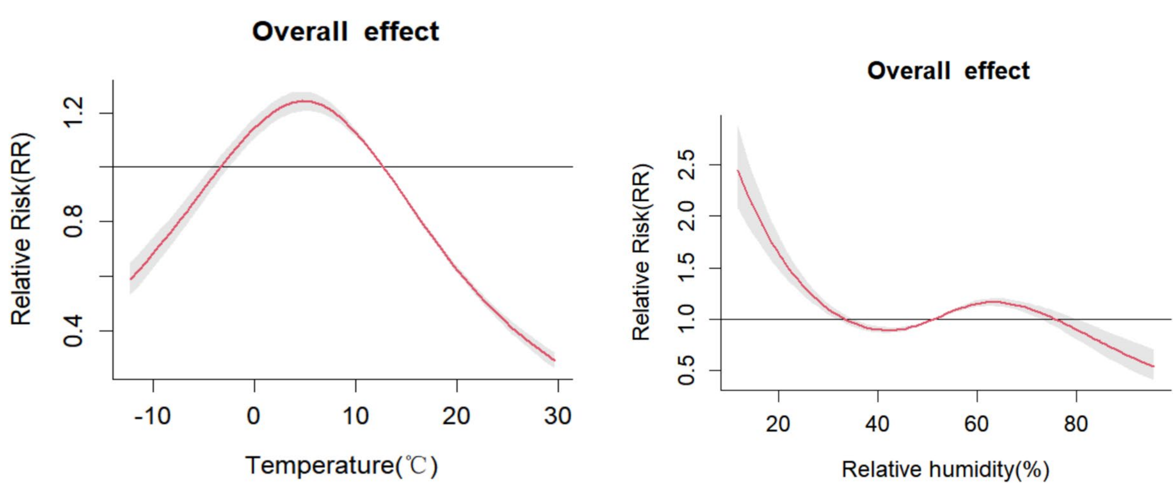

Fig. 1 The overall cumulative exposure response curves for temperature and relative humidity versus the relative risk of hospitalization for LRTI

Table 2 The cumulative lag effect of extreme temperature on ALRI hospitalization

Temperature	lag	RR	95%CI	
			Lower	Upper
-4.1 ℃	0–1	1.182	1.157	1.208
	0–2	1.269	1.230	1.309
	0–3	1.350	1.298	1.405
	0–4	1.425	1.360	1.493
	0–5	1.491	1.414	1.572
	0–6	1.547	1.459	1.640
	0–7	1.591	1.494	1.694
	0–8	1.622	1.518	1.734
	0–9	1.641	1.532	1.757
	0–10	1.645	1.533	1.764
	0–11	1.635	1.524	1.755
	0–12	1.612	1.502	1.729
	0–13	1.575	1.470	1.687
	0–14	1.526	1.428	1.632
	0–15	1.466	1.376	1.563
	0–16	1.397	1.315	1.484
	0–17	1.319	1.247	1.396
	0–18	1.236	1.173	1.302
	0–19	1.147	1.093	1.204
	0–20	1.056	1.010	1.105
	0–21	0.964	0.923	1.007
25.43 ℃	0–1	1.088	1.062	1.115
	0–2	1.121	1.083	1.162
	0–3	1.146	1.096	1.198
	0–4	1.162	1.102	1.224
	0–5	1.168	1.100	1.239
	0–6	1.164	1.091	1.243
	0–7	1.151	1.074	1.234
	0–8	1.129	1.049	1.215
	0–9	1.098	1.018	1.184
	0–10	1.059	0.981	1.144
	0–11	1.013	0.938	1.094
	0–12	0.961	0.891	1.037
	0–13	0.905	0.840	0.974
	0–14	0.844	0.786	0.907
	0–15	0.781	0.730	0.837
	0–16	0.717	0.673	0.765
	0–17	0.653	0.615	0.694
	0–18	0.590	0.557	0.624
	0–19	0.528	0.500	0.558
	0–20	0.469	0.445	0.495
	0–21	0.413	0.391	0.437

lag0-1 to lag0-20, extreme low temperature (-4.1 °C, P5) had a hazardous effect on LRTI hospitalization in children. The effect was greatest at lag0-10 with RR = 1.645 (95% CI: 1.533, 1.764). At lag0-1 to lag0-9, extreme high temperature (25.43 °C, P95) had a hazardous effect on hospitalization for LRTI in children. The effect was greatest at lag0-9 with RR = 1.098 (95% CI: 1.018, 1.184).

Table S2 demonstrates the effect of extreme temperatures on LRTI hospitalization in children of different gender. The effects stratified by gender are similar to those for all populations. At very low temperatures, the highest RR for LRTI hospitalization was 1.575 (95% CI:1.438, 1.726) for boys and 1.748 (95% CI:1.567, 1.950) for girls. At very high temperatures, the highest RR for LRTI hospitalization was 1.160 (95% CI: 1.073, 1.253) for boys and 1.180 (95% CI: 1.076, 1.294) for girls.

Table S3 illustrates the cumulative lagged effects of extreme temperatures on LRTI hospitalizations in children of different ages. The effects stratified by age were again similar to those for all. At extreme low temperatures, the highest RR was 1.544 (95% CI: 1.427, 1.671) for LRTI hospitalization in children aged < 5 years, and 2.045 (95% CI: 1.758, 2.379) in children aged 5–14 years. At extreme high temperatures, the highest RR value was 1.154 (95% CI: 1.077, 1.236) for LRTI hospitalization in children aged < 5 years, and 1.198 (95% CI: 1.053, 1.362) in children aged 5–14 years.

Table 3 demonstrates the effect of different levels of relative humidity on LRTI hospitalization in children, using the median humidity of 51.17% as a reference, during the study period. At lag0-16 to lag0-21, extreme low relative humidity (26.70%, 5th) had a harmful effect on LRTI hospitalization. The effect was greatest at lag0-21 with RR = 1.235 (95% CI: 1.163, 1.311). However, extreme high relative humidity (76.70%, 95th) did not show a harmful effect on LRTI hospitalization.

Table S4 demonstrates the results of the cumulative lagged effect of extreme relative humidity on LRTI hospitalization in children of different gender. At extreme low relative humidity, the highest RR for LRTI hospitalization was 1.233 (95% CI: 1.140, 1.333) for boys and 1.238 (95% CI: 1.128, 1.359) for girls. The extreme high relative humidity showed no harmful effects on LRTI hospitalization in children of different gender.

Table S5 demonstrates the results of the cumulative lagged effect of extreme relative humidity on LRTI hospitalizations in children of different ages. At extreme low relative humidity, the highest RR was 1.177 (95% CI: 1.099, 1.260) for LRTI hospitalization in children aged < 5 years, and the highest RR was 1.438 (95% CI: 1.267, 1.632) for LRTI hospitalization in children aged 5–14 years. The extremely high relative humidity had no effect on LRTI hospitalization in children aged < 5 years, but the highest RR was 1.430 (95% CI: 1.217, 1.681) for LRTI hospitalization in children aged 5–14 years. The extreme high relative humidity showed no harmful effects on LRTI hospitalization in children aged < 5 years.

Table 3 The cumulative lag effect of extreme relative humidity on ALRI hospitalization

Relative humidity	lag	RR	95%CI	
			Lower	Upper
26.71%	0–1	0.971	0.958	0.984
	0–2	0.960	0.941	0.979
	0–3	0.952	0.928	0.975
	0–4	0.946	0.918	0.974
	0–5	0.942	0.910	0.975
	0–6	0.941	0.906	0.977
	0–7	0.942	0.904	0.981
	0–8	0.945	0.904	0.988
	0–9	0.951	0.907	0.996
	0–10	0.959	0.913	1.006
	0–11	0.969	0.921	1.019
	0–12	0.982	0.933	1.034
	0–13	0.997	0.946	1.051
	0–14	1.016	0.963	1.071
	0–15	1.037	0.982	1.094
	0–16	1.061	1.005	1.120
	0–17	1.088	1.030	1.150
	0–18	1.119	1.059	1.183
	0–19	1.154	1.090	1.221
	0–20	1.192	1.125	1.264
	0–21	1.235	1.163	1.311
76.71%	0–1	0.918	0.904	0.933
	0–2	0.886	0.866	0.906
	0–3	0.858	0.833	0.883
	0–4	0.834	0.805	0.864
	0–5	0.814	0.782	0.848
	0–6	0.799	0.763	0.835
	0–7	0.786	0.748	0.826
	0–8	0.778	0.737	0.820
	0–9	0.772	0.730	0.817
	0–10	0.770	0.725	0.817
	0–11	0.771	0.724	0.820
	0–12	0.775	0.726	0.827
	0–13	0.782	0.732	0.836
	0–14	0.793	0.741	0.849
	0–15	0.807	0.753	0.866
	0–16	0.825	0.768	0.887
	0–17	0.847	0.788	0.912
	0–18	0.874	0.811	0.941
	0–19	0.904	0.838	0.976
	0–20	0.940	0.869	1.017
	0–21	0.981	0.904	1.065

The sensitivity results showed that the RR results for the exposure–response relationship between changes in extreme ambient temperature, relative humidity and hospitalization rates of children with LRTI were consistent after varying the degrees of freedom and maximum lag days (Figure S1-S6). These all indicate the robustness of the model constructed in this study.

Discussion

The occurrence and development of diseases are not only related to the human immune system, but also influenced by external factors such as temperature and relative humidity. This study used a distributed lag non-linear model to investigate the effects of temperature and relative humidity on the hospitalization of children with LRTI in Lanzhou, China from 2014 to 2019. After adjusting for the confounding effects of major air pollution, we found that low temperature (5th, -4.1℃), high temperature (95th, 25.43℃), and low relative humidity (5th, 26.71%) all have harmful effects on the hospitalization of children with LRTI. Previous studies have confirmed the harmful effects of temperature and relative humidity on human health. However, there is limited research on the hospitalization of children with LRTI. The research we conducted in Lanzhou not only fills the gap in related research in the inland areas of northwest China. And it has also added relevant evidence in this regard. This study also conducted subgroup analysis. Both low and high temperatures have a greater impact on girls and children aged 5–14 years. Low relative humidity has a greater impact on boys and children aged 5–14 years. High relative humidity (95th, 76.71%) has a greater impact on children aged 5–14 years.

At present, the mechanisms governing the effects of high and low levels of temperature on respiratory disease are unknown. A previous study showed that high temperatures promote the growth and exposure of indoor air allergens [18]. An animal study showed that high and low temperatures increase airway inflammatory responses [19]. The combination of these factors may be the underlying biological mechanism for the effect of temperature on respiratory disease. In addition, the cold temperatures may also increase the chance of respiratory illness by significantly suppressing the body's immune system or by promoting the survival and spread of respiratory viruses [18, 20]. Furthermore, it has also been shown that temperature can induce adverse respiratory events through thermoregulatory pathways [21]. The mechanisms by which humidity affects respiratory disease are similarly unknown. It was found in an animal study that high humidity exacerbates airway hyperresponsiveness, remodelling and inflammatory responses in mice, thereby promoting allergic reactions through oxidative stress [22]. It might suggest that humidity can increase the occurrence of respiratory diseases by increasing the occurrence of respiratory allergic reactions. Although these studies provide possible potential mechanisms by which ambient temperature and relative humidity affect respiratory disease. However, the studies were based on animal experiments. Studies on the mechanisms by which temperature and relative humidity affect respiratory diseases in humans are still lacking. Therefore, future studies should progressively investigate the mechanisms by which these factors affect humans, especially children.

The present study found a non-linear relationship between temperature and hospitalization for respiratory illness, with an inverted U-shaped exposure–response curve. This is similar to the results of a study in Baotou, China [17]. However, several studies have reported an S-, V-, J-, and U-shaped relationship between temperature and exposure response to outpatient visits for respiratory diseases [23–26]. These are different from the results of our study. On the one hand, because patients who choose outpatient care were more sensitive to changes in meteorological factors. Whereas inpatients are all in more serious condition and are less likely to go out in extreme temperature conditions. On the other hand, the exposure–response relationship is related to the geographical conditions of the study area, the type of climate, and the lifestyle habits of the study population [27, 28]. The climate is dry, rainfall is scarce, and severe weather such as sand and dust occur more often in Lanzhou. This also contribute to the differences in the study results. This study found an overall trend of negative correlation between humidity and the exposure–response relationship for LRTI hospitalizations in children. The lower the humidity, the higher the number of LRTI hospitalizations. This is consistent with previous studies [29]. Lower humidity could lead to drying of the respiratory mucosa, which reduces immunity and thus facilitates the spread of respiratory viruses, thereby increasing the risk of hospitalization for LRTI in children.

This study found that both high and low levels of temperature were associated with hospitalization for LRTI in children. This is consistent with previous findings. An Australian study found that both high and low temperatures were associated with hospital admissions for respiratory illness in children [30]. A Spanish study showed an effect of high temperature on the risk of hospitalization for all lower respiratory diseases, with RR values of 1.288 (95% CI: 1.240, 1.339) and 1.307 (95% CI: 1.219, 1.402) for pneumonia and bronchitis, respectively, whereas hypothermia was associated with a higher effect on mortality from pneumonia, with an RR value of 1.734 (95% CI. 1.219, 2.468) [11]. However, some studies have found different results. A study found that low temperature (25th) was associated with respiratory hospitalization in children with an RR value of 1.032 (95% CI:1.011, 1.053), but the estimated effect of high temperature (75th) on respiratory hospitalization was lower in Fuzhou, China [13].

This study found that low levels of humidity (0–30%) were more highly correlated with LRTI hospitalizations in children. Similarly, a study found a non-linear negative correlation between humidity and respiratory illness hospitalizations, with a higher estimated effect of lower humidity (25th) on childhood respiratory hospitalizations compared to the reference value, with an RR of 1.021 (95% CI: 1.013, 1.029) [13]. Lower humidity may favour aerosol transmission of viruses, such as influenza viruses [31]. This may further contribute to the incidence of respiratory illness in children, thus further increasing hospital admissions. However, the present study also observed that higher humidity is equally harmful to LRTI hospitalization in children. A possible explanation is that high humidity weather increases the incidence of allergic diseases, including respiratory diseases [32].

The results of the subgroup analyses in this study showed that although both low and high temperatures had a lagged effect of harm of one day more for boys than for girls, the relative risk value for the lagged effect was stronger for girls. Low temperatures had two more days of lagged effects of harm for children aged <5 years for children aged 5–14 years old, but the value of risk for lagged effects was stronger for children aged 5–14 year. High temperatures had stronger harmful effects for children aged 5–14 years. Taken together, ambient temperature had a stronger effect on girls and children aged 5–14 years. The lag days and effect values for the effect of low humidity were stronger for boys. This study did not find harmful effects of high humidity on children of different genders. Low humidity had a stronger effect on children aged 5–14 years in terms of lag days and effect values. High humidity likewise had a stronger effect on children aged 5–14 years. Taken together, relative humidity had a stronger effect on children aged 5–14 years. Low relative humidity has a stronger effect on boys. Children of different gender have different sensitivities to different meteorological factors. This is due to physical differences [33]. Estrogen affects thermoregulation, which makes girls more vulnerable to temperature changes [17]. Temperature and humidity can also affect the respiratory system by lowering the body's immunity [8]. Older children spend more time outdoors than younger children, which increases their outdoor exposure to bad weather and thus their susceptibility to respiratory disease [33].

Currently, there are fewer studies related to the effects of meteorological factors on respiratory diseases in children. One study, while revealing that meteorological factors were significantly associated with hospitalization for lower respiratory tract infections in children, did not estimate effect values in Shenmu, China [8]. Studies in Thailand found that high relative humidity was associated with the incidence of pneumonia in children [34, 35]. This is different from the results of our study. This was attributed to demographic factors and the degree of adaptation to local climatic conditions. The present study was conducted in Lanzhou, China, which helped to reveal the characteristics of hospitalization for lower respiratory diseases in children under the unique local climatic conditions.

In conclusion, we conducted this study to investigate the effects of ambient temperature and relative humidity on hospitalization of children with LRTI in inland northwest China. This study not only fills the knowledge gap of related studies in this region, but also provides valuable data to support the development of public health strategies under different climatic conditions. By revealing how changes in meteorological factors affect the risk of hospitalization for childhood LRTI, our study provides an important basis for future interventions and health policy development. Local authorities can quickly take appropriate measures to safeguard children's health when faced with extreme weather events. For example, when temperatures are too low or too high, school closures can be implemented or children's outdoor exposure to adverse weather conditions can be reduced.

However, there are some limitations of this study. Firstly, this study only included holiday variables in the model construction to control for the effect of public holidays and did not take into account that school children are affected by the school semester. This can lead to a difference between the results of the study and the actual situation. Secondly, seasonal variables were not included in this study. This is not conducive to the revelation of more comprehensive findings. In addition, this study only explored a single city and did not conduct a multi-city or national study. Future studies should conduct a national study and consider more influential variables such as school semester and seasonality. This would reveal more detailed and widely used findings.

Conclusion

The extremely high temperatures, extremely low temperatures and extremely low relative humidity have detrimental effects on hospitalization for LRTI in children. Girls and the children aged 5–14 years are more sensitive. These findings call for infrastructure to mitigate weather-related health risks to children, particularly during extreme temperature or humidity events. The focus should be on protecting children's health during adverse weather conditions.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20619-1.

Supplementary Material 1.

Acknowledgements
The authors acknowledge the contribution and collaboration of all those who participated in this study.

Authors' contributions
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Wan-cheng Zhang, Ye Ruan, Ling Jianglong and Wang Lei. The first draft of the manuscript was written by Wan-cheng Zhang. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
None.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The present study was considered exempt from institutional review board approval since the data used was collected for administrative purpose without any personal identifiers.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 19 August 2024 Accepted: 5 November 2024
Published online: 12 November 2024

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