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Burden of non-COVID-19 lower respiratory infections in China (1990–2021): a global burden of disease study analysis

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Abstract

Background The assessment of lower respiratory infection (LRI) mortality, incidence, and responsible pathogens in China provides a scientific basis for the prevention and management of LRI, especially for evaluating the impact of coronavirus disease 2019 (COVID-19). We provide a national estimate of the non-COVID-19 LRI burden and trends on people from 1990 to 2021 based on Global Burden of Disease (GBD) study 2021.

Methods We estimated China's mortality, incidence, disability-adjusted life years (DALYs), risk factors and aetiology attribution for LRI without including COVID-19 by using the estimated data of GBD study 2021. Mortality, incidence, DALYs, risk factors and aetiology were stratified by sex and age. Trends were evaluated using estimated annual percentage change.

Results In 2021, it is estimated that there were 206930.22 deaths (95% uncertainty interval [UI]: 171260.88–251990.47), with all-age mortality rate of 14.54 deaths (95% UI: 12.04–17.71) per 100,000 population. Compared to 2019, the all-age mortality rate had a 3.60% increase. Analyzing risk factors from 1990 to 2021, we found that the percentage of DALYs attributed to tobacco increased from 7.44% (95% UI: 1.26–15.72%) to 22.14% (95% UI: 3.28–38.41%), and that attributable to ambient particulate matter pollution increased from 19.84% (95% UI: 8.79–30.20%) to 32.72% (95% UI: 22.78–41.77%). The leading cause of mortality from LRIs remains *Streptococcus pneumoniae* from 1990 to 2021. However, the proportions of viral infections decreased. Compared to 2019, the proportion of deaths in 2021 caused by Influenza decreased from 13.03 to 2.70%, and the proportion of deaths due to RSV decreased from 2.21 to 0.41%.

Conclusions In China, substantial progress has been made in reducing LRI mortality, yet LRIs have remained a threat in China from 1990 to 2021. During the COVID-19 pandemic, the mortality attributable to Influenza and RSV declined. Effective vaccines and treatments targeted at the main pathogens of LRI are important.

Clinical trial number Not applicable.

Keywords Lower respiratory infection, Global burden of disease, Mortality, Aetiologies

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Introduction

Lower respiratory infections (LRIs) cause more deaths annually than any other category of infectious diseases [1]. Although the conjugate vaccines against *Streptococcus pneumoniae* and *Haemophilus influenzae* type b have been introduced, LRIs are still the leading cause of morbidity and mortality among adults older than 70 years and children younger than 5 years globally [2]. It is estimated that there were 344 million incident episodes and 2.18 million deaths of LRI in 2021 worldwide [2]. LRIs, including bronchitis and pneumonia, can be caused by a variety of pathogens. Bacteria, viruses and fungi can all cause LRIs and their prevalence varied among different countries and regions [2]. LRIs caused by these pathogens usually present with similar symptoms, making the identification of pathogens important to treatment and protection.

In December 2019, the coronavirus disease 2019 (COVID-19) pandemic emerged in China [3]. From 2020 to 2021, a series of non-pharmaceutical interventions (NPIs) against COVID-19 have been taken in China to control the pandemic. These NPIs not only successfully reduce the transmission of COVID-19, but may also curb the incidence of other pathogens [2]. Thus, the aetiologies' alterations of non-COVID-19 LRIs in China needs to be further evaluated.

The assessment of LRI mortality, incidence and responsible pathogens is a scientific foundation for the prevention and management of LRIs. Recently, the latest analysis of global incidence and mortality burden of non-COVID-19 LRIs based on Global Burden of Disease (GBD) study 2021 has been published [2]. However, the burden of LRIs and the changes in epidemiological trends attributable to the COVID-19 pandemic in China from 1990 to 2021 have yet to be explored. Thus, in this study, we aimed to comprehensively evaluate the LRI mortality, incidence, risk factors and aetiologies in China from 1990 to 2021, before and during COVID-19 pandemic, which will help the development of health policy decisions and initiatives.

Methods

Data collection

The study design and methodology are based on the GBD 2021 study, as previously reported [2, 4]. GBD 2021, which was led by the Institute for Health Metrics and Evaluation at the University of Washington, produces data on incidence and mortality rates, disease burden, and various risk factors from 1990 to 2021 of 204 countries and territories [2]. All the data analyzed in this study were obtained from GBD 2021 (https://ghdx.healthdata.org/gbd-2021). The estimation of sex-, age-specific morta lity, incidence, disability-adjusted life years (DALYs) was used to analyze the disease burden of LRIs in China. The 25th and 975th ranked values of 1000 draws were used to calculate the 95% uncertainty intervals (UIs).

Definitions

LRI is defined as acute pneumonia or bronchiolitis whose symptoms include cough, fever, and shortness of breath, and COVID-19, pertussis, and tuberculosis are not included in the GBD case criteria of LRI [2]. LRIs mapped to WHO International Classification of Diseases (ICD) codes: A48.1, A70, B96.0-96.1, B97.21, B97.4-B97.6, J09-J11.89, J12-J13.9, J14-J14.0, J15-J15.8, J20-J21.9, J85.1, J91.0, P23.0-P23.4, U04-U04.9.

Study design and analysis

The total burden of LRIs in China is defined as deaths, incidence and disabilities caused by different pathogens. The study population is divided into five age subgroups: <5 years, 5–14 years, 15–49 years, 50–69 years and ≥70 years. We divided the population into age subgroups based on a study published by the GBD 2021 Lower Respiratory Infections and Antimicrobial Resistance Collaborators [2]. The risk factors included all risk factors, environmental/occupational risks, unsafe water, sanitation, and handwashing, air pollution, non-optimal temperature, behavioral risks, child and maternal malnutrition and tobacco. Aetiologies included *Acinetobacter baumannii*, *Chlamydia spp*, *Enterobacter spp*, *Escherichia coli*, fungi, group B streptococcus, *H influenzae*, influenza viruses, *Klebsiella pneumoniae*, *Legionella spp*, *Mycoplasma spp*, polymicrobial infections, *Pseudomonas aeruginosa*, Respiratory syncytial virus (RSV), *S aureus*, *S pneumoniae*, other viruses and other bacterial pathogens.

Incidence, mortality and DALYs are used to evaluate the disease burden of LRIs in China, summarized by sex and age. We presented the number of deaths, mortality rates, DALYs number of different groups in 1990, 2019, 2020 and 2021. To compare the impact of COVID-19, we calculated the changes from 1990 to 2019 and 2019 to 2021, respectively. We also evaluated the risk factors and aetiologies of different age groups in different years. The overall mortality was estimated by the Cause of Death Ensemble model (CODEm), which analyzed various potential models in different combinations [5]. LRI incidence was estimated using the compartmental Bayesian meta-regression model DisMod-MR 2.1 [6].

Results

Mortality of LRIs in China from 1990 to 2021

During 1990 to 2010, the death number of LRIs decreased dramatically, which decreased from 474883.35 (95% uncertainty interval [UI]: 414630.66-532254.56) to 188096.49 (95% UI: 168703.45–217940.82). The death number of LRIs increased in 2019 compared to 2010, and slightly decreased in 2020. Interestingly, it continued

to rise in 2021, surpassing the death number of 2019 (Fig. 1). The changes in the mortality rate followed the same trend.

The number of estimated deaths decreased from 474883.35 (95% UI: 414630.66–532254.56) in 1990 to 198570.51 (95% UI: 168703.45–217940.82) in 2019, representing a 58.19% decrease before the COVID-19 pandemic. The all-age mortality rate decreased from 40.37 deaths (95% UI: 35.24–45.24) per 100,000 population in 1990 to 14.04 deaths (95% UI: 11.91–16.96) per 100,000 population in 2019, a 60.85% decrease (95% UI: 65.83–56.13) (Table 1; Fig. 1).

In 2021, during the COVID-19 pandemic, 206930.22 (95% UI: 171260.88–251990.47) deaths was estimated, with all-age mortality rate of 14.54 deaths (95% UI: 12.04–17.71) per 100,000 population. Compared to 2019, the all-age mortality rate had a 3.60% increase (95% UI: 1.09–4.42) (Table 1; Fig. 1).

As shown in Fig. 1, the sex-specific mortality of LRIs followed the same pattern from 1990 to 2021. However, the age-specific mortality of LRIs varied in different groups, especially during the COVID-19 pandemic, which was different from the global trend. In the age < 5 years, 5–14 years and 15–49 years groups, both the number of deaths and the mortality rate have decreased since 1990. In contrast, trends in the 50–69 years and ≥ 70 years age groups differed. In the 50–69 years group, both the number of deaths and the mortality rate decreased before 2019. In 2021, the number of deaths and the mortality increased since 2020. In the age ≥ 70 group, the death number decreased since 1990. The death number in 2021 (165678.66, 95% UI: 134605.09–203775.29) had a 75.08% increase compared to 1990, and had a 7.15% increase compared to 2019. The mortality rate of the age ≥ 70 group in 2021 (138.87 per 100000 population, 95% UI: 112.83–170.80) had a 44.92% decrease compared to 1990, and had a 2.50% decrease compared to 2019.

In 2021, among all age groups, adults aged 70 years and older had the highest mortality rate (138.87 per 100000 population, 95% UI: 112.83–170.80), followed by children younger than 5 years (13.02 per 100000 population, 95% UI: 10.32–16.09).

Incidence and disability-adjusted life years (DALYs) of LRIs in China from 1990 to 2021

From 1990 to 2021, despite the COVID-19 pandemic, the incidence number of LRIs in China decreased from 50936861.51 (95% UI: 47531532.05-54596483.21) to 44704579.03 (95% UI: 41780822.90-47783964.58). Similarly, the incidence rate decreased from 4329.68 per 100,000 population (95% UI: 4040.23-4640.75) to 3142.13 per 100,000 population (95% UI: 2936.63-3358.57) (Table 2).

The sex- and age-specific incidence of LRIs showed similar patterns from 1990 to 2021. Similar to the global trend, the decline of incidence rate of LRIs in China was primarily attributable to reductions in incidence among children younger than 5 years, which decreased 81.44%, from 16638.35 per 100,000 population (95% UI: 14661.88-18916.42) in 1990 to 3088.76 per 100,000 population (95%UI: 2571.93-3649.69) in 2021 (Table 2). By contrast, the incidence rate among 15–49 years declined at a lower rate from 1990 to 2021, with an overall decrease of 17.93% (Table 2).

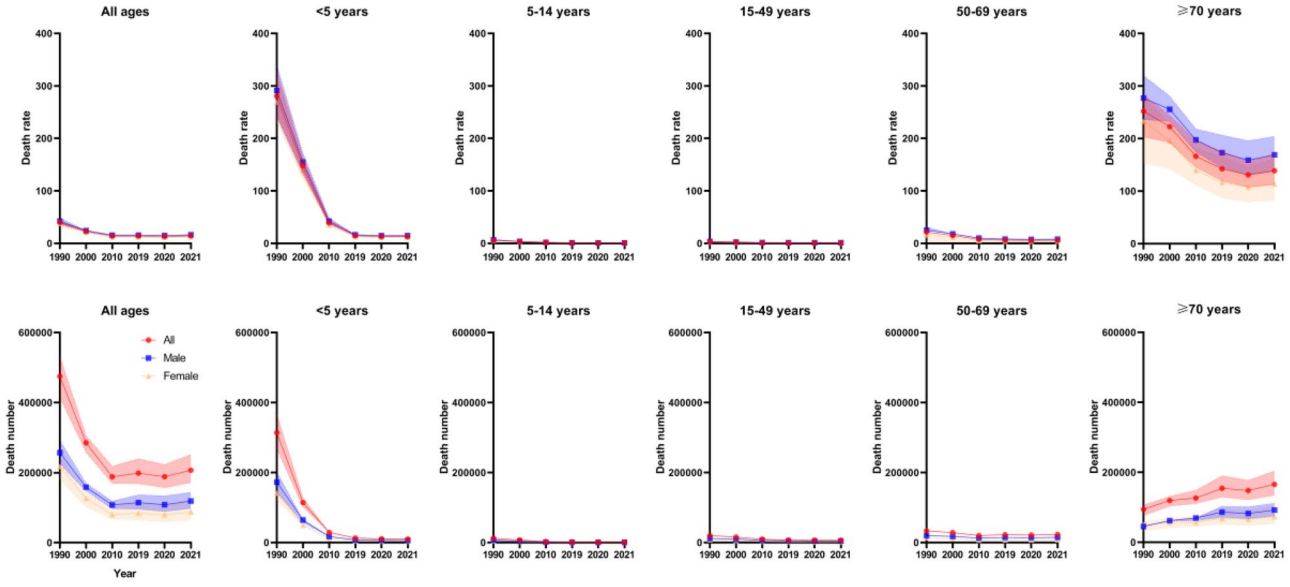

Fig. 1 LRI mortality rates and death counts in China by age and sex, 1990–2021. Upper graphs show mortality rates per 100,000 population. Lower graphs show death counts. Shaded areas represent 95% uncertainty intervals. LRI = lower respiratory infection

Table 1 The death and mortality rate of lower respiratory infections in 2019, 2020 and 2021, and their mortality rate changes in China

	1990		2019		2020		2021		Mortality rate changes (%)	
	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	1990–2019 (95% UI)	2019–2021 (95% UI)
Total	474883.35 (414630.66, 532254.56)	40.37 (35.24, 45.24)	198570.51 (168464.45, 239920.77)	14.04 (11.91, 16.96)	188435.58 (156864.73, 223277.73)	13.27 (11.05, 15.73)	206930.22 (171260.88, 251990.47)	14.54 (12.04, 17.71)	-60.85 (-65.83, -56.13)	3.60 (1.09, 4.42)
Gender										
Male	257237.77 (225825.74, 292395.90)	42.39 (37.21, 48.18)	114652.79 (95947.28, 136885.30)	15.85 (13.26, 18.92)	108523.20 (88954.14, 133866.26)	14.94 (12.25, 18.43)	119076.39 (97962.16, 143880.87)	16.35 (13.45, 19.76)	-62.61 (-64.36, -60.73)	3.15 (1.43, 4.44)
Female	246830.34 (181268.43, 246830.34)	38.21 (31.82, 43.33)	83917.72 (65121.81, 116404.40)	12.15 (9.43, 16.85)	79912.38 (60463.51, 106806.07)	11.53 (8.72, 15.41)	87853.84 (64860.01, 123116.86)	12.65 (9.34, 17.72)	-70.37 (-71.96, -55.90)	4.12 (-0.95, 5.16)
Age										
< 5 years	313888.76 (268268.62, 367033.40)	280.74 (239.94, 328.28)	12960.36 (10684.97, 15343.85)	14.72 (12.14, 17.43)	10993.84 (8769.93, 13217.69)	13.04 (10.41, 15.68)	10116.26 (8015.55, 12493.84)	13.02 (10.32, 16.09)	-94.76 (-94.94, -94.69)	-11.55 (-14.99, -7.69)
5–14 years	12680.67 (10086.68, 14434.47)	6.14 (4.88, 6.99)	1590.40 (1383.81, 1869.98)	0.94 (0.81, 1.10)	1469.88 (1261.56, 1727.18)	0.84 (0.72, 0.98)	1551.77 (1310.07, 1860.91)	0.85 (0.72, 1.02)	-84.69 (-84.26, -83.40)	-9.57 (-11.11, -7.27)
15–49 years	20323.09 (16487.33, 23311.06)	3.05 (2.47, 3.50)	6997.68 (5861.82, 8570.59)	1.02 (0.85, 1.25)	6371.49 (5189.88, 7730.78)	0.95 (0.77, 1.15)	6610.01 (5361.31, 8171.72)	1.00 (0.81, 1.23)	-66.56 (-65.59, -64.29)	-1.96 (-4.71, -1.60)
50–69 years	33363.01 (27314.31, 38657.71)	21.71 (17.77, 25.15)	22391.97 (18300.22, 27911.34)	6.18 (5.05, 7.71)	21490.93 (17194.48, 26323.24)	5.77 (4.62, 7.07)	22973.52 (18172.53, 28624.10)	6.04 (4.78, 7.52)	-71.53 (-71.58, -69.34)	-2.27 (-5.35, -2.46)
≥ 70 years	94627.82 (76251.50, 106194.06)	252.14 (203.18, 282.96)	154630.11 (129433.22, 190229.71)	142.43 (119.22, 175.22)	148109.44 (121493.45, 177459.07)	131.01 (107.46, 156.97)	165678.66 (134605.09, 203775.29)	138.87 (112.83, 170.80)	-43.51 (-41.32, -38.08)	-2.50 (-5.36, -2.52)

[a]The unit of the rate is per 100,000 population

The all-age DALYs attributable to LRIs have consistently decreased in China since 1990. It decreased from 32576309.91 per 1000 population (95% UI: 28139744.13-37498332.81) in 1990 to 4106779.20 per 1000 population (95% UI: 3504140.94-4808452.64) (Supplementary Table 1). The sex-specific DALYs of LRIs showed similar patterns from 1990 to 2021.

Risk factors attributable to dalys due to LRIs in China from 1990 to 2021

All risk factors of both sexes accounted for 87.59% (95% UI: 79.42-93.69%) of the DALYs due to LRIs in 1990 and 66.01% (95% UI: 53.75-76.20%) in 2019, which had a 24.64% decrease. In 2021, the all risk factors of both sexes accounted for 66.50% (95% UI: 54.35-76.66%) of the DALYs due to LRIs, which had a 0.74% increase compared to that of 2019 (Table 3).

From 1990 to 2021, the percentage of DALYs attributed by environmental/occupational risks decreased from 56.40% (95% UI: 29.17-75.80%) to 39.20% (95% UI: 19.83-55.31%) (Table 3). The subcategories of environmental/occupational risks, including unsafe water, sanitation, and handwashing, air pollution and non-optimal temperature all showed different degrees of decrease. However, the percentage of DALYs attributed by the subcategory of ambient particulate matter pollution increased from 7.44% (95% UI: 1.26-15.72%) to 22.14% (95% UI: 3.28-38.41%).

From 1990 to 2021, the percentage of DALYs attributed by behavioral risks decreased from 74.68% (95% UI: 65.69-81.60%) to 37.40% (95% UI: 28.22-46.10%) (Table 3). Child and maternal malnutrition, which is a subcategory of behavioral risks, also decreased since 1990. However, different patterns were observed in the percentage of DALYs attributed by tobacco (Fig. 2; Table 3). In 1990, the percentage of DALYs attributed by tobacco was 19.06% (95% UI: 7.84-29.48%). In 2021, it was 26.53% (95% UI: 16.31-35.55%), which increased by 39.19% compared to 1990. The increase of the percentage of DALYs attributed by tobacco was largely contributed by males. From 1990 to 2021, the percentage of DALYs attributed by tobacco increased from 19.84% (95% UI: 8.79-30.20%) to 32.72% (95% UI: 22.78-41.77%), which had a 64.92% increase. However, in females, it had a 5.89% decrease from 1990 to 2021.

Table 2 The incidence count and rate of lower respiratory infections in 2019, 2020 and 2021, and their rate changes in China

	1990		2019		2020		2021		Incidence rate changes (%)	
	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	Cases (95% UI)	Rate[a] (95% UI)	1990–2019 (95% UI)	2019–2021 (95% UI)
Total	50936861.51 (47531532.05, 54596483.21)	4329.68 (4040.23, 4640.75)	49990284.24 (46645202.01, 53587528.59)	3534.46 (3297.95, 3788.79)	46057443.82 (42857697.87, 49377317.44)	3244.66 (3019.24, 3478.54)	44704579.03 (41780822.90, 47783964.58)	3142.13 (2936.63, 3358.57)	-18.37 (-18.37, -18.36)	-11.10 (-11.36, -10.96)
Gender										
Male	25866748.68 (24096968.84, 27685432.73)	4262.54 (3970.90, 4562.24)	26612100.57 (24891789.70, 28656573.78)	3678.41 (3440.62, 3961.00)	25045751.28 (23322338.33, 26881233.98)	3448.38 (3211.09, 3701.09)	23297710.44 (21689676.62, 24928265.77)	3199.78 (2978.93, 3423.73)	-13.70 (-13.78, -13.35)	-13.01 (-13.42, -13.00)
Female	25070112.84 (23395687.46, 26890639.32)	4401.21 (4107.26, 4720.82)	23378183.67 (21780656.37, 25312435.86)	3383.72 (3152.49, 3663.68)	21011692.54 (19527478.17, 22702067.54)	3031.21 (2817.09, 3275.06)	21406868.60 (19956561.78, 23040767.49)	3081.71 (2872.93, 3316.92)	-23.11 (-23.25, -22.39)	-8.93 (-9.45, -8.87)
Age										
< 5 years	18602675.25 (16392870.15, 21149701.05)	16638.35 (14661.88, 18916.42)	3551864.75 (2970555.73, 4160536.04)	4034.95 (3374.58, 4726.41)	2959737.70 (2452372.46, 3567726.13)	3511.91 (2909.89, 4233.33)	2398985.19 (1997575.87, 2834649.53)	3088.76 (2571.93, 3649.69)	-75.75 (-76.98, -75.01)	-23.45 (-23.79, -22.78)
5–14 years	7194299.65 (5875420.73, 8818697.74)	3482.74 (2844.27, 4269.10)	4110939.32 (3224739.67, 5123643.00)	2420.83 (1898.97, 3017.18)	4023817.86 (3167779.68, 5045486.45)	2289.69 (1802.58, 2871.05)	4051173.47 (3185169.09, 5061325.34)	2226.37 (1750.45, 2781.51)	-30.49 (-33.24, -29.33)	-8.03 (-8.82, -7.81)
15–49 years	8457618.76 (7542568.49, 9414577.40)	1268.29 (1131.07, 1411.79)	7948689.07 (6979452.98, 9010862.39)	1159.17 (1017.83, 1314.07)	7226078.69 (6325060.67, 8173296.64)	1072.21 (938.52, 1212.76)	6904551.14 (6042101.12, 7817454.87)	1040.94 (910.92, 1178.57)	-8.60 (-10.01, -6.92)	-10.20 (-10.50, -10.31)
50–69 years	8708030.96 (7836517.17, 9607935.51)	5665.63 (5098.60, 6251.13)	12910491.87 (11652756.22, 14176570.09)	3564.08 (3216.87, 3913.59)	12289345.27 (11154077.04, 13532266.12)	3299.39 (2994.60, 3633.09)	11985530.01 (10771122.83, 13110349.09)	3149.86 (2830.71, 3445.47)	-37.09 (-36.91, -37.39)	-11.62 (-12.00, -11.96)
≥ 70 years	7974236.89 (7074245.13, 8849545.64)	21247.84 (18849.75, 23580.15)	21468299.24 (19116220.90, 23885758.43)	19774.44 (17607.94, 22001.16)	19558464.30 (17438525.82, 21753975.55)	17299.90 (15424.77, 19241.88)	19364339.22 (17359257.38, 21451831.02)	16231.08 (14550.43, 17980.80)	-6.93 (-6.59, -7.70)	--17.92 (-17.36, -18.27)

[a]The unit of the rate is per 100,000 population

Aetiologies of LRIs in China

The change of aetiologies of LRIs in China was shown in Fig. 3A. In 1990, the pathogen responsible for the largest proportion of all-age LRI mortality episodes in China was *Streptococcus pneumoniae*, which caused an estimated 165798.10 (95% UI: 143691.44–189099.08) deaths (Fig. 3B). The leading five causes of LRI mortality episodes in China in 1990 were *Streptococcus pneumonia*, Influenza, *Staphylococcus aureus*, *Klebsiella pneumonia* and other viral etiologies, which accounted for 35.05%, 9.03%, 8.51%, 7.53% and 7.01% of deaths, respectively (Fig. 3B).

Since 2019, the proportions of these pathogens changed (Fig. 3C and D). In 2021, the pathogen responsible for the largest proportion of all-age LRI mortality episodes in China was still *Streptococcus pneumoniae*, which caused an estimated 51179.81 (95% UI: 42055.40–62158.09) deaths (Fig. 3E). The leading five causes of LRI mortality episodes in China in 2021 were *Streptococcus pneumonia*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia* and other bacterial pathogens, which accounted for 24.75%, 22.23%, 7.48%, 7.17% and 6.84% of deaths (Fig. 3E). Compared to 2019, the proportion of deaths caused by Influenza decreased from 13.03 to 2.70%, the proportion of deaths caused by RSV decreased from 2.21 to 0.41%, and the proportion of deaths caused by *Mycoplasma* increased from 1.97 to 2.23% (Fig. 3E).

The age-specific analysis of the data in 2021 showed that in all age groups, Streptococcus pneumonia led to most death cases (Fig. 4). Apart from children younger than 5 years, for whom the second-ranked aetiology was other viral etiologies, other age groups' second-ranked aetiology was all *Staphylococcus aureus*. Also, the proportion of deaths caused by *Staphylococcus aureus* increased with age. In people under the age of 50, the three leading causes of LRI mortality episodes in China in 2021 all were *Streptococcus pneumonia*, *Staphylococcus aureus* and other viral etiologies. But in people over 50 years, the three leading causes of LRI mortality episodes in China in 2021 were *Streptococcus pneumonia*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

Table 3 Risk factors attributable to disability-adjusted life years due to lower respiratory infections in 2019, 2020 and 2021, and their changes in China

	Percentage (%) of disability-adjusted life years (95% UI)											
Risk factors	**1990**			**2019**			**2020**			**2021**		
	Both sexes	**Male**	**Female**	**Both sexes**	**Male**	**Female**	**Both sexes**	**Male**	**Female**	**Both sexes**	**Male**	**Female**
All risk factors	87.59 (79.42, 93.69)	87.49 (79.70, 93.24)	87.49 (78.77, 93.78)	66.01 (53.75, 76.20)	67.35 (56.18, 77.09)	63.57 (50.17, 74.64)	66.28 (54.80, 76.01)	67.64 (56.48, 77.26)	63.72 (50.90, 74.49)	66.50 (54.35, 76.66)	67.85 (56.10, 77.51)	63.94 (50.84, 74.97)
Environmental/occupational risks	56.40 (29.17, 75.80)	55.32 (29.21, 74.58)	57.72 (29.27, 77.23)	39.20 (19.99, 55.07)	39.03 (19.96, 54.64)	39.45 (19.94, 55.56)	38.30 (19.62, 54.06)	38.14 (19.68, 53.52)	38.55 (19.54, 54.40)	39.20 (19.83, 55.31)	39.04 (19.70, 54.61)	39.44 (19.76, 55.81)
Unsafe water, sanitation, and handwashing	9.54 (-5.38, 26.15)	9.54 (-5.39, 26.10)	9.55 (-5.38, 26.20)	3.11 (-1.50, 9.32)	3.11 (-1.50, 9.34)	3.12 (-1.50, 9.28)	3.01 (-1.44, 8.98)	3.00 (-1.44, 9.00)	3.01 (-1.44, 8.95)	2.90 (-1.37, 8.59)	2.90 (-1.37, 8.55)	2.90 (-1.37, 8.67)
Air pollution	43.62 (9.20, 66.50)	42.22 (9.46, 64.88)	45.35 (9.22, 68.84)	28.03 (4.55, 46.36)	27.83 (4.59, 46.07)	28.32 (4.56, 46.86)	26.92 (4.20, 44.85)	26.73 (4.28, 44.58)	27.21 (4.13, 45.34)	27.98 (4.26, 46.28)	27.78 (4.31, 45.99)	28.27 (4.28, 46.74)
Ambient particulate matter pollution	7.44 (1.26, 15.72)	8.11 (1.39, 17.02)	6.61 (1.10, 14.22)	22.09 (3.49, 38.38)	22.51 (3.52, 38.88)	21.45 (3.45, 37.80)	21.60 (3.25, 37.55)	21.97 (3.30, 38.18)	21.02 (3.21, 37.03)	22.14 (3.28, 38.41)	22.55 (3.31, 39.05)	21.49 (3.23, 37.85)
Non-optimal temperature	14.40 (12.00, 17.01)	14.43 (12.04, 17.06)	14.36 (11.94, 16.94)	12.93 (10.05, 15.64)	12.93 (9.99, 15.70)	12.92 (9.99, 15.58)	13.08 (10.15, 15.77)	13.07 (10.08, 15.79)	13.07 (10.22, 15.72)	13.17 (9.98, 16.20)	13.18 (9.99, 16.26)	13.15 (9.99, 16.09)
Behavioral risks	74.68 (65.69, 81.60)	75.89 (66.78, 82.78)	73.19 (64.11, 80.85)	39.30 (29.98, 47.62)	45.23 (36.28, 53.16)	30.31 (20.55, 39.27)	38.73 (29.06, 47.29)	44.97 (36.04, 53.01)	29.22 (19.22, 38.08)	37.40 (28.22, 46.10)	43.86 (34.81, 52.12)	27.58 (17.78, 36.26)
Child and maternal malnutrition	67.36 (56.35, 74.99)	67.68 (56.94, 75.37)	66.97 (55.25, 75.78)	15.82 (12.08, 21.27)	15.98 (11.96, 21.71)	15.70 (11.32, 21.72)	14.97 (10.96, 20.67)	15.35 (11.04, 21.14)	14.54 (10.01, 20.59)	13.04 (9.45, 18.04)	13.37 (9.66, 18.52)	12.65 (8.65, 18.17)
Tobacco	19.06 (7.84, 29.48)	19.84 (8.79, 30.20)	18.09 (6.65, 28.93)	26.11 (15.67, 35.72)	31.90 (21.81, 41.35)	17.23 (7.06, 26.83)	26.25 (16.15, 35.50)	32.19 (22.02, 41.76)	17.09 (7.01, 26.56)	26.53 (16.31, 35.55)	32.72 (22.78, 41.77)	17.03 (6.92, 26.26)

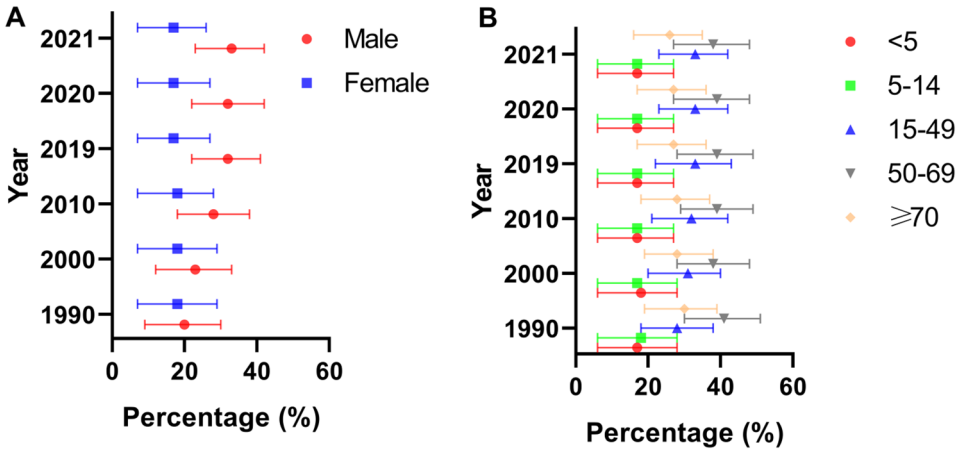

Fig. 2 The percentage of DALYs attributed by tobacco by age and sex, 1990–2021. DALYs = disability-adjusted life years

Discussion

Based on GBD 2021, we analyzed the burden of LRI in China attributable to 18 pathogen categories by age group from 1990 to 2021. Our results showed the estimated burden changes before and during COVID-19 pandemic, which can manifest the impact of COVID-19 pandemic on LRI in China.

The incidence of LRI in China decreased annually since 1990, which is similar with the global trend [2]. This may be due to the improvement in public health measures. For example, the introduction of pneumococcal conjugate vaccine (PCV) in China among children aged 0–5 years reduced the incidence of all-cause pneumonia [7]. The improvements in medical standards and public health facilities in China can effectively prevent the occurrence of respiratory infections [8]. Other risk factors, such as air pollution, can also affect the LRI incidence [2]. Chinese authorities have taken a series of actions to tackle air pollution, which may reduce the incidence of LRI to some extent [9].

The death number and mortality rate of non-COVID-19 lower respiratory infections in China declined year by year from 1990 to 2020. However, in 2021, the death number (206930.22 [95% UI: 171260.88-251990.47]) and mortality rate (14.54% [95% UI: 12.04, 17.71]) increased compared to 2020. This increase in 2021 deviated from the decline observed between 1990 and 2020. Additionally, this trend differed from the global pattern, where the all-age LRI mortality rate decreased by 50.9% from 1990 to 2021 [2]. The fluctuations in LRI mortality may be the result of a combination of factors. First, the COVID-19 pandemic has disrupted the health systems globally, including China [10]. Due to the delayed healthcare services by healthcare facilities and patients' worry during the pandemic waves, the diagnosis, treatment, and management of other diseases may be affected [10, 11]. Second, it has been reported that COVID-19, especially long covid and severe COVID-19, can cause long-term respiratory damage and affect many systems, which may contribute to the increased mortality [12, 13]. Future studies that consider the impact of COVID-19 pandemic and use real-world data should be warranted to further investigate the death number and mortality change in China.

Similar to the global trend, among the total population, children under 5 years and adults over 70 years in China had the highest mortality rates from 1990 to 2021. The mortality rate of children under 5 years has declined steeply since 1990, from 280.74 (95% UI: 239.94–328.28) to 13.02 (95% UI: 10.32–16.09). The mortality rate of adults over 70 years decreased from 252.14 (95% UI: 203.18–282.96) to 138.87 (95% UI: 112.83–170.80), showing a smaller degree of reduction. Compared to 2020, the mortality rate of adults over 70 years in 2021 increased from 131.01 (95% UI: 107.46-156.97) to 138.87 (95% UI: 112.83–170.80). Older age has been reported as a risk factor of respiratory infections [14]. It has been reported that over 1 million people over 70 died from lower respiratory tract infections in 2016 [15]. By 2040, in China, the number of people aged 60 years or older is predicted to increase to 402 million, representing almost 28% of the population [16]. Thus, the management of diseases, improvement of healthcare, and introduction of vaccination should be further strengthened in the future.

By analyzing the risk factors attributable to DALYs due to LRIs in China, we found that the percentage of DALYs attributed by the ambient particulate matter pollution increased year by year from 1990 to 2021. Ambient particulate matter pollution has been closely related to LRIs. In 2019, 6.67 million deaths worldwide were attributed to air pollution, a multi-component combination of gases, liquids, and particle matter [17]. With China's tremendous economic growth over the last 40 years, air pollution, especially particulate matter pollution, has become

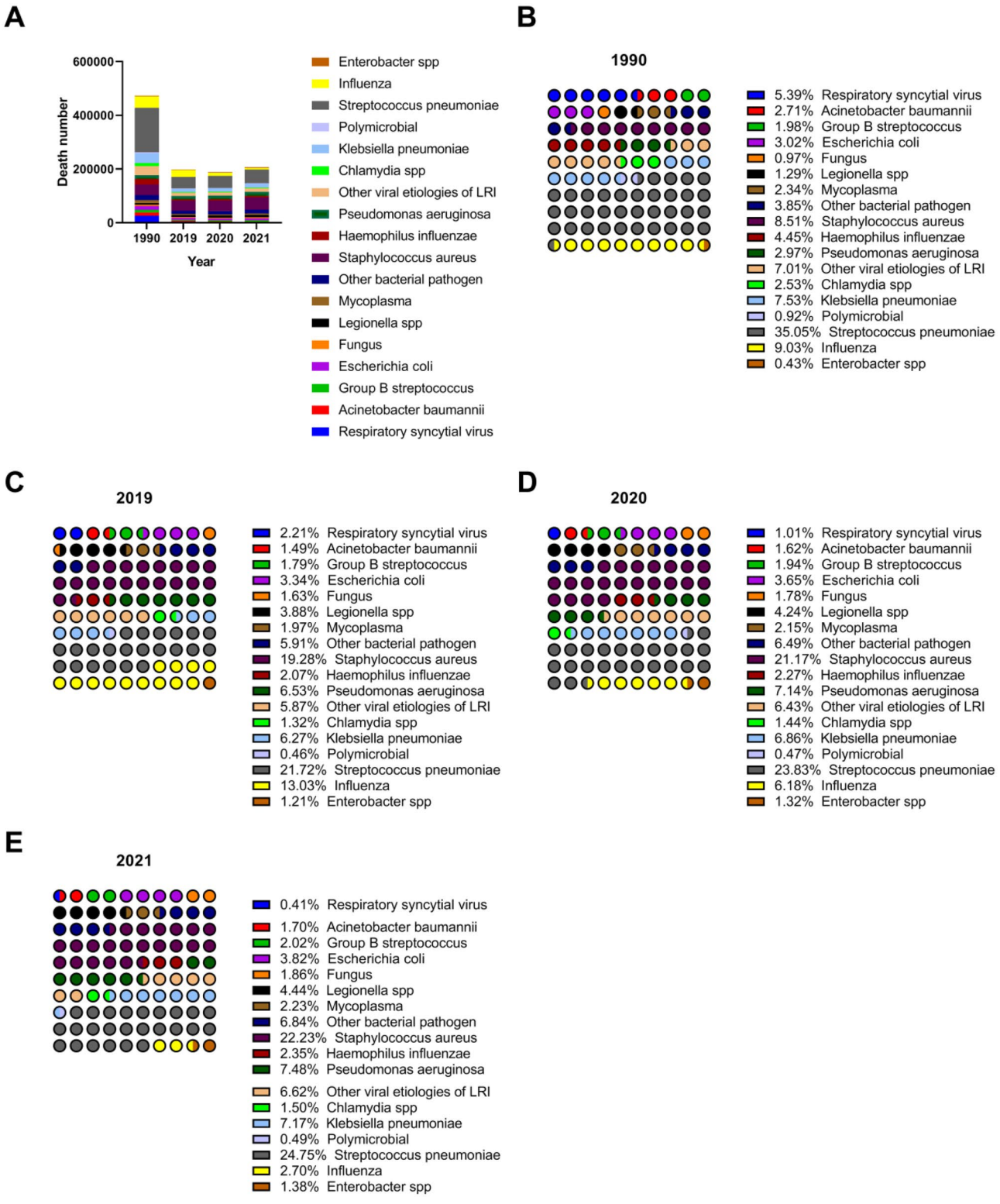

Fig. 3 Aetiologies of LRIs in China, 1990–2021

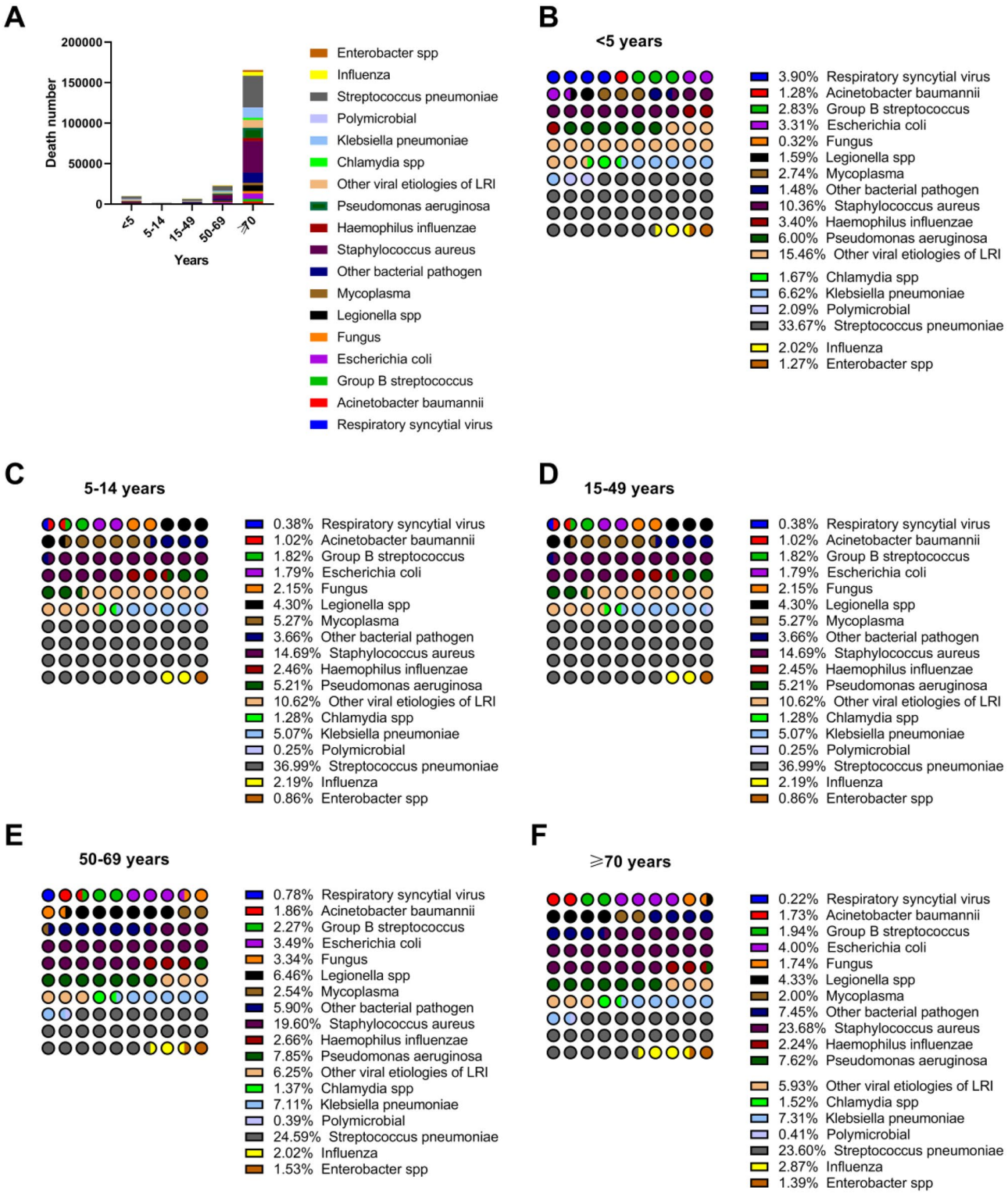

Fig. 4 Aetiologies of LRIs in China by age in 2021

more serious [18]. Thus, necessary actions are required in the future to enhance air quality and reduce the air pollution-related morbidity and mortality.

Another risk factor that keeps increasing is tobacco. The percentage of DALYs attributed by tobacco has increased from 19.06% (95% UI: 7.84-29.48%) to 26.53% (95% UI: 16.31-35.55%) since 1990, especially in males. It is commonly known that smoking contributes to respiratory infectious diseases [19]. The tobacco industry generates 10% of China government's annual income from the over 300 million smokers, leading to the highest prevalence and the worst outcomes of smoking related pulmonary diseases [20]. Thus, it is needed that effective tobacco control policies should be implemented.

The aetiologies of LRIs in China have changed since 1990. The leading cause of mortality from LRIs remains *Streptococcus pneumoniae* from 1990 to 2021. However, the proportions of viruses decreased. Influenza accounted for 9.03%, 13.03%, 6.18% and 2.70% of deaths in 1990, 2019, 2020 and 2021, respectively. RSV accounted for 5.39%, 2.21%, 1.01% and 0.41% of deaths in 1990, 2019, 2020 and 2021, respectively. It can be observed that the proportions of Influenza decreased since 2020. The COVID-19-related NPIs had a significant impact on the prevalence of respiratory viruses, both in China and worldwide [2, 21, 22]. As COVID-19 restrictions have been eased, effective surveillance and adaptive strategies will be pivotal in addressing the changing landscape of respiratory infections in the post-pandemic era.

By analyzing the age-specific aetiologies of LRIs in 2021, we found that *Streptococcus pneumonia* caused most of deaths in all age groups. Similarly, the pathogen responsible for most of LRI death cases globally was also *Streptococcus pneumonia*, which caused an estimated 505,000 deaths [2]. RSV caused 3.90% of deaths in children under 5 years, but it caused less than 1% in other age groups. In contrast, *Staphylococcus aureus* accounted for more deaths in older adults, especially adults aged 70 and above. Our findings highlighted the persistent dominance of *Streptococcus pneumonia* across all age groups, underscoring the continued importance of pneumococcal vaccination. Moreover, the substantial burden of RSV in young children suggests a need for targeted prevention strategies. Given the diverse aetiologies, our results advocate for age-specific LRI management procedures, especially during peak seasons for respiratory infections. Further research into the evolving epidemiology of these pathogens will be required to make public health interventions and improve outcomes for all age groups affected by LRIs.

Based on our results, several prevention and control strategies should be considered in the future. First, the air pollution and tobacco use should be further controlled to minimize risk factors. Second, the landscape of respiratory infections has changed in the post-pandemic era, with aetiologies of lower respiratory infections (LRIs) differing across age groups. For example, RSV infections should receive greater attention in children under 5 years of age, while *Staphylococcus aureus* should be more closely monitored in adults aged 70 and older.

There are several limitations of our study. First, the GBD data is based on cleaned, reported data that is subsequently adjusted using models, rather than being directly sourced from real-world data from each country. This modeling process may introduce estimation biases. Second, when estimating the effect of the COVID-19 pandemic on influenza and RSV incidence, GBD data relied exclusively on case notification data from national and multinational surveillance networks, which cannot differentiate between a true decrease in LRI incidence and a reduction in healthcare-seeking behavior.

Conclusions

In conclusion, our study showed that LRIs continued to be a threat in China during the COVID-19 pandemic. The mortality of LRIs, especially in vulnerable populations, should not be overlooked. Risk factors, including ambient particulate matter pollution and tobacco use, have been associated with the percentage of DALYs. Moreover, the aetiologies of LRIs in China have changed since 1990. These findings highlight the importance of continuous surveillance and monitoring of respiratory infections, even in the post-pandemic era. Further epidemiological studies are needed to assess the long-term effects of COVID-19 on LRI trends and to guide the development of effective interventions.

Abbreviations

LRI	Lower Respiratory Infection
GBD	Global Burden of Disease
DALYs	Disability-Adjusted Life Years
UI	Uncertainty Interval
COVID-19	Coronavirus Disease 2019
NPIs	Non-Pharmaceutical Interventions
RSV	Respiratory Syncytial Virus
CODEm	Cause of Death Ensemble model
PCV	Pneumococcal Conjugate Vaccine

Supplementary Information

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Supplementary Material 1

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Not applicable.

Author contributions

ML and HZ conceived the study. ML prepared the first draft and finalized the manuscript based on comments from all other authors. ML, ZS and WJ collected and analyzed the data. ZS and WJ participated in the data

preparation and verified the data. HZ provided important comments on the manuscript. All authors read and approved the final manuscript.

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

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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